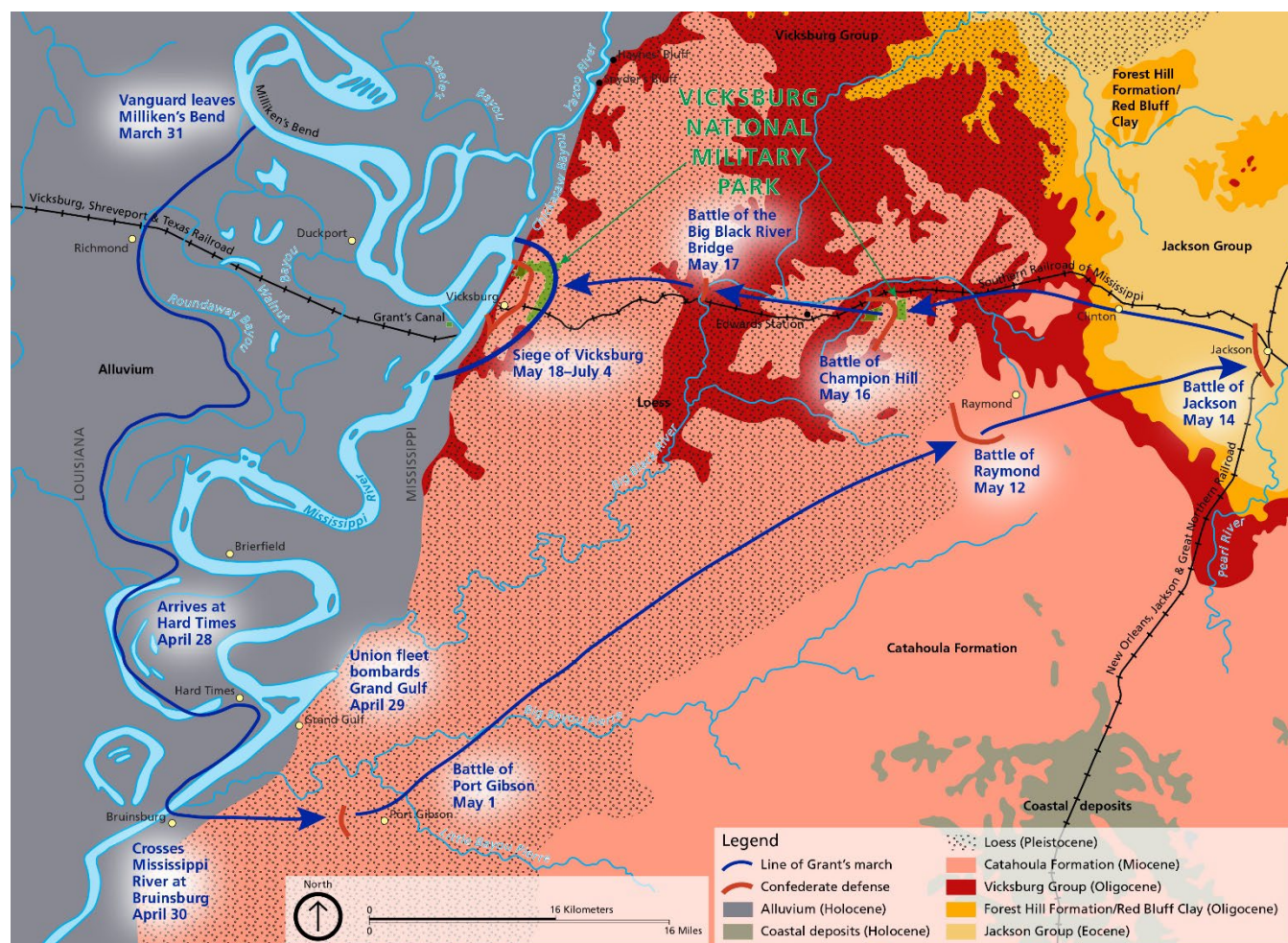




Vicksburg National Military Park

Geologic and Soil Resources Inventory Summary



On the cover: During the Vicksburg Campaign of the American Civil War, geology served as the foundation across which Union troops advanced (blue arrows on the figure) and held Vicksburg siege (blue line) and where Confederate troops defended their positions (red lines on the figure). Geologic features underlying the military maneuvers included loess (an accumulation of windblown silt), bedrock, and alluvium (river deposits). Bedrock includes the Jackson Group, Forest Hill Formation/Red Bluff Clay, Vicksburg Group, and Catahoula Formation. Alluvium (clay, silt, sand, and gravel) represents the Mississippi River alluvial plain. Landforms such as meander bends, oxbow lakes, terraces, floodplains, and channels record the river's presence on the landscape. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using the *Geologic Map of Mississippi* (Bicker 1969) and an NPS graphic by the Harper's Ferry Center.

Vicksburg National Military Park

Geologic and Soil Resources Inventory Summary

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Abstract

This document summarizes the status of the National Park Service (NPS) Geologic and Soil Resources Inventory (GSRI) for Vicksburg National Military Park (VICK). It provides information on geologic and soil resource management needs. This document is intended to assist park staff with prioritizing technical assistance requests and/or inventory and assessment funding proposals.

From oldest to youngest, geologic heritage values at VICK include fossils—the oldest of which are from the Paleozoic Era (539 million to 252 million years ago) and contained within pre-loess terrace deposits; stratotypes (reference rock exposures) that are approximately 32 million years old (Oligocene Epoch); the establishment of the Mississippi River system, which is recognized by the deposition of sediment into the Gulf of Mexico, between about 23 million and 5 million years ago (Miocene Epoch); loess—two studies provide ages for the timing of deposition: 28,000–23,000 years ago or 25,860–19,670 years ago; and travertine, including cave-like flowstone and dripstone. In historic times, geologic heritage values include the uses of bedrock, which began as early as the 1830s; notable scientists, who began exploring the area in ca. 1845; the USS *Cairo*, which started to be buried by sediment in 1862; commemorative stones, the first of which was placed in 1864; floods, including the 1876 flood that diverted the Mississippi River away from Vicksburg; and diversion of the Yazoo River, completed in 1903.

Inventory needs related to geologic heritage values include (1) paleontological inventories of the Champion Hill Unit and the Raymond and Port Gibson Battlefields, (2) cave and archeological assessment of the (possible) Mint Spring rock shelter, (3) geologic inventory of commemorative stones, (4) inventory of quarries, (5) plan for the preservation of the Mint Spring Formation type section, (6) plan for the preservation of earthworks, and (7) inventory of travertine exposures (i.e., former waterfalls).

Needs for resource management include (1) compilation of Mississippi Department of Environmental Quality (MDEQ) Mississippi Geological Survey source maps into the GRI GIS data model, (2) development of a working definition and understanding of loess for resource management, (3) development of a loess landscape conceptual model, (4) compilation of groundwater data, (5) inventory of springs and seeps, (6) analysis and application of the VICK landslide inventory data, (7) erosion management plan, and (8) inventory and monitoring plan for soil moisture and nutrients.

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Background of the GSRI

In the late 1990s, the Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) programs were established as two of the 12 original baseline inventories in the NPS Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data for more than 270 parks, which served as a common starting point for natural resource monitoring. For both the GRI and SRI, the primary deliverable was a digital (GIS) map. Scoping summaries, geologic map posters, and GRI reports were also produced for most of the 270 parks. In addition, many soil surveys were produced. These baseline GRI and SRI products are available on the [GRI products webpage](#) and on the [NPS DataStore](#), accessed through the [Integrated Resource Management Applications \(IRMA\) portal](#).

As of 2024, the I&M program is transitioning from a baseline inventory strategy to one that addresses park needs as proposed by park managers. The GRI and SRI are now unified as one inventory program—the Geologic and Soil Resources Inventory (GSRI)—and will be integrated into the new Inventories & Assessment (I&A) Program. Through the new I&A program, park managers will be able to submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call. This transition will begin in FY25, with new guidance enacted for the GSRI. See the [GSRI SharePoint site](#) for more information regarding this transition.

In this transition period before the new guidance is completed, 13 “priority” parks, including Vicksburg National Military Park (referred to as VICK or the “park” throughout this document), were identified as having a scoping summary (see KellerLynn 2010b) but missing a baseline GRI report. This GSRI summary serves as a substitute for a baseline GRI report and is intended to support VICK participation in the new inventory program. This summary documents the status of GRI and SRI deliverables and provides information about current geology and soil resource management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, a meeting and correspondence with VICK and Gulf Coast Network (GULN) staff, and the “best professional judgment” of GSRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

GRI Scoping Summary

The GRI team held a scoping meeting at VICK on 14 April 2010. The meeting brought together NPS staff and local geologic experts. A scoping summary (KellerLynn 2010b) summarizes the findings of that meeting.

GRI GIS Data

The GRI program funded geologic mapping of four 7.5-minute quadrangles (scale 1:24,000) of interest for VICK: (1) Long Lake, (2) Redwood, (3) Vicksburg West, and (4) Vicksburg East. Mapping was conducted by Mississippi State University (MSU) as part of a master’s thesis (Smith 2016). Upon completion of mapping, the GRI team compiled the four MSU maps (Smith and

Schmitz 2016a, 2016b, 2016c, 2016d) into a digital geologic-GIS map that covered the main battlefield unit, the detached units in Vicksburg, and the Grant's Canal site. These data were delivered to park managers in 2021 and are available on the [NPS DataStore](#); search "GRI" and "VICK."

A review of the MSU project by geologists at the Mississippi Department of Environmental Quality (MDEQ) Mississippi Geological Survey, revealed many issues in the interpretation of the geology as mapped. Therefore, park managers chose to not use these data for resource management purposes (Chuck Beightol, VICK, natural resources manager, review comment, 28 January 2025).

In 2025, the MDEQ Mississippi Geological Survey published new maps for the Redwood, Vicksburg East, and Vicksburg West quadrangles (Palmer et al. 2025a, 2025b, 2025c). Because the Long Lake quadrangle is in Louisiana, no new map was completed for it by the MDEQ Mississippi Geological Survey. Notably, these new maps are not compiled as GRI GIS data model, but park managers could consider submitting a proposal to the I&A program for that work. Incorporation of these data into the GRI GIS data model would allow for use with other NPS GIS products.

The MDEQ Mississippi Geological Survey maps were used by the GSRI to create a geologic map poster. A benefit of the poster is that it displays the main battlefield unit and the detached units in Vicksburg all on one sheet. Moreover, selected park features (e.g., locations of the tour road, tour stops, state monuments, and the Mint Spring Formation type section) have been added to the poster.

To provide geologic maps for the Champion Hill Unit (designated as part of VICK) and the Raymond and Port Gibson Battlefields (not yet designated as part of VICK), the GRI team funded the MDEQ Mississippi Geological Survey to map the Edwards and Widows Creek quadrangles (east of Vicksburg). The Edwards quadrangle, which covers the Champion Hill Unit, was mapped at the 1:24,000 scale by Leard et al. (2023a). The Widows Creek quadrangle, which covers the Port Gibson Battlefield, was mapped at the 1:24,000 scale by Starnes and Leard (2021). No geologic mapping at the 1:24,000 scale covers the Raymond Battlefield; it is on the Terry NW quadrangle. However, the Terry NW quadrangle is immediately south of the Raymond quadrangle, which was mapped at the 1:24,000 scale by Leard and Starnes (2021) for a GRI-funded project for Natchez Trace Parkway (see KellerLynn 2010a); thereby, the geology of the Raymond Battlefield could be inferred from the geologic map of the Raymond quadrangle. Geologic maps for the Champion Hill Unit and the Raymond and Port Gibson Battlefields are included as inset maps on the VICK geologic map poster. These maps are not compiled as GRI GIS data model, but park managers could consider submitting a proposal to the I&A program for that work. Incorporation of these data into the GRI GIS data model would allow for use with other NPS GIS products.

SRI Data

The SRI completed a Soil Survey Geographic (SSURGO; i.e., soil map database) for VICK in 2007 ([National Park Service 2007](#)), which is available on IRMA. This database, however, has not been updated or revised as new data became available, nor will it be in the future.

The most current soil data (map and tabular data) for VICK are available via the Natural Resources Conservation Service (NRCS) [Web Soil Survey \(WSS\)](#), which is updated and maintained regularly. Management-focused maps for the park or potential project areas can be developed on-demand on the website. The WSS homepage gives instructions for how to view and download soil data.

Soil surveys cover all areas of VICK as well as the Port Gibson and Raymond Battlefields (Table 1). These soil surveys were produced for counties, or in the case of Louisiana, for parishes. The main battlefield and detached units in Vicksburg are in Warren County, Mississippi; a legacy soil survey was completed by Cole and Carter (1964). Grant's Canal is in Madison Parish, Louisiana; a legacy soil survey was completed by Weems et al. (1982). The Champion Hill Unit and the Raymond Battlefield are in Hinds County, Mississippi; legacy soil surveys were completed by Kocher and Goodman (1918) and Cole et al. (1979). The Port Gibson Battlefield is in Claiborne County, Mississippi; a legacy soil survey was completed by Lane and Cole (1963).

Table 1. Web Soil Survey areas.

WSS Area Code	WSS Area Name	Associated Park Unit	Soil Survey Status
MS021	Claiborne County, Mississippi	Port Gibson Battlefield	Complete
MS049	Hinds County, Mississippi	Champion Hill Unit and Raymond Battlefield	Complete
LA065	Madison Parish, Louisiana	Grant's Canal	Complete
MS149	Warren County, Mississippi	Main battlefield and detached units in Vicksburg	Complete

Future GSRI Products

Future GSRI products will be determined by the project proposals submitted by park managers and will typically include a geospatial (GIS) component. The GSRI will fund projects that

- collect new data or derive new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic heritage, soil features or processes, or geohazards;
- include features or processes at an individual feature or landscape scale;
- include groups of features or maps of multiple features in a defined area of management needs;
- are a snapshot in time and may establish a baseline for monitoring or assessment.

GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological resources (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunamis, and sinkholes), eolian, erosion,

soil suitability and limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.

- Features and processes covered by other sources of funding and **not** eligible for GSRI funding are Abandoned Mineral Lands (AML), orphaned oil and gas wells, coastal processes, coastal storm response, sea level change projections or mitigation, coastal engineering structures, or shoreline sediment movement.
- The GSRI will also accept proposals for new baseline products, including a geologic (geologic or surficial) or soil map or report, especially for parks not included in the original 270 I&M parks. Park managers requesting these products will need to indicate a management need that the baseline data will support.

Prior NPS-Supported Geologic and Soil Projects

The following is a list of geologic- and soil-related work conducted at VICK in the past. The list does not include baseline inventories (see “Baseline GSRI Products”). The list was compiled using IRMA and is provided so that future work at VICK may build upon past findings. Full citations of the work are included in “Literature Cited.”

Erosion Study

The foundation document (National Park Service 2014) notes that erosion condition information is currently being analyzed by Ameristar and that information could be used for park planning at Louisiana Circle, Navy Circle, and South Fort. The Ameristar report is not posted on IRMA, and park staff have not been able to find the report (Chuck Beightol, VICK, natural resources manager, review comment, 28 January 2025).

Geoscientists-in-the-Parks

From January to March 2018, Krista Hardin served as a Geoscientists-in-the-Parks (GIP) participant. Work included signs and handouts regarding erosion issues at VICK, geology web pages, two site bulletins (general geology and geology’s influence on the Vicksburg Campaign), a public lecture, and a geology manual. Hardin also participated in water quality sampling.

From January to March 2022, Megan Rich received GIP support for the park’s first paleontological inventory. That work was published as an NPS Natural Resource Report (Rich et al. 2023b).

The GIP program is now part of the NPS Scientists in Parks (SIP) program. Except for some completed projects posted on IRMA (e.g., Rich et al. 2023b), GIP or SIP work is not accessible online. Park managers should contact the SIP program managers for assistance in obtaining this work.

Hydrologic Data

- *Vicksburg National Military Park Long-Term Monitoring Projects by the Gulf Coast Network* (Carlson 2022). *Note:* The GULN gathers data at three permanent sites for water quality monitoring at VICK. These sites are streams, and monitoring involves surface water. Groundwater is not monitored in VICK (Daniel Hiatt, GULN, aquatic ecologist, written comment, 13 February 2025).
- Hydrographic and Impairment Statistics Database: VICK (Tucker and Ling 2017, 2025)

Lidar

Lidar data sets are potentially significant for the GSRI because the imagery can be used to monitor, manage, and predict landscape change. Also, lidar can serve as a base map for geologic mapping projects. A general concern is the long-term storage (space and accessibility) of these large data sets (GSRI discussion, 22 May 2024).

The following lidar data sets cover Vicksburg, Mississippi, and vicinity; many of them are available from the [NOAA Digital Coast: Data Access Viewer](#). The data sets are listed by collection date, oldest to newest, and a reference citation is provided (where available):

- EAARL Topography, Vicksburg National Military Park: First Surface (Nayegandhi et al. 2007)
- EAARL Topography, Vicksburg National Military Park: Bare Earth (Nayegandhi et al. 2008)
- 2009–2010 US Army Corps of Engineers (USACE) Vicksburg District Lidar: Mississippi River Delta (US Army Corps of Engineers 2013)
- 2014 USGS Lidar Point Cloud MS_MSDELTAZOO_PHASE1_2009 002725 (US Geological Survey 2014). *Note:* These are the data used to produce the landslide inventory map of the northwestern part of the main battlefield unit (Ashland and DeWitt 2024).
- 2016–2017 USGS Lidar: Mississippi NRCS (US Geological Survey 2017) *Note:* This is the only 2016 data known for VICK. It covers about 75% of the eastern side of the main unit (Jeff Bracewell, GULN, GIS specialist, written communication, 11 February 2025).
- 2018–2020 USGS Lidar: Mississippi Delta, MS (US Geological Survey 2020)
- UAS-borne Lidar 0.5m DTM for parts of Vicksburg National Military Park - December 2022 (DeWitt 2024)

The following three data sets are thought to exist (Chuck Beightol, VICK, natural resources manager, written communication, 23 May 2024) but could not be confirmed by online searches or correspondence with Jeff Bracewell (GULN, GIS specialist) during preparation of this GSRI summary:

- 2016 data set of all the park (1m+ resolution; data source unknown)
- 2020 IMT lidar data set by the USACE of select areas (<0.3m resolution) *Note:* This may be part of the Mississippi River Delta project (US Geological Survey 2020), which was completed over the course of several years due to weather (Jeff Bracewell, GULN, GIS specialist, written communication, 11 February 2025).
- 2020 LiDAR data set of the whole park by the USGS (was possibly contracted to the MDEQ; 1m+ resolution). *Note:* This could possibly be part of UAS-borne Lidar 0.5m DTM for parts of Vicksburg National Military Park - December 2022 (DeWitt 2024) (Jeff Bracewell, GULN, GIS specialist, written communication, 11 February 2025) but seems unlikely because the collection dates are different (i.e., 2020 vs. 2022).

Natural Resource Summary and Condition Assessments

- *Natural Resource Summary for Vicksburg National Military Park (VICK), Final Report* (Cooper et al. 2004)
- *Natural Resource Condition Assessment for Vicksburg National Military Park* (Sundin et al. 2014)

Paleontological Resource Inventories

- *Preliminary Geological and Paleontological Resources Assessment* (Kerbo and McDonald 2005)
- *Paleontological Resource Inventory and Monitoring, Gulf Coast Network* (Kenworthy et al. 2007)
- *Vicksburg National Military Park: Paleontological Resource Inventory* (Rich et al. 2023b)

Projects with a Soil Component

- *Air Quality Related Values (AQRVs) for Gulf Coast Network (GULN) Parks: Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics* (Sullivan 2016, includes information about soil sensitive to pollutants)
- *Develop and Implement a Habitat Management Plan for Prairie Nymph* (Hill et al. 2019, includes soil characteristics)
- *Collection Permit: Collection and Analysis of Concrete, Mortar, and Soil Samples at Wisconsin State Memorial* (Bond et al. 2022)

Slope Failure Studies

- *Subsurface Field Investigation for the Connecting Avenue Slide* (Bobba 2004)
- *Topographic/Geotechnical Surveys at RR Redoubt/TX Memorial Bluff* (Desai et al. 2016)
- *Slope Failure Study, Logue Circle* (Williams et al. 2021)
- *Stabilize Mint Spring Bayou Redesign Services—Geotechnical Investigation & Wetland Investigation* (Desai et al. 2022)

In addition, the natural resource summary (Cooper et al. 2004) cites an investigation of a slide area at the Mint Spring Bayou bridge by Sherman (1962) and a geotechnical investigation in Vicksburg National Cemetery conducted by Burns Cooley Dennis, Inc. (2002). Neither of these studies is posted on IRMA.

Stratotype Inventory

- *National Park Service, Geologic Type Section Inventory: Gulf Coast Inventory & Monitoring Network* (Henderson et al. 2022)

Geologic Setting and History

VICK is marked by two primary geologic features: the Mississippi River (see “Features of the Mississippi River”) and a loess landscape (accumulation of windblown silt; see “Loess” and “Resource Management in Loess Landscapes”). The Mississippi River is a classic meandering river. The channel is constantly shifting across a broad, flat alluvial plain (see [Leard et al. 2025](#)) composed of alluvium (stream-deposited sediments), which can be thicker than 30 m (100 ft; Palmer et al. 2025a). The alluvial plain comprises the river’s modern and past channels and floodplains, which are mapped as meander belts (geologic map unit **Qmb**; see poster), cut-off channels (**Qcc**; see poster), and backswamps (**Qbs**; not on poster; see Palmer et al. 2025a [Redwood quadrangle]). In addition, alluvial fans (**Qaf**; aprons of sediments from tributary streams) coalesce with the alluvium of the Mississippi River (see poster).

Loess is largely responsible for the topography at VICK, including ridgelines and deeply channeled ravines. Loess blankets the pre-loess surface with substantial local variations in thickness but generally thickens toward the west. About 12 m (40 ft) of loess overlies the pre-loess surface in the Vicksburg area (i.e., Redwood, Vicksburg East, and Vicksburg West quadrangles; Palmer et al. 2025a, 2025b, 2025c). The pre-loess topography is composed of either pre-loess terrace deposits (**Qtpl**; floodplain of the ancestral Mississippi River) or bedrock, including the Vicksburg Group (**Tv**), Catahoula Formation (**Tca**), or Hattiesburg Formation (**Tha**; at the Port Gibson Battlefield; see poster). The Vicksburg Group is divided into the Forest Hill Formation, Mint Spring Formation, Marianna Limestone, Glendon Limestone, Byram Formation, and Bucatunna Clay (Palmer et al. 2025a, 2025b, 2025c).

On the eastern side of the Mississippi River, a line of loess-covered bluffs rises above the alluvial plain. The loess bluff at Fort Hill is one of the most dramatic topographic features of VICK. It is 104 m (340 ft) above sea level and rises more than 80 m (265 ft) above the alluvial plain (see poster). This steeply sloped knoll overlooking the Mississippi River played a key role in the defense of Vicksburg due to its commanding position (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009). The loess bluffs that line the river are not everywhere as high everywhere as at Vicksburg but are nonetheless imposing throughout the entire length of the lower Mississippi River valley (Grabau 2000).

Three tributaries (small, perennial streams) of the Mississippi River drain VICK: (1) Mint Spring Bayou (officially “Mint Spring Branch”; US Board on Geographic Names 1981), (2) Glass Bayou, and (3) Durden Creek (see poster). Mint Spring and Glass Bayous drain into the Yazoo River, which joins the Mississippi River, whereas Durden Creek flows into Hatcher Bayou, which flows into the Mississippi River. Mint Spring Bayou is divided into upper and lower reaches by a 10-m- (33-ft-) high waterfall (Hiatt 2023). The Mint Spring and Glass Bayous have cut through loess, the Catahoula Formation, and into the Vicksburg Group. Durden Creek has cut through loess and into pre-loess terrace deposits (see poster). Incision of loess has created steep-walled ravines.

The following are significant geologic events that led to the present-day landscape at VICK:

- About 200 million years ago (Jurassic Period), the Gulf of Mexico basin formed as the supercontinent Pangaea was undergoing continental rifting and break up (Pindell 1985; Kious and Tilling 1996).
- About 100 million–66 million years ago (Late Cretaceous Period), a vast inland sea known as the “Western Interior Seaway” or the “Cretaceous Interior Seaway” extended south to north across North America from the Gulf of Mexico to the Arctic Ocean. An eastern embayment of the seaway—the Mississippi Embayment, which extended northward from the Gulf of Mexico into southern Illinois—became an actively subsiding basin at that time. The embayment also became a major controlling factor in determining the course and sediment dispersal of the Mississippi River system during the following Paleogene Period (66 million–23 million years ago; Dockery and Thompson 2016).
- Between 66 million and 23 million years ago (Paleogene Period; Paleocene, Oligocene, and Eocene Epochs), regional-scale river systems, including what would become the Mississippi River, began to discharge into the Gulf of Mexico, depositing large volumes of sediment (Galloway et al. 2011).
- About 32 million years ago (Oligocene Epoch), marl, limestone, clay, and sandstone of the Vicksburg Group accumulated as sea level rose and fell along the Gulf Coast. The Forest Hill Formation was deposited first, just before a major marine transgression (sea level rise). As marine waters inundated the landscape, the Mint Spring Formation, followed by the Marianna and Glendon Limestones were deposited. As sea level fell, the Byram Formation and overlying Bucatunna Clay were deposited.
- Between 23 million and 5 million years ago (Miocene Epoch), the Mississippi River system emerged as the primary focus for sediment input into the Gulf of Mexico (Blum and Roberts 2012).
- About 23 million years ago (Miocene Epoch), mudstone and sandstone began to accumulate in lagoons and deltas, respectively, as part of the Catahoula Formation. The formation marks the introduction of terrestrial sediments (vs. marine sediments) into the northern Gulf of Mexico, which has continued uninterrupted to the present day (Dockery and Thompson 2016).
- Before the initial advance of continental ice sheets, the Missouri and Ohio Rivers had flowed northeastward into Canada and drained into Hudson Bay (Biek and Gonzalez 2001; Blum and Roberts 2012), but by 640,000 years ago (Pleistocene Epoch), advancing ice sheets diverted the ancestral Missouri and Ohio Rivers to the south, forcing them to empty into the Mississippi River drainage. The Yazoo River was established when the Ohio River converged with the Mississippi River north of Memphis, abandoning the Yazoo Basin (Kolb et al. 1976).
- During river diversion by continental ice sheets, the Mississippi River flowed at a higher elevation than it does today. The former elevation and location of the ancestral floodplain are recorded by pre-loess terrace deposits (**Qtpl**; see poster). The base of this terrace occurs at

approximately 67 m (220 ft) above sea level and is now masked by about 12 m (40 ft) of loess overburden (Palmer et al. 2025a, 2025b, 2025c).

- Sediments, initially deposited by glaciers upstream, were transported downstream by the Mississippi River and deposited in pre-loess terrace deposits. These deposits contain large boulders that came down the Ohio and Mississippi Rivers in floating blocks of ice, a process known as “ice rafting” (Dockey et al. 2008). In VICK, some of these sediments consist of fossils from the Paleozoic Era (539 million to 252 million years ago; Rich et al. 2023b).
- Loess was deposited on the Mississippi River floodplain and the adjacent upland area in the Late Pleistocene Epoch. Pigati et al. (2014) provide an age range of 28,000 to 23,000 (calendar) years ago (Pleistocene Epoch). Snowden and Priddy (1968) provide an age range of 25,860 to 19,670 years ago. *Note:* Both studies utilized radiocarbon dating. Dates were converted to calendar years by Pigati et al. (2014). For the radiocarbon ages by Snowden and Priddy (1968), CALIB REV8.2 (Reimer et al. 2020) was used to convert radiocarbon ages to calendar years for this GSRI summary.
- Between 18,000 and 12,000 years ago (Pleistocene Epoch), rivers responded to meltwater discharge that was an order of magnitude greater than today (comparable in scale to the present-day Amazon River; Bentley et al. 2016). Rivers were braided at that time.
- At 9,190–8,070 years ago (Holocene Epoch), wide, rapidly migrating meander belts of the Mississippi River first developed, marking the change from a braided (glacial) to meandering (nonglacial) system (Fisk 1944; Prokocki 2009; Bentley et al. 2016).
- At present, the Mississippi River continues to meander across its floodplain.

Park Significance and Establishment

Waged between 29 March and 4 July 1863, the Vicksburg Campaign occurred two years into the American Civil War (12 April 1861 to 26 May 1865). The Vicksburg Campaign encompassed battles in west-central Mississippi at Port Gibson, Raymond, Jackson, Champion Hill, and Big Black River Bridge (see cover graphic), as well as 47 days of Union siege operations (18 May to 4 July) against the Confederate forces defending the city of Vicksburg. Confederate troops were under the command of Lieutenant General John C. Pemberton. Union troops were commanded by Major General Ulysses S. Grant. Grant's strategy for Vicksburg was to lay siege and cut off all supplies and communications from the rest of the Confederacy. Coupled with the siege and fall of Port Hudson, Louisiana (22 May to 9 July 1863), the success of the Vicksburg Campaign gave the Union undisputed control of the Mississippi River.

Thirty-four years following the war, VICK was established on 21 February 1899 (Public Law 62, 30 Stat. 841) "to commemorate the campaign, siege, and defense of Vicksburg, Mississippi, and to preserve the history of the battles and operations of the siege and defense on the ground where they were fought and carried on." With Antietam, Chickamauga/Chattanooga, Gettysburg, and Shiloh, Vicksburg was one of the first five national military parks established by the federal government. These parks were initially administered by the War Department, but in 1933, they were transferred to the stewardship of the NPS.

Sense of Place

VICK protects hallowed ground on which more than 100,000 soldiers fought, and many died, for the control of the Mississippi River during the American Civil War. As directed by the enabling legislation, commemoration is the primary land use of VICK. Visitors get a sense of what took place at the main battlefield unit while exploring the commemorative landscape (see "Commemorative Landscape"). The solemnity of VICK is a fundamental value, and maintaining this sense of solemnity is an important goal in any future management decision (National Park Service 2014).

VICK is also a high-quality natural area. It preserves one of the few remaining public land tracts of loess-bluff hardwood forest with diverse transitional habitat in the lower Mississippi River corridor/Mississippi Delta region. It supports migratory birds; provides habitat for the rare flower, prairie nymph (*Herbertia lahue*); and serves as refuge for other species that have lost habitat due to urban development and agrarian monoculture (National Park Service 2014). Recreational uses at VICK include walking and biking along the tour road and hiking along the wooded trail (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009).

Vicksburg, Mississippi

The city of Vicksburg takes its name from Newitt Vick, a Methodist circuit rider. Vick built a plantation and a Methodist church on his property and envisioned the town that would one day bear his name (Surratt 2022). The city of Vicksburg was established in 1825.

In 1819, Vick settled in the area then called “Walnut Hills,” which consists of the cliffs and hills in the vicinity of what is now Vicksburg National Cemetery. In the 1700s, the land was part of Fort Nogales, a Spanish colonial fort located at the confluence of the Mississippi and Yazoo Rivers. Meaning “walnuts” in Spanish, the name of the fort as well as the early 19th-century American settlement called “Walnut Hills” reflect the surrounding groves of North American black walnut (*Juglans nigra*).

The city of Vicksburg is 64 km (40 mi) west of the Mississippi state capital, Jackson, and 377 km (234 mi) northwest of New Orleans, Louisiana. It was built just below the confluence of the Yazoo and Mississippi Rivers, thereby capitalizing on the economic and transportation opportunities provided by these rivers. The city is also a railroad hub; the historic Southern Railroad of Mississippi, now known as the Kansas City Southern Railroad, stops in Vicksburg. The combination of river, rail, and road created economic value in non-war times and a tremendously important strategic military position in wartime.

Main Battlefield Unit

- Geologic map units: Vicksburg Group (**Tv**), Catahoula Formation (**Tca**), pre-loess terrace deposits (**Qtpl**), loess (**Ql**), meander belt (**Qmb**), cut-off channel (**Qcc**), and alluvium (**Qal**; see poster)

Cradling the city to its north and east, the main battlefield unit of VICK resembles a crescent (see poster). A small portion extends into the Yazoo River Diversion Canal, which is in a former channel of the Mississippi River. The main battlefield unit features cultural resources, some of which are also geologic resources (see “Geologic Heritage”), including reconstructed forts, trenches, earthworks, gun batteries, the 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 2014).

The “primary organizing element” of the main battlefield unit is the 26-km (16-mi) tour road (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009, p. 88), which winds its way through the complex terrain, tracing both the Union and Confederate siege and defense lines and providing access to important fortifications and engagement sites. The road serves as a “tour guide,” allowing visitors to experience what took place via 15 designated stops (see poster). Descriptions of the stops are presented on the park guide (map) and via a self-guided tour available as a free NPS mobile app.

Vicksburg National Cemetery

- Geologic map units: Vicksburg Group (**Tv**) and loess (**Ql**; see poster)

Established shortly after the war ended in 1866, VICK includes Vicksburg National Cemetery, which is situated on a bluff overlooking the Yazoo River Diversion Canal (see poster). Covering 45 ha (110 ac), the national cemetery was constructed on land that was occupied by Union forces during the siege. Landscaping features include terraces, tree-lined roads, a perimeter wall, and entrance gates. These features reflect formal Victorian design principles intended to honor the dead (National Park

Service 2014). Due to the rugged terrain, extensive landscaping was necessary to prepare the grave sites (Miller 1976).

The cemetery serves as the final resting place for 17,077 Civil War soldiers and sailors, of whom 12,909 are unknown. Approximately 40% of the burials are believed to be of the US Colored Troops, some of whom served as occupation forces in Vicksburg following the siege. Civil War-era burials also include a war nurse and a female veteran. An additional 1,280 burials are occupied by soldiers and sailors who fought in the Indian Wars, the Spanish-American War, the First and Second World Wars, and the Korean War. Also included is a memorial section to honor veterans of the Vietnam War. Additionally, 27 US government workers are interred (Joyner 2024).

Most of the Confederates who died during the siege were buried behind Confederate lines, mainly in the Vicksburg City Cemetery (Cedar Hill Cemetery), in an area called “Soldiers’ Rest.”

Approximately 5,000 Confederate soldiers are believed to be buried there, of whom only 1,600 are identified. Only four Confederate burials are known to occur in Vicksburg National Cemetery (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009).

Detached Units in Vicksburg

Geologic map units: Catahoula Formation (**Tca**) and loess (**Ql**; see poster)

Three detached units—Louisiana Circle, South Fort, and Navy Circle—mark the southern end of the Confederate and Union lines in Vicksburg. These units are located on the loess bluffs that overlook the Mississippi River. They possess commanding views, which were of strategic importance during the war. Each unit is between 0.4 and 1.2 ha (1.0 and 3.0 ac) and includes remnants of earthen fortifications from the siege. The two northern fortifications—Louisiana Circle and South Fort—are associated with the Confederate defensive line established in 1862. Navy Circle was established by Union forces as part of their offensive siege line in 1863.

VICK also preserves Pemberton’s Headquarters, the command center for Confederate forces during the siege. Located in downtown Vicksburg, the two-story masonry structure is a significant resource related to the siege and defense. It provides a tangible link between the battlefield landscape and the community of Vicksburg (National Park Service 2014). Like the three detached units, the Catahoula Formation (**Tca**) and loess (**Ql**) underlie Pemberton’s Headquarters (see poster).

Grant’s Canal

- Geologic map unit: abandoned channel (**Qac**—not featured on the geologic map poster; mapped as part of the MSU project [Smith and Schmitz 2016a] in Louisiana)

Located on the Mississippi River alluvial plain in Madison Parish, Louisiana, the site of Grant’s Canal was part of a Union military strategy to build a navigable waterway meant to bypass the city of Vicksburg and its defenses (see “Features of the Mississippi River”). Much of the canal has been demolished by more recent agricultural operations, but a small remaining tract retains most of the canal’s original width and depth. Working in conjunction with The Conservation Fund, this tract of land was donated to the NPS by local landowners in 1990.

In addition to connecting visitors to a distinctive chapter and military strategy in the Vicksburg Campaign, Grant's Canal recognizes the actions of US Colored Troops during the battle of Milliken's Bend (north of Vicksburg). Also, the Connecticut State Memorial, which honors the 9th Connecticut Volunteer Regiment, is located at the site; this is one of 23 memorials that recognize troops by state (see poster).

Detached Battlefield Units

- Geologic map units at Champion Hill Unit: Vicksburg Group (**Tv**), Catahoula Formation (**Tca**), loess (**Ql**), alluvial terrace (**Qalt**), and alluvium (**Qal**; see poster)
- Geologic map units at Port Gibson Battlefield: Hattiesburg Formation (**Tha**), loess (**Ql**), alluvial terrace (**Qalt**), and alluvium (**Qal**; see poster)
- Geologic map units at Raymond Battlefield: Catahoula Formation (**Tca**), loess (**Ql**), and alluvium (**Qal**; see poster)

Most of VICK is located along the Mississippi River; however, a few parcels, representing the battles at Champion Hill, Port Gibson, and Raymond, are located farther afield. Of these, Champion Hill has been designated as a unit of the National Park System. Work and funding by the American Battlefield Trust, the Mississippi Department of Archives and History, the Land and Water Conservation Fund, and a Battlefield Land Acquisition Grant from the NPS American Battlefield Protection Program enabled inclusion of the battlefield into the National Park System as part of VICK. Similar funding strategies will likely be implemented at the Port Gibson and Raymond Battlefields (Chuck Beightol, VICK, natural resources manager, Teams chat, 4 June 2024).

Combined, the three detached sites will add 4,727 ha (11,680 ac) to VICK (National Park Service 2014). Prior administrations of VICK discussed staffing these battlefields with interpretive rangers. Due to staffing shortages, however, the present NPS management of these units will primarily focus on maintaining the landscape and hiring contractors to repair assets. The condition of the roads throughout these lands, which have come into disrepair, is a concern for visitor access. The NPS does not own these roads, and if funding is not procured and an agreement is not reached with the county to fix and maintain these roads, then visitation to these units will be limited (Chuck Beightol, VICK, natural resources manager, written communication, 28 January 2025).

Geologic Heritage

Geologic heritage, or geoheritage, exists where geology overlaps with human experiences and values. It encompasses significant geologic features, landforms, and landscapes characteristics, which are recognized for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, and economic. Important for VICK, geoheritage is a way of viewing history “through a geological window” (Higgins 2002, p. 21).

This section highlights notable geoheritage features at VICK. They are discussed in chronological order, though stratotypes are discussed before paleontological resources, even though some fossils in VICK are older than the bedrock.

Stratotypes

Stratotypes are important geologic reference exposures that help identify, define, and correlate geologic units from one area to another. Akin to natural libraries of Earth history, stratotypes preserve meaningful clues to the past and serve as outdoor geologic classrooms. When geologists formally propose or describe a layer or body of rock, a stratotype is assigned to exposures containing all (or most) of the diagnostic features. Stratotypes have significant scientific value and are typically accessible, world-class locations to study outcrops.

The NPS geologic type section inventory for the Gulf Coast Inventory & Monitoring Network (Henderson et al. 2022) identified two stratotypes for VICK: (1) the Vicksburg Group type area and (2) the Mint Spring Formation type section/type locality. A type area is a broader geographic area that encompasses the stratotype. A type section is a reference rock exposure. A type locality is a specific geographic location of the reference rock exposure.

In addition, Krinitzsky and Turnbill (1967) informally named a “type section of Mississippi loess” at Vicksburg (see “Loess”). First described by Priddy et al. (1964), a typical locality consists of the following, top to bottom: (1) the “Vicksburg loess,” which is leached in a thin uppermost layer but is calcareous (carbonate/CaCO₃-rich) in the remainder of the section; (2) a basal transition zone, which is weathered, generally noncalcareous, and contains a distinct buried soil horizon; and (3) a pre-Vicksburg loess, which may be calcareous and unweathered to noncalcareous and greatly weathered.

Type Area of the Vicksburg Group

The Vicksburg Group is exposed in a belt of rocks that runs east–west across the state (see [Bicker 1969](#)). The type area of the Vicksburg Group is Vicksburg, Mississippi. It was defined by Conrad (1847) for exposures in and around the city and in the bluffs overlooking the Mississippi River.

The Vicksburg Group consists of sand, clay, shell fragments, organic material, and the green mineral glauconite. As sea level rose and fell, these constituents were deposited in various settings: delta, lagoon, marine shelf, and land above high tide. The Vicksburg Group is divided into six formations: Forest Hill Formation, Mint Spring Formation, Mariana Limestone, Glendon Limestone, Byram Formation, and Bucatunna Clay (Palmer et al. 2025a, 2025b, and 2025c).

Type Section/Type Locality of the Mint Spring Formation

The Mint Spring Formation type section/type locality at VICK is in the lower course of Mint Spring Bayou (Cooke and Cushman 1923; Morse 1935; Mellen 1941; Tonti 1955; Baughman 1971; MacNeil and Dockery 1984). First described by Cooke (1918), these rocks were originally classified as a member of the Marianna Limestone. The exposure of the Mint Spring Formation in the type section measures 3–4 m (9–13 ft) thick and consists of light-greenish gray to dark-gray, fossiliferous, glauconitic sandy marls (mixture of clay and calcium carbonate, typically in the form of shell fragments) and limy sand.

The type locality—Mint Spring Bayou—is a picturesque waterfall setting (Figure 1). Although not formally named in the Geographic Names Information System (GNIS), “Mint Spring Falls” is one of the tallest in the state and is designated as a “Mississippi State Natural Feature” (National Park Service 2014). As such, the setting is a showcase of VICK geology and has been highlighted in many publications. For example, an impressive 1941 photograph of the type section appears on the front cover of *National Park Service Geologic Type Section Inventory, Gulf Coast Inventory & Monitoring Network* (Henderson et al. 2022), and a present-day photograph is displayed on the cover of *Vicksburg National Military Park, Paleontological Resource Inventory* (Rich et al. 2023b). The type locality is currently off-limits to visitors (see “Preservation of Stratotypes”).

In addition to its stratigraphic significance, Mint Spring Bayou (the slow-moving stream into which Mint Spring Falls spills) has historic significance and is identified in the VICK foundation document (National Park Service 2014) as an “other important resource and value.” The bayou is considered an important battlefield landscape feature because during the defense/siege of Vicksburg, it served as a boundary between battle lines and as a source of freshwater for both Union and Confederate soldiers.

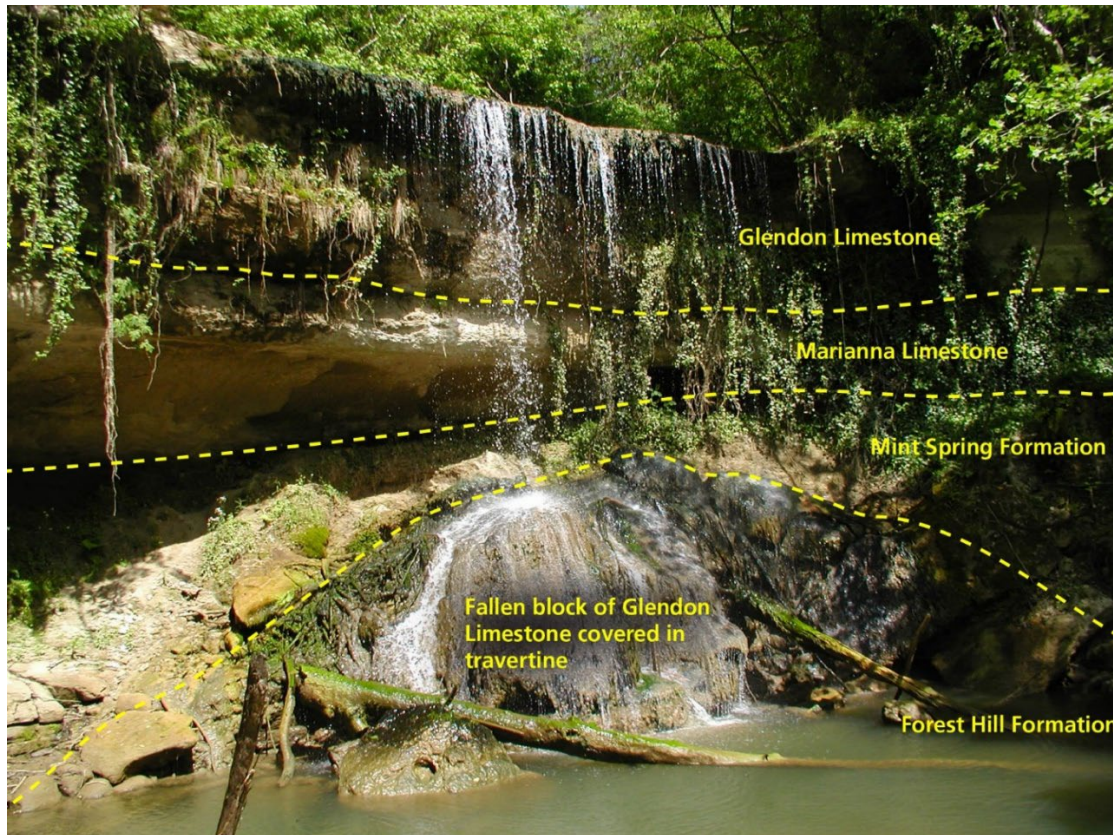


Figure 1. Photograph of the Mint Spring Formation type section. The type section is beneath a waterfall in the lower course of Mint Spring Bayou at VICK. In addition to the Mint Spring Formation, three other formations of the Vicksburg Group are exposed at the type section. The Forest Hill Formation and Marianna Limestone bound the Mint Spring Formation, below and above, respectively. In addition, the Glendon Limestone is exposed at the type section. It lies above the Marianna Limestone and is the formation over which Mint Spring Bayou falls. Photograph by Katie KellerLynn (Colorado State University), taken 2010; annotations by Trista Thornberry-Ehrlich (Colorado State University).

Paleontological Resources

The rocks at VICK are fossiliferous, a feature that adds to their geologic heritage value. During a paleontological resource inventory in 2023—the first of its kind at VICK—fossils were collected or observed at 72 localities at the main battlefield unit. The inventory shows that essentially every geologic unit exposed at VICK is fossiliferous (Rich et al. 2023b); only the Forest Hill Formation is not fossiliferous in the park, though it hosts fossils elsewhere. Monroe (1954) and Moore (1965) document plant fossils from the Forest Hill Formation in and around Jackson. Leard et al. (2023b) describe silicified wood in the Forest Hill Formation as “common” in Yazoo, Warren, and Hinds Counties (i.e., Phoenix quadrangle).

The paleontological resource inventory by Rich et al. (2023b) did not survey the Champion Hill Unit or the Port Gibson and Raymond Battlefields. However, the rock units present at those sites suggest the possibility of future fossil discoveries.

A geologic heritage value associated with the paleontological resources at VICK is the inception and growth of American paleontology. Fossils from VICK are part of that 19th-century story and are important for their scientific, aesthetic, cultural, and educational values. The origin of American paleontology is revealed in a chronological breakdown (collection dates and names) of the taxa associated with NPS areas, in particular VICK and two parks in Virginia (Colonial National Historical Park [COLO] and Petersburg National Battlefield [PETE]). Interestingly, the chronology records an interruption caused by the American Civil War. The oldest names in the chronology were contributed by Timothy Abbott Conrad (1803–1877) and come from areas associated with VICK, COLO, and PETE. Conrad contributed a staggering 171 potential taxa to the chronology of American paleontology (Tweet et al. 2016).

Vicksburg Group Fossils

The fossils of the Vicksburg Group are well-known and globally significant. The diversity of fossil mollusks is particularly notable (Rich et al. 2023b). The Vicksburg Group contains an estimated 547 molluscan taxa, making it the best record of marine fauna from the early Oligocene Epoch (about 34 million to 27 million years ago) in North America and possibly the Western Hemisphere (Dockery and Thompson 2016).

Featuring 325 documented molluscan taxa, the Mint Spring Formation is the most paleontologically diverse formation of the Vicksburg Group (Dockery 1986; Dockery and Thompson 2016). Like the Mint Spring Formation, the Byram Formation is also very fossiliferous and known for its abundant mollusks (Cooke 1918). Significantly, the gastropods in the Byram Formation show even greater diversity than the mollusks it contains (Rich et al. 2023b).

Another interesting feature associated with the Vicksburg Group is effigy pipes and stone tools, which are fashioned from the Glendon Limestone. The limestone is identified by *Lepidocyclina superaare*—distinctive, dime-sized, wafer-like foraminifera fossils. A prominent outcrop of Glendon Limestone within VICK is a probable source area for the stone used in these pipes (Rich et al. 2023a). Effigy pipes and stone tools fashioned from the Glendon Limestone provide evidence of human use and interest of the paleontological resources from the Vicksburg area extending back to the Middle Archaic [cultural] Period (6000–3000 BCE) (Webb 1971; Steponaitis and Dockery 2011).

Fossils in Pre-Loess Terrace Deposits

The oldest fossils at VICK occur in the pre-loess terrace deposits. The deposits accumulated from 600,000 to 10,000 years ago (during the Late Pleistocene Epoch; Dockery et al. 2008), though the fossils themselves are much older. Fossils found in the pre-loess terrace deposits include Paleozoic corals, bryozoans, crinoids, brachiopods, bivalves, gastropods, and trilobites (Rich et al. 2023b).

These ancient fossils were transported by the ancestral Mississippi River from source-rock areas upstream from VICK, including northern Mississippi and other states as far away as Minnesota (Dockery et al. 2008). Studied elsewhere in the lower Mississippi River valley, pre-loess terrace deposits also contain the oldest known examples of igneous (volcanic) gravels exposed at the surface in Mississippi. This volcanic gravel, which originated from the St. Francois Mountains in

southwestern Missouri, carries with it the implication that glacial extent was farther southwest than previously documented (Pizarro et al. 2024).

Fossils in Loess

Loess contains fossils, including terrestrial and freshwater snails as well as microfossils, plant fossils, and vertebrate fossils (Rich et al. 2023b). With respect to vertebrate fossils, which are commonly of great interest to visitors, at least two occurrences of mastodon bones have been documented from the loess in Vicksburg, though not within VICK (Priddy et al. 1966; Kolb et al. 1976; Rich et al. 2023b). The proximity of many of the other discoveries of mastodon fossils to VICK indicates the potential for similar finds within the park (Kenworthy et al. 2007).

Loess

Loess is an accumulation of windblown silt (see “Resource Management in Loess Landscapes”). For more than a century, scientists (e.g., Hilgard 1879) have recognized that the silt in loess is produced primarily through glacial grinding. Loess deposits in North America occur south of the area that was occupied by the Laurentide and Cordilleran ice sheets (Figure 2). These ice sheets covered most of Canada during the last and previous glaciations, leaving the regions with little loess. Even after the ice sheets retreated, little loess accumulated in Canada because silt-sized particles carried by meltwater streams were deposited in large proglacial lakes (immediately in front of a glacier; Flint 1971). Vegetation colonized most of the former lake surfaces shortly after lake drainage, and thus little opportunity occurred for entrainment (the process of picking up and transporting sediment) by the wind. South of the ice sheets, however, loess deposition was extensive. By far the greatest extent of loess (and that with the greatest thickness) in North America is in the Great Plains region east of the Rocky Mountains and extending into the greater Mississippi River drainage basin (Muhs 2013).



Figure 2. Map showing the distribution of loess in North America. The map illustrates what North America looked like about 15,000–12,000 years ago. The white area represents glacial ice. Yellow shaded areas represent loess deposits. At that time, paleowinds at Vicksburg were from the west. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Muhs (2013, figure 15), which compiled data from Péwé (1975), Dyke et al. (2002), Bettis et al. (2003), Muhs et al. (2003), and Busacca et al. (2004).

Loess has many features of significance that impacted the Vicksburg Campaign and the geologic heritage of VICK:

- Loess ridges form the primary land access points into the city. Only six avenues of approach existed between the fortified Confederate ridge and the smaller, less continuous Union fortified ridge; all approaches were drainage divides/ridges with roads located atop them. During the war, these approaches became the scenes of the heaviest fighting because, typically, the intervening terrain (ravines) was impassable (steep slopes filled with dense vegetation; Larson et al. 2004; Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009).
- Loess bluffs made the city a natural fortress. The clear vistas and imposing landscape favored military defense. The high bluffs provided such an advantage that Grant's troops were prevented from taking the city by direct assaults, despite outnumbering Confederate forces (National Park Service n.d.).
- Loess is easy to dig, and vertical cuts stand almost indefinitely (Grabau 2000; Larson et al. 2004); therefore, military trenches, approaches, and parallels were excavated into it. Union troops dug lines with the intent of approaching Confederate defenses and setting off explosives beneath fortifications.
- Makeshift caves were dug into the loess, becoming havens from the relentless artillery shelling for Vicksburg citizens and Confederate soldiers alike. Notably, when the caves received direct hits, they often collapsed, leaving the loess susceptible to water erosion (National Park Service n.d.).
- Similar to makeshift caves, Union soldiers constructed "shebangs" into exposed loess slopes. The term "shebang" can refer to any type of temporary shelter built by soldiers, but in this case, they were cave-like quarters (dugouts) that faced away from the Confederate artillery. Union forces created a network of shebangs on the slope southeast of Shirley House (the only surviving wartime structure in VICK; Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009). During the siege, Shirley House served as headquarters for the 45th Illinois Infantry, whose members built the shebangs.
- The particle size of loess became a factor during the siege, caking the soldiers' clothing, coating their equipment, and turning roads into quagmires after summer showers. These conditions were mentally and physically challenging, significantly undermining the soldiers' morale, especially the Confederates, who had no option but to remain in their trenches (Myers et al. 2005).
- The hydrologic properties associated with loess contributed to the shortage of water within the city during the siege. Vicksburg has historically relied on cisterns for water because little groundwater (for wells) exists in the loess. Union soldiers forced the Confederate troops to rely on the cisterns by polluting (i.e., throwing dead animals into) the streams that flowed through the city. Ultimately, cisterns went dry, causing a water shortage, which, in turn,

contributed to the outbreak of disease and the inability to treat wounded soldiers (Larson et al. 2004; Myers et al. 2005).

- In addition to its influence during the Vicksburg Campaign, loess affected early cultural settlement patterns and agricultural activities and later influenced park development and subsequent management by focusing construction and road building on the ridgelines (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009).

Features of the Mississippi River

The Mississippi River's channel is highly unstable and constantly shifting. The location of the river channel in 1825 was significant for the establishment of Vicksburg because it was one of only a few places where the river met the valley wall, making it accessible for shipping, transport, and travel on the river. Then and now, other places where the river meets the valley wall are Natchez, Mississippi, and Baton Rouge, Louisiana.

In addition to the location of the channel, another significant factor for the establishment of Vicksburg as a shipping port was the location of bedrock outcrops. The Mint Spring Formation lies at the base of the loess bluffs at approximately river level (Dockery and Thompson 2016). As a result, bedrock keeps the river's erosive capabilities in check and allows for ship landings on solid ground.

The primary objective of the military engagement at Vicksburg was control of the Mississippi River. For the Union, control meant gunboats (see "Buried in Silt and Sand: USS *Cairo*"). For the Confederacy, which lacked a navy, control meant heavy-artillery batteries built along the banks of the river. Meander bends became an important factor in placing batteries because the eddies associated with them tended to throw ships out of control. Tuscumbia Bend—the hairpin meander bend adjacent to Fort Hill (see poster)—figured strongly in the Vicksburg Campaign. Near the water's edge, opposite this turbulent turn, the Confederates placed Water Battery at the base of Fort Hill. Water Battery was one of the most effective river defenses (Grabau 2000).

Grant envisioned diverting the Union gunboats away from the Confederate batteries by building a canal across the narrow meander neck at De Soto Point—the long, low-lying peninsula that jutted up between the north- and south-flowing reaches of the river (see poster). The point/peninsula was named for the Spanish explorer Hernando De Soto, who became the first known European to enter the region in 1540–1541 (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009). "Grant's canal" would have changed the course of the Mississippi River (and the course of the war), leaving Vicksburg high and dry and allowing Union troops to bypass the treacherous Tuscumbia Bend. Construction began in summer 1862 but soon stopped due to disease and heat exhaustion. The project was resumed in 1863 but was short-lived because of flooding and exposure. Ultimately, Grant rejected the possibility of a frontal attack on Vicksburg and focused his attention on the larger campaign (Henderson 2000). As it happens, the Mississippi River itself cut through De Soto Point in 1876 (see "Yazoo River Diversion Canal"), which is why the peninsula looks as it does on the geologic map (see poster).

Natural levees are another conspicuous landform of the Mississippi River. The distribution (and higher elevation) of natural levees influenced human settlements, transportation routes, and agricultural and industrial activities (Chapman et al. 2004). At the time of the war, natural levees were the sites of plantations such as Bruinsburg and Hard Times (see cover graphic), which were also locations where Union soldiers camped and crossed the river.

Bayous (creeks or secondary watercourses that are tributaries to the Mississippi River) are another characteristic feature. Especially during “high water” (see “Floods”), bayous create a network of interconnecting waterways, many of which are navigable.

Backswamps (depressions on the floodplain) are also a characteristic feature. Backswamps accumulate fine-grained sediments, including thick, massive sequences of overbank (floodwater) deposits. Backswamps host dense stands of bald cypress, tupelo, willow, and oaks, creating habitat for alligators, snakes, fish, aquatic birds, and mammals (National Park Service n.d.).

Karst, Cave Features, and Travertine

Karst (landscape underlain by limestone or other soluble bedrock that has been eroded by dissolution, producing sinkholes, caves, and underground drainages) occurs in Mississippi (see Moore et al. 2005). However, the Vicksburg Group, which crosses the state, does not become karstic until farther east, where the Marianna Limestone is the source of caves from Smith County to Wayne County (see [Bicker 1969](#); Dockery and Thompson 2016). East of VICK, the rocks of the Vicksburg Group become less of a marl (mixture of clay and calcium carbonate [CaCO_3]) and more of a limestone (“pure” calcium carbonate), which is conducive to cave formation (James Starnes, MDEQ Mississippi Geological Survey, geologist, email communication, 16 July 2024).

The interpretation of an “exposed cave passage” along Glass Bayou (Wells 1997, p. 12) persisted in NPS documents for two decades (e.g., Cooper et al. 2004, p. 9 and 13; Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009, p. 89). However, that interpretation is now deemed “inaccurate” (James Starnes, MDEQ Mississippi Geological Survey, geologist, email communication, 16 July 2024). At the location of the so-called “exposed cave passage,” Glass Bayou is a slow-moving perennial stream that is approximately 2 m (7 ft) wide. Water depth ranges from 3 to 10 cm (1 to 4 in) with occasional pools containing water as much as 30 cm (12 in) deep. The flow rate is relatively low due to the low gradient. The streambed is composed of pre-loess gravel that contains scattered pieces of flowstones and root molds (types of calcium carbonate deposits [discussed in the next paragraph]) transported from upstream. No overhang, knickpoint (sudden change in slope), or alcove occur within this section of the stream (Chuck Beightol, VICK, natural resources manager, email communication, 17 July 2024).

Although no cave passages ever formed along Glass Bayou (and later collapsed, becoming “exposed”), features such as “flowstone” and “dripstone” (general terms for any CaCO_3 deposit or other mineral formed in caves by flowing or dripping water, respectively) along this stretch of the stream and elsewhere in VICK resemble cave features. At VICK, these features are composed of travertine, a form of CaCO_3 . Because CaCO_3 accumulates in loess (see, e.g., Russell 1944; Pécsi

1990), the source material of the travertine is thought to be the loess. The flowstone and dripstone form where carbon dioxide (CO_2) escapes from the carbonate-rich water via flowing or dripping. As a result, some of the most impressive concentrations of travertine at VICK, and elsewhere in Mississippi, are along waterfalls, where water spills over exposed bedrock in an active stream channel. These dripstone and flowstone features tend to break off with erosion and are incorporated within the stream alluvium. These features are not exclusive to waterfalls along the outcrop of the Vicksburg Group; they also are found as thick coatings at waterfalls over outcrops in the Catahoula sandstone (James Starnes, MDEQ Mississippi Geological Survey, geologist, email communications, 16 and 17 July 2024). Travertine is a stream precipitate (deposited in solid form from solution) that coats various substrates such as gravel bars, botanical litter, and exposed roots. It can form anywhere along the length of the channel, not just at waterfalls or at seeps (James Starnes, MDEQ Mississippi Geological Survey, geologist, email communications, 16 and 17 July 2024).

Three additional travertine or cave-like curiosities are of interest for geologic heritage at VICK. First, because travertine forms as a result of flowing water, an outcrop of travertine at VICK (or elsewhere in the area) likely marks the site of a former (abandoned) waterfall (Dockery and Thompson 2016), which visitors could find while exploring beyond the tour road. Encountering an outcrop of travertine without running water would provide an opportunity to teach visitors about geology in the field. Second, modern plant leaves coated with travertine (Figure 3) may be mistaken for true fossils (Rich et al. 2023b). Third, visitors who enter the Illinois State Memorial may notice “stalactites” (cylindrical mineral deposits hanging from the ceiling of a cave) at the top of a marble pillar (Figure 4). Like travertine in streams and calcite in caves, marble—which is also composed of CaCO_3 —provides another example of a cave-like feature formed via the loss of CO_2 by flowing/dripping water, albeit in a rather unexpected setting.



Figure 3. Photograph of a travertine-coated leaf. Appearing like a fossil, this specimen is a modern leaf coated in travertine. Photograph courtesy of James Starnes (MDEQ Mississippi Geological Survey).



Figure 4. Photograph of “dripstone” in the Illinois State Memorial. Marble caves are rare but do exist (see GRI report about Oregon Caves National Monument by KellerLynn 2011). Cave-like conditions promote the formation of dripstone in the marble interior of the memorial. Photograph by Katie KellerLynn (Colorado State University), taken 2010.

Uses of Bedrock and Gravel

The following information about the bedrock and pre-loess terrace deposits at VICK is of value for geologic heritage and may be of interest to park managers and interpreters. Sources of information include *The Geology of Mississippi* (Dockery and Thompson 2016), which notes uses of the Marianna and Glendon Limestones, and the paleontological resource inventory (Rich et al. 2023b), which notes some uses of local bedrock and gravel.

- Marianna Limestone—Given the softness of the Marianna Limestone, it is easily sawed into blocks (Cooke and Cushman 1923) and was used for chimneys so often that it acquired the nickname “chimney rock” (Rich et al. 2023b). Additionally, the limestone has been quarried for agricultural lime and used in Portland cement (Dockery and Thompson 2016).
- Glendon Limestone—Like the Marianna Limestone, the Glendon Limestone has been quarried for agricultural lime, Portland cement, and building stones (Dockery and Thompson 2016).
- Catahoula Formation—Stones have been used as rip-rap for levees, floors for spillways, and railroad ballast. Interestingly, the Catahoula Formation comprises the building stone of the basement and pavements of the state house in Jackson. A quarry east of Raymond (see

“Inventory of Quarries”) provided that stone between 1833 and 1839 (Monroe 1954). Purportedly (ca. 1836), one of the stone contractors for the state house pilfered the best stone to sell for headstones, footstones, and large square tombs (Skates 1990, p. 37). Examples of these grave markers can be seen today in the Confederate cemetery in Raymond (Dockery and Thompson 2016).

- Pre-loess terrace deposits—The gravel in pre-loess terrace deposits is highly variable in size, shape, color, and rock type, and includes chert, agate, jasper, and quartz. Some pieces contain fossil molds, impressions, or the fossils themselves. Humans have used these rocks to craft beads, toys, and projectile points (Dockery et al. 2008). Projectile points knapped from gravel were found by Rich et al. (2023b) as part of a survey of streams at VICK; these projectile points are the first recorded pre-Civil War archeological resource found at VICK. Paleozoic fossils, commonly found protruding from the stream gravels (Rich et al. 2023b), are the oldest known geologic heritage feature within VICK (see “Paleontological Resources”).

Notable Scientists for Geologic Heritage

The following chronological list illustrates a long history of interest in the rocks and fossils at VICK:

ca. 1828—French naturalist Charles Alexandre Lesueur traveled down the Mississippi River by flatboat on his way to New Orleans. En route, he came upon and sketched the fossil beds at Walnut Hills and collected diverse fossils, including corals, bryozoans, bivalves, gastropods, scaphopods, crabs, echinoids, shark and ray teeth, fish otoliths, foraminifera, and possibly remains of marine mammals, from the rocks now known as the Vicksburg Group (Conrad 1847; see next entry and “Stratotypes”). Whether these specimens came from within the boundaries of what is now VICK is not known because the geographic and stratigraphic provenance data of these specimens are limited (Rich et al. 2023b). The year after Lesueur traveled down the Mississippi River, he illustrated his findings in a series of 12 plates, accompanied by a manuscript that may likely be the earliest detailed geologic investigation in Mississippi. Lesueur’s findings were not officially published for more than 150 years (Dockery 1982a, 1982b).

ca. 1845—Timothy Abbott Conrad, who scientifically recognized and named the Vicksburg Group (Conrad 1847), traveled to the area via the Mississippi River to collect marine fossils. He spent two weeks near Vicksburg in spring 1845 and subsequently published his observations (Conrad 1846a, 1846b, 1846c, 1848a, 1848b).

ca. 1846—Charles Lyell, one of the founders of geology, made two extended visits to the United States from Scotland. He toured, observed geologic features, and made fossil collections. During his second visit in 1846, Lyell and his wife, Mary Horner Lyell, traveled up the Mississippi River, leaving from New Orleans before stopping at Natchez and then Vicksburg. The Lyells collected many shells and corals from the Vicksburg Group. Their findings were published in 1849 (Lyell 1849). In addition, Lyell is recognized as popularizing loess (i.e., introducing it into the European and American public domain; Smalley et al. 2001). Lyell spread the word on loess through his *Principles of Geology* (Lyell 1833). Notably, a cross section of the valley at Vicksburg, which clearly shows the loess, appears as figure 23 in *Principles of Geology*. Lyell assumed an alluvial origin for

the silty material. Later, Richthofen (1882) established its eolian (transported and deposited by wind) origin.

ca. 1854—Naturalist Benjamin L. C. Wailes authored *Report on the Agriculture and Geology of Mississippi* (Wailes 1854), which is the first published book about Mississippi geology. In that text, Wailes describes the extent of Walnut Hills and defines it as including what is now VICK.

ca. 1863—The most famous “scientist for geologic heritage” at VICK is John Wesley Powell, who is best known for his post-Civil War career: leading an expedition down the Colorado River through the Grand Canyon in 1869, being the second director of the US Geological Survey (1881–1894), and becoming the first director of the Bureau of American Ethnology at the Smithsonian (1879–1902). Important for VICK, Powell was present during the siege. He enlisted in the Union Army as a cartographer, topographer, and military engineer. At Vicksburg, he led Battery F, later known as “Battery Powell,” laying down a corduroy road of logs and constructing bridges on the Mississippi River floodplain, digging trenches in the loess, and constructing earthworks, for instance, at Ransom’s Gun Path (Winschel 2017; see poster). Various books (e.g., Darrah 1951; Stegner 1954; Rabbitt 1980; Worster 2001) document Powell as having collected fossils during the siege. Although attempts have been made to find the “Powell collection” (see Rich et al. 2023b), which was sent to his alma mater, Wheaton College, in Wheaton, Illinois, these specimens cannot be located and were potentially destroyed in a fire at Illinois Wesleyan University (Rich et al. 2023a, 2023b).

Other influential people who contributed to the current understanding of VICK geology and paleontology include four USGS geologists—Charles Wythe Cooke, Joseph A. Cushman, Julia Gardner, and F. Stearns MacNeil—and two Mississippi state geologists—William Clifford Morse and David Dockery. Dockery was a GRI scoping participant in 2010 (see scoping summary by KellerLynn 2010b), acknowledged in the paleontology inventory (Rich et al. 2023b), and became the Mississippi state geologist in 2017.

Buried in Silt and Sand: USS *Cairo*

The USS *Cairo* was part of a Union flotilla of gunboats tasked with destroying Confederate batteries and clearing the Mississippi River and its tributaries of torpedoes (underwater mines). On 12 December 1862, two explosions in quick succession impacted the wooden-hulled ironclad *Cairo* on the Yazoo River near Vicksburg. The first tore a gaping hole into the port (left) bow. The second detonated a moment later near the armored belt amidships on the starboard (right) side. The hole in the bow proved fatal for the boat. The crew breached the *Cairo* and then abandoned ship. Within 12 minutes, the *Cairo* slid from the riverbank into six fathoms (11 m or 36 ft) of water without any loss of life (National Park Service 2024b).

Over the years, the USS *Cairo* was slowly buried by silt and sand. Encased in sediment, the gunboat became a time capsule of unique, historical artifacts preserved against corrosion and biological degradation. As members of the crew died and decades passed, the boat’s whereabouts became a matter of speculation by the residents of Vicksburg as well as the NPS.

Using modern and Civil War-era maps and documents, a magnetic compass, and the assistance of Don Jacks and Warren Grabau (author of *Ninety-Eight Days: A Geographer's View of the Vicksburg Campaign*, which was extremely useful in preparing this GSRI summary), Edwin C. Bearss (historian at VICK) found the gunboat in 1956. Three years later, divers confirmed the find (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009). With support from the State of Mississippi, State Senator H. V. Cooper, and local authorities, the *Cairo* was salvaged from the bottom of the river in 1964 (National Park Service 2024b). Construction of the USS *Cairo* Museum, which is partially embedded in a hillside within the boundaries of Vicksburg National Cemetery, was completed in 1980. In 1985, the public viewed the restored gunboat for the first time (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009).

Commemorative Landscape

The commemorative landscape at VICK is a fundamental resource and value (National Park Service 2014). In addition to ensuring a sense of solemnity (see “Sense of Place”), commemorative landscape features honor commanders and common soldiers alike, mark places on the battlefield where troops were positioned, and direct visitors to locations where significant actions took place. Many of these commemorative landscape features are geologic features (i.e., building stone such as granite) and, therefore, have geologic heritage value and interesting geologic origins worthy of investigation and interpretation (see “Inventory of Commemorative Stones”).

More than 95% of the commemorative features were erected before 1917, and even before the war ended, efforts toward commemoration were underway (National Park Service 2014). On 4 July 1864—the first anniversary of the surrender—a small stone obelisk was placed to mark the site where the surrender interview between Pemberton and Grant took place. The obelisk was damaged by visitors who chipped pieces of stone from its shaft for souvenirs; consequently, it was removed to the Cherry Street Railroad Station in 1867, to Vicksburg National Cemetery in 1868, and to the VICK visitor center in 1970 (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009).

The commemorative landscape features are impressive in number and cost. With respect to number, nearly 1,400 features—including 284 regimental monuments, 239 regimental markers, 95 relief portraits, and 62 busts—line the tour road. Additionally, 645 iron tablets and guideposts mark trench lines, batteries, and infantry positions and describe battle events (National Park Service 2014). With respect to cost, contributions came from individuals, large corporations, and appropriations from the state and federal governments (Miller 1976).

The architectural design of the commemorative landscape features is also impressive, including the state monuments. The enabling legislation permits the states that had troops engaged in the campaign, siege, or defense to erect monuments in honor of their troops (see poster). The earliest state monument (Massachusetts) was dedicated in 1903 (National Park Service 2014); the latest (Connecticut) was dedicated in 2008 at the Grant's Canal site. When originally erected, all the state monuments were within VICK, but a change in boundary now places five of these monuments south

of the boundary (see poster). The NPS still maintains these monuments, however. The VICK webpage—“[Monuments and Memorials](#)”—provides more information.

Floods

Changes in the water level of the Mississippi River at Vicksburg are dramatic. Between extreme low water, which normally occurs in November and December, and spring high water, which normally occurs sometime between early March and late May, change is on the order of 60 ft (18 m; Grabau 2000). Furthermore, flooding is a regular occurrence. Flood stage—which signifies the level at which the river threatens lives, property, commerce, or travel—is 43 ft (13 m) at Vicksburg. The highest flood on record—57.10 ft (17.4 m)—occurred on 19 May 2011. Before that, 4 May 1927 held the record at 56.20 ft (17.1 m) (National Water Prediction Service 2024). Within VICK, flooding on the Mississippi River causes Mint Spring Bayou to back up to the waterfall where turbid flood waters deposit sediment (KellerLynn 2010b).

Yazoo River Diversion Canal

During the Vicksburg Campaign, the Mississippi River flowed past Vicksburg, making an almost 180° meander (Tuscumbia Bend) at the northern end of the city (see poster). A significant change occurred in spring 1876 when the river in flood stage cut through De Soto Point and took a new course, approximately 5 km (3 mi) south of Fort Hill. The river accomplished on its own what the Union Army had tried to do at Grant’s Canal. This natural event validates Grant’s concept of mimicking geologic processes by digging a canal to induce a meander cutoff (Higgins 2002).

As is usual with oxbow formation (Figure 5), the river built sandbars across the mouth of the abandoned channel, converting the river bend at De Soto Point into an oxbow lake, which became known as Centennial Lake. Such lakes are common in the Mississippi alluvial plain (Grabau 2000).

Following a 27-year gap, the city eventually regained its port status when the US Army Corps of Engineers created the Yazoo River Diversion Canal, which edges VICK for approximately 0.8 km (0.5 mi). Both Mint Spring Bayou and Glass Bayou empty into it (see poster). The canal reroutes the Yazoo River into the old Mississippi River bend (National Park Service n.d.). The project dammed the natural outlet of the Yazoo River and then cut a channel connecting the north end of Centennial Lake. Waterflow from the Yazoo River keeps the old channel in front of Vicksburg scoured out and navigable.

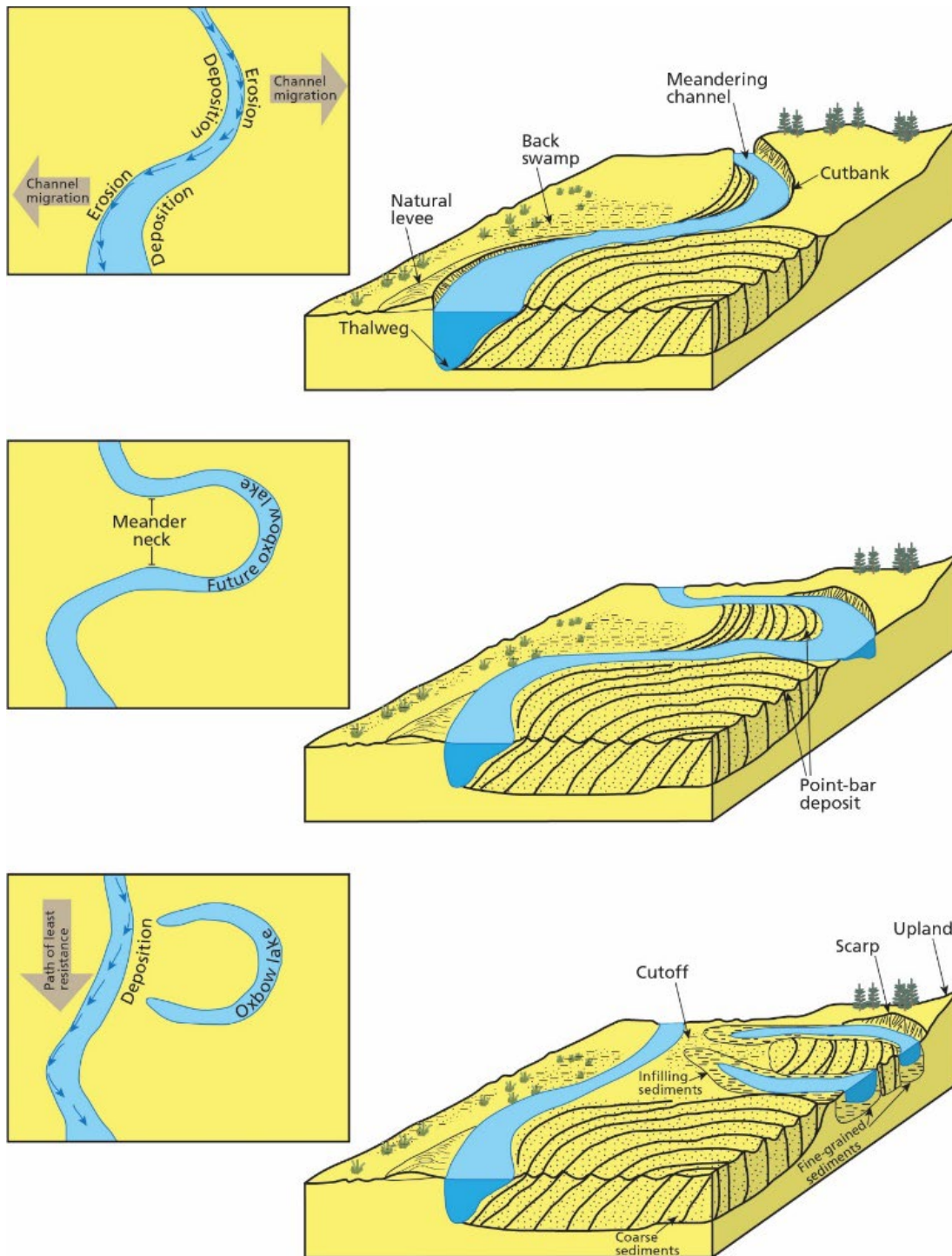


Figure 5. Illustration of oxbow formation. Meanders originate from the enlargement of bends in the flow path of a river. On the inside of the bend, a series of sand and gravel bars accumulate to produce a point-bar deposit. A meander may become constricted, creating a narrow meander neck. The neck may be cut through by bank caving or by overflow during a flood, permitting the stream to bypass the bend and create a cutoff, whose meander bend is sealed off from the main channel by silt deposits (infilling sediments), thus becoming an oxbow. When an oxbow contains water, it is known as an oxbow lake. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Resource Management Issues and Inventory Needs

This section summarizes the geologic resource management issues, inventory needs, and geologic hazards that were identified during the 2010 scoping meeting and more recently during discussions and correspondence with VICK staff as well as research during preparation of this GSRI summary. Geologic issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what is needed to ensure effective management of geologic resources at VICK. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Refer to [Guidance for Resource Management SharePoint](#) for more information regarding geologic resource management.

Summary of Geologic and Soil Hazards

The dynamic landscapes of many National Park System units present various natural hazards that threaten NPS facilities, staff, visitors, or resources. Many of these natural hazards are geologic (e.g., volcanoes, earthquakes, and landslides). The Addressing Climate Change and Natural Hazards Handbook (National Park Service 2015a, 2023), grounded in [NPS Policy Memorandum \(PM\) 15-01 \(Jarvis 2015\)](#), provides a process and information to help identify, avoid, and mitigate risks associated with changing environmental conditions, natural hazards, and effects on proposed and planned facility investments. The handbook supports NPS planning guidance, policy directives, and executive orders and does not supersede existing mandated compliance processes and policies. Additional guidance for facility management, such as [Climate-Smart Planning Principles](#) and [Recommended Practices](#), has been developed to support effective decision making.

According to PM 15-01, managers should apply the handbook's guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (Table 2) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board submittal process at the Investment Concept (IC) stage. Table 2 is a screening tool to be used at the IC stage to help teams determine potential climate change effects and natural hazards to a proposed facilities investment. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis. Ground-disturbing activities should neither be approved nor denied based upon the information in the checklist. Table 2 includes selected geologic and soil hazards listed in Part 1 of the handbook (National Park Service 2023). If needed, Part 2 of the handbook could inform the completion of the checklist, such as whether a hazard is applicable. Contact the GRD with any questions.

Table 2. Geologic and soil hazards checklist.

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Source(s) of Information for Best Professional Judgment
Sea Level Change	Not applicable	Not applicable	Not applicable
Coastal Storm Surge	Not applicable	Not applicable	Not applicable
Flash Flood	Not applicable	Not applicable	Not applicable
Riverine Flood	Inundation at Mint Spring Bayou Destruction of infrastructure (e.g., through impact or saturation) Stream channel migration and streambank erosion Water quality effects Diminished water supply Reduced or precluded visitation	Known hazard—extreme riverine flooding hazard (SHIRA) “Susceptible to flooding” (FEMA, national flood hazard layer)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) FEMA, National Flood Hazard Layer (NFHL)
Lake and Reservoir Level Change	Not applicable	Not applicable	Not applicable
Precipitation: Increased Extreme Events	Increased number of days with extreme precipitation Rapid runoff Surface erosion Floods Disruption to transportation routes Water damage to structures from driven rain Water quality impacts (e.g., stormwater runoff into freshwater systems) Increased potential for landslides Considerably drier and also wetter years than experienced historically (National Park Service 2024c) Unstable saturated soils Reduced or precluded visitation Power failure due to areawide power outages Tree fall, brought on by heavy precipitation, threatens earthworks	Known hazard (National Park Service 2024c) Low hazard level for ice storms and lightning (SHIRA) Moderate hazard level for hail (SHIRA)	National Park Service (2024c) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Source(s) of Information for Best Professional Judgment
Precipitation: Altered Patterns and Changing Humidity	Local flooding Mold growth Wood decay Drought or worsening drought Fire Water supply change Considerably drier and also wetter years than experienced historically (National Park Service 2024c)	Known hazard (National Park Service 2024c)	National Park Service (2024c)
Drought: Increased Frequency, Intensity, Magnitude, and Duration	Limited water supply for visitor, staff, and operational needs (e.g., potable and fire suppression water) Increased competition for available water and water supply impacts (e.g., water supply curtailment by state agencies) Crack/heave damage in drier soils Increased vulnerability to wildfire Change to river levels Rapid evaporation of surface water	Known hazard	National Park Service (2024c) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Permafrost Dynamics	Not applicable	Not applicable	Not applicable
Landslides	Impacts to trails (e.g., to Mint Spring Bayou) Reduced or precluded visitation Impacts to roads, infrastructure, and the commemorative landscape	Known hazard—susceptible to landslides (SHIRA)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) Lutton (2009) Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. (2009)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Source(s) of Information for Best Professional Judgment
Earthquake	Falling objects Collapsing structures Inoperability of major building systems (e.g., power, sewer, water) Liquefaction (e.g., loss of strength to foundations, silt deposition, standing water) susceptibility is very high (CUSEC n.d.) Trigger to other hazards (e.g., landslides)	Known hazard—low (SHIRA). Earthquakes have occurred throughout Mississippi, and earthquakes of low magnitude will continue to occur. Many earthquakes in neighboring (and distant) states have been felt in parts of Mississippi. The greatest risk to Mississippi is from the New Madrid Seismic Zone, the southern end of which is about 60 km (40 mi) from the northwest corner of Mississippi (Bograd and Yassin 2021).	Bograd and Yassin (2021) Central United States Earthquake Consortium (n.d.) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) National Seismic Hazard Model (USGS Earthquake Hazards Program 2022)
Tsunami	Not applicable	Not applicable	Not applicable

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Source(s) of Information for Best Professional Judgment
Shrink/Swell Soils	Extensive cracking of the ground surface Damage to infrastructure (e.g., building foundations, roads, and trails) Damage to plant roots Increased landslide susceptibility Slippery trail conditions	Potential hazard According to Cole and Carter (1964), the soils of the loess hills generally have a low to moderate shrink-swell potential. However, the Web Soil Survey (WSS) shows that the Sharkey, Tunica, and Commerce Series at VICK have high shrink-swell potential.	Soil survey for Warren County, Mississippi (Cole and Carter 1964) USDA Natural Resource Conservation Service, Web Soil Survey (WSS)
Volcanic Eruption	Not applicable	Not applicable	Not applicable
Hydrothermal Activity (e.g., geysers)	Not applicable	Not applicable	Not applicable
Subsurface Hazards: Cave/Karst (sinkholes)	Subsidence on earthworks Surface collapse Potential contamination at the (possible) rock shelter at the Mint Spring Formation type section	Potential hazard—high hazard for karst-related sinkhole susceptibility (current and future; SHIRA); however, the Vicksburg Group is not known to be karstic until farther east.	James Starnes (MDEQ Mississippi Geological Survey, geologist, email communication, 16 July 2024) Dockery and Thompson (2016) GSRI discussion (22 May 2024) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Subsurface Hazards: Abandoned Mineral Lands	Not applicable	Not applicable	Not applicable

Legislatively Required Geologic Inventories

Some laws, regulations, and policies specifically apply to geologic and soil resources or processes. These include legislatively required inventories. The NPS GRD has an [article series](#) that summarizes these laws, regulations, and policies. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or anthropogenic activity.

Caves and Karst

All cave features are nonrenewable resources. The Federal Cave Resources Protection Act of 1988 stipulates that all “significant caves” in NPS areas will be identified, regulation or restriction of use will be employed as needed to protect cave resources, and significant caves will be included in land management planning. The act also imposes penalties for causing harm to a cave or cave resources and exempts park staff from releasing specific location information for significant caves in response to a Freedom of Information Act request.

The Mint Spring Formation type section strongly resembles a rock shelter (see Figure 1). For the purposes of resource management in the National Park System, rock shelters are considered a type of cave. Because the roof of overhanging rock provides the potential for human use—such as for storage, use as a seasonal campsite, or as a longer-term domicile—rock shelters are commonly considered archeological resources in addition to being geologic resources. With respect to archeology, however, rock shelters and caves differ. Caves are subterranean systems containing areas that are, to some degree, permanently dark, whereas rock shelters are cavities that are always lit by direct or indirect sunlight (Pat Seiser, National Cave and Karst Research Institute, cave and karst management science director, written communication, 9 May 2023).

The possible rock shelter at the Mint Spring Formation type section likely formed as a result of undercutting by a stream into a layer of soft marl below a more resistant, travertine-coated limestone ledge. However, a field investigation by a cave resource specialist is needed to determine the presence of a rock shelter at this location.

Two pieces of legislation underscore the significance of rock shelters as archeological and cave resources, respectively: The Archeological and Historic Preservation Act of 1974 requires the preservation of archeological resources. The Federal Cave Resources Protection Act of 1988 requires the identification of “significant caves” on federal lands, the regulation/restriction of use of those caves as appropriate, and the inclusion of significant caves in land management planning efforts.

The NPS manages caves, including rock shelters, in accordance with approved cave management plans (National Park Service 2006, §4.8.2.2). The Mint Spring rock shelter does not have a cave management plan, but an assessment for the need of such a plan could be made in conjunction with an archeological assessment, which is identified as a medium-priority data and/or GIS need in the foundation document (National Park Service 2014).

Interestingly, the foundation document notes the possibility of finding “subsurface” archeological resources throughout the park (National Park Service 2014, p. 11). The meaning of “subsurface” is not clear and may simply mean “buried.” However, the possible link to cave resources warrants clarification and possible investigation as part of a comprehensive archeological survey and cave management plan.

Geothermal Features and Springs

Geothermal refers to heat or energy produced in Earth’s interior. Geothermal features may include geysers, fumaroles, hot springs, and bubbling mud pits. The Geothermal Steam Act of 1970, amended in 1988 and 2021, prohibits geothermal leasing in parks and authorizes the Secretary of the Interior to mitigate or not issue geothermal leases outside parks that would have a significant adverse impact on significant thermal features in the 17 park units listed in the act.

VICK is not listed in the Geothermal Steam Act of 1970 or its 1988 and 2021 amendments.

Paleontological Resources Inventory and Protection

All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act (PRPA). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources. The NPS has completed three assessments or inventories on the paleontological resources at VICK: Kerbo and McDonald (2005), Kenworthy et al. (2007), and Rich et al. (2023b). These inventories covered the main battlefield unit. An inventory is needed for the Champion Hill Unit as well as the Raymond and Port Gibson Battlefields.

Inventory Needs

The following table (Table 3) presents geologic and soil resources inventory needs, which were identified during a follow-up meeting and correspondence with park staff as well as in NPS documents and a broader review of the scientific literature. The order—in the table and the discussions that follow—is prioritized in that inventories for caves/karst and paleontological resources are legislatively required, so they appear first (see “Legislatively Required Geologic Inventories”). Another NPS priority is a geologic map, which is the primary deliverable of a baseline geologic inventory (see “Baseline GSRI Products”). Except for the Grant’s Canal Unit, geologic map data for VICK are available from the MDEQ Mississippi Geological Survey (see poster). These data, however, need to be incorporated into the GRI GIS data model for use with other NPS GIS products. Though neither legislatively required nor a baseline-inventory priority, developing the knowledge, tools, and ability to perform resource management in a loess landscape is critical for resource managers at VICK. Many inventory needs listed in Table 3 would support resource management in a loess landscape; these could be considered “high priority” from a GSRI perspective. Other inventory needs address the preservation of the Mint Spring type section/locality and the preservation of earthworks; these could be considered “medium priority” from a GSRI perspective. Of interest for interpretation, education, and the enhancement of visitor experience are inventories of

commemorative stones, travertine exposures, and quarries; these could be considered “low priority” with respect to natural hazards and visitor safety, though they do have significant geologic heritage value.

Table 3. List of identified geologic and soil resource inventory needs in VICK.

Subject	Inventory Need(s)	Reference(s)
Cave Management Plan	Assess the Mint Spring Formation type locality for the existence of a rock shelter and archeological resources within the rock shelter. Develop a cave management plan based on those findings.	NPS Management Policies 2006, sections 4.8.1.2 and 4.8.1.2 GRD article series about caves and karst systems
Paleontological Resources	Conduct paleontological resource inventories at the Champion Hill Unit and the Port Gibson and Raymond Battlefields.	Rich et al. (2023b)
Geologic Map	Compile MDEQ Mississippi Geological Survey map data into the GRI GIS data model for use in resource management at VICK.	Leard and Starnes (2021)—Raymond quadrangle (Raymond Battlefield) Starnes and Leard (2021)—Widows Creek quadrangle (Port Gibson Battlefield) Leard et al. (2023a)—Edwards quadrangle (Champion Hill Unit) Palmer et al. (2025a)—Redwood quadrangle (main unit) Palmer et al. (2025b)—Vicksburg East quadrangle (main unit) Palmer et al. (2025c)—Vicksburg West quadrangle (main unit)
Resource Management in Loess Landscapes	Compile known research and develop a definition and understanding of loess as an entity in and of itself (neither soil, sediment, nor rock) and apply it to resource management at VICK.	Pécsi (1990) Sprafke and Obreht (2016)
Loess Landscape Conceptual Model	Develop a conceptual model to promote an understanding of water movement on and within loess slopes, geologic hazards in loess landscapes, and potential areas for severe erosion. It could then be used as a tool to understand anthropogenic impacts. Existing data from borings can inform the model. The cross sections on MDEQ Mississippi Geological Survey map posters may be useful for the development of the loess landscape conceptual model.	Murphy and Albertson (1996) Sprafke and Obreht (2016) Zhu et al. (2021) Feng et al. (2024) California Geological Survey 3D mapping USGS 3D model that covers VICK Palmer et al. (2025a, 2025b, 2025c)

Subject	Inventory Need(s)	Reference(s)
Groundwater Data	Compile existing groundwater data for VICK and establish a monitoring protocol that would advance an understanding of water movement in a loess landscape. This information will inform park planning at USS <i>Cairo</i> , Vicksburg National Cemetery, and Mint Spring Bayou, as well as a loess landscape conceptual model.	Gandl (1979) Ackerman (1989) USGS National Water Information System (NWIS)
Inventory of Seeps and Springs	Inventory seeps and springs at VICK and incorporate locations into GIS. Use the findings to better understand streamflow at VICK. This information will also inform a loess landscape conceptual model.	Grabau (2000) Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. (2009)
Analysis and Interpretation of the Landslide Inventory	Analyze landslide inventory data to identify the types of landslides at VICK, their activity (hazard potential), and their role in landscape evolution. Apply this information to a loess landscape conceptual model.	Curden and Varnes (1996) Murphy and Albertson (1996) Lutton (2009) Guzzetti et al. (2012) Peng et al. (2018) Wang et al. (2020) Map data for a landslide inventory of the northwestern part of Vicksburg National Military Park, Mississippi (Ashland and DeWitt 2024) Zhang et al. (2024)
Erosion Management Plan	Following the development of a loess landscape conceptual model, a parkwide erosion management plan can be developed to address the variety of water and soil movements in and on geomorphic features (e.g., ridge, slope, ravine, terrace, bluff, and bayou) at VICK.	Zhu et al. (2021)
Erosion Management Plan	Compile all known data (reports, maps, photographs) of past erosion studies at VICK and it use to advance an understanding of severe erosion at VICK as well as to inform a loess landscape conceptual model.	Ameristar report
Monitoring Soil Moisture and Nutrients	Monitor soil moisture and nutrients in conjunction with terrestrial vegetation at established GULN plots. Use data to develop proxies and predictive models to understand and address invasive plant species and determine where to expend eradication efforts.	Zhuang et al. (2018) Carlson (2022)

Subject	Inventory Need(s)	Reference(s)
Preservation of Stratotypes	Develop a stratotype protection plan for the Mint Spring Formation type section/locality.	Henderson et al. (2020)
Preservation of Earthworks	Develop a plan for the preservation of earthworks that considers multiple strategies in addition to revegetation. Strategies should apply a geomorphic perspective (e.g., awareness of landforms and how they change over time).	The section about earthworks (§5.3.5.1.6) in Management Policies 2006 (National Park Service 2006) NPS Unstable Slope Management Program
Inventory of Commemorative Stones	An updated survey of important features of the commemorative landscape (compatible with GIS) is a high-priority data need (National Park Service 2014, p. 43). An inventory of the commemorative stones at VICK could be done as part of this survey while making geologic heritage connections.	Miller (1976) Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. (2009) National Park Service (2014) National Park Service (2024a) Future consultation with MDEQ Mississippi Geological Survey geologists
Inventory of Quarries	Identify and document historic quarries to make connections between geologic resources and human uses of them. Use this information to enhance visitor experience in interpretive programs and materials. Because quarries are an archeological resource, which is an “other important resource and value” (National Park Service 2014, p.11), an inventory is also important for NPS planning processes.	Dockery and Thompson (2016) National Park Service (2014) Rich et al. (2023b)
Inventory of Travertine Exposures <i>Note:</i> Discussed in “Karst, Cave Features, and Travertine” section.	Inventory locations of travertine exposures at VICK and analyze/interpret as possible former waterfall locations. Information could be used to create an interpretive guide for visitors.	Dockery and Thompson (2016)

Resource Management in Loess Landscapes

Contemporary definitions agree that loess is an eolian (entrained, transported, and deposited by the wind) accumulation of mainly silt-sized particles (e.g., see Muhs 2007; Muhs et al. 2014). Silt particles are between 0.0039 and 0.063 mm (0.00015 and 0.0025 in) in diameter. The term “accumulation” seems purposefully used (and properly vague) in this definition because depending on a researcher’s background, loess might be classified as soil, sediment, or even rock. Sprafke and Obrecht (2016, p. 205–206) conclude, “To date, we can only state that loess is neither sediment, soil,

nor rock, but something complex in between, and that loessification [syn- and post-sedimentary processes in the formation of loess] and related processes need to be understood to give a satisfying loess definition.”

As such, it seems important for park managers to treat loess as an entity in and of itself and apply open-minded concepts and multidisciplinary practices to resource management across the landscape. For example, simply applying a biological approach (i.e., focusing on vegetative cover), a geologic approach (i.e., focusing on the origin and deposition of loess), or a soil approach (i.e., focusing on in situ, post-depositional processes) will likely be insufficient in treating this complex material. All three approaches and types of expertise are required.

One of the most striking characteristics of loess is its ability to form vertical faces, for instance, along river or stream banks and in road cuts (Muhs 2007). Loess has the ability to “stand in nearly vertical bluffs as much as [12 m] 40 ft high” (Kolb 1967, p. 4). Inter-particle binding by clays or carbonates results in considerable material strength, explaining this ability (Muhs 2007). However, many questions remain about the mechanisms that are responsible for the structural characteristics of loess. Thereby, compiling what is known about loess in the Vicksburg area, as well as other areas nationally (e.g., Tennessee [Larsen et al. 2020]) and worldwide (e.g., New Zealand [Schmidt et al. 2005] and China [Hu et al. 2020; Huang et al. 2020; Wang et al. 2020; Feng et al. 2024]), may reveal management options not previously considered.

Another characteristic of loess in need of further investigation is the complexity of water movement through the landscape. Researchers have observed [12 types of preferential flow](#) in loess landscapes (Feng et al. 2024). Some groundbreaking models and technologies—used for the study of the Chinese Loess Plateau (e.g., Wang et al. 2020; Feng et al. 2024)—are likely applicable to VICK and are worthy of consideration by park managers. A conceptual model would help both park managers and the public visualize how water moves through the loess landscape at VICK. Moreover, a conceptual model would help identify the influence of loess on other environmental factors such as soil types, vegetation species and vigor, soil moisture, drought potential, geologic hazards (e.g., landslides and subsidence), loess cave development, and areas of potential erosion.

A possible partner in the development of a conceptual model is the US Army Engineer Waterways Experiment Station (WES) in Vicksburg. A study by Murphy and Albertson (1996), which compiled engineering geologic data into GIS, indicates the capabilities of WES and the possible applicability to VICK. For example, data compiled by Murphy and Albertson (1996) were from borings drilled for groundwater resources or construction, and one of the borings (“J2”) was from Mint Spring Bayou. These borehole data could be useful in determining how water is moving through the subsurface at VICK.

The MDEQ Mississippi Geological Survey is another potential partner in the development of a loess landscape conceptual model. In particular, the cross sections on their map posters (e.g., Palmer et al. 2025a, 2025b, and 2025c) and the baseline understanding associated with the cross sections would be useful in developing a loess landscape conceptual model for VICK.

Another possible partner is the University of Memphis, Department of Earth Science (see Larsen et al. 2020), though the landscape studied by that group (i.e., western Tennessee) has a much thinner loess covering than VICK; also, lateral recharge of the groundwater system (i.e., to/from the Memphis aquifer) may play a greater role than it does at VICK.

Groundwater Data

The foundation document (National Park Service 2014) identifies groundwater/soil data as a medium-priority data need. Groundwater/soil data are needed to address issues such as erosion and subsidence caused by underground springs and drainage around the USS *Cairo*, Vicksburg National Cemetery, and Mint Spring Bayou.

Before prudent resource management decisions can be made, a better understanding of water movement, including types of groundwater movement (see [figure 9](#) in Feng et al. 2024), through the loess landscape is needed. Groundwater data would be useful in supporting the development of a loess landscape conceptual model (see “Resource Management in Loess Landscapes”) as well as a predictive model for landslides (see “Interpretation and Analysis of the Landslide Inventory”). At present, the GULN does not monitor groundwater at VICK, but monitoring this resource at the network level is a common practice in the NPS, so engaging the GULN in developing a groundwater management plan—as well as in the development of a loess landscape conceptual model—seems prudent.

In-depth research of existing data sources is needed, but cursory searches (such as during preparation of this GSRI summary) of IRMA; the MDEQ website, including pages for the Mississippi Office of Land and Water Resources; the USGS publications warehouse; and GeoRef (database of geologic citations) revealed little information about groundwater (other than water quality) at VICK. Because groundwater flow in the loess landscape at VICK may be connected to the Mississippi River alluvial aquifer and the Oligocene aquifer, which consists of rocks in the Vicksburg Group (see Ackerman 1989 and Gandl 1979, respectively), searching for information about those aquifers may yield some information.

The USGS maintains the National Water Information System (NWIS), a searchable database, but the data appear to be for the Mississippi River at Vicksburg (monitoring location USCE 07289000), not for groundwater. VICK is part of the Lower Mississippi River–Natchez watershed with hydrologic unit code (HUC) 08060100 and the Lower Yazoo watershed (HUC 8030208). Searches using these hydrologic codes may facilitate the discovery of groundwater data.

Park managers are encouraged to contact the NPS Water Resources Division (WRD) for assistance in gathering and analyzing groundwater data. WRD provides assistance with issues related to water quality, water supply, floodplains, wetlands, and water rights. Park managers are directed to the [WRD website](#) for program specifics and [contact information](#). Park managers can formally request assistance from the WRD via <https://irma.nps.gov/Star/> (available on the DOI network only).

Inventory of Springs and Seeps

An inventory of springs and seeps is needed at VICK. Their locations have not been formally documented in GIS, and this information is needed for resource management in a loess landscape. Because seeps and springs occur naturally at the contact between two geologic units (e.g., potentially between loess and pre-loess terrace deposits), faults, other geologic structures (e.g., anticlines), or near landslides, an inventory of their locations could provide valuable data for a loess landscape conceptual model as well as inform a predictive model for landslides (see “Interpretation and Analysis of the Landslide Inventory”). Moreover, because springs and seeps provide important habitat for many amphibians and reptiles—including spotted dusky salamanders (*Desmognathus conanti*) and box turtles (*Terrapene carolina*), which forage in the shallow waters and often rehydrate themselves in these areas before traveling through drier, upland territory (National Park Service 2015b)—an inventory also has biological importance.

Many assumptions are made about springs at VICK, the most basic being that they exist. As suggested by its name, a spring is thought to feed Mint Spring Bayou, but the location of said spring is not known by park staff. Moreover, an antebellum description of the Shirley House suggests that that property included a spring, which was “a never failing water source” (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009, p. 174). Other springs have been witnessed by park staff, but their locations are not known to have been documented (National Park Service, review comments provided to Cultural Landscape Report [CLR] team relating to 75% draft, Part 1, August 2007).

Another assumption is that springs (and seeps) feed the streams at VICK. A GULN water quality report (Meiman 2012, p. 13) notes that “the streams of VICK are generally supplied by many small seeps and springs found throughout the Cenozoic limestones (Morse 1935) under the steeply rolling loess hills of the park”; notably, Morse (1935) is a reference for the limestone, not the seeps or springs, so no additional information about seeps and springs at VICK is available from that source. At present, research by the GULN or other entity is not known to have documented a connection between spring discharge and streamflow at VICK. An understanding of the connection between spring discharge and streamflow at VICK would be valuable for the loess landscape conceptual model.

Interpretation and Analysis of the Landslide Inventory

[Map data for a landslide inventory of the northwestern part of Vicksburg National Military Park, Mississippi](#) (Ashland and DeWitt 2024) by the US Geological Survey (USGS) represents the first comprehensive landslide inventory at VICK. This is an important step in achieving an improved understanding of the distribution of landslides across the landscape. However, further analysis of the map data is needed, including the identification of the types of landslides, their activity (hazard potential), and their role in landscape evolution.

Identifying characteristics of landslides at VICK may enable correlation to established classification systems (e.g., Cruden and Varnes 1996; Peng et al. 2018), allowing for greater understanding based on a larger body of work. Significantly, landslide characteristics will dictate management and

engineering response; for example, a landslide that peels away in sheet-like slabs will require a different response than one that slides along its base. Likewise, applying terminology from established classification systems for landslide identification at VICK will improve understanding and communication with other scientists and the public.

In the process of analyzing the landslide inventory data, a researcher could compare present findings to past work on landslides in the Vicksburg area, for example, by Lutton (2009). The following are some characteristics of landslides in Vicksburg as documented by Lutton (1969):

- A distinctive arch type of shear failure, called an alcove failure, is fairly common in the steep highway cut banks in Vicksburg. Work by W. J. Turnbull and R. J. Lutton at WES attributed arched failures to undercutting by erosion at the foot of the bank or saturation by ponding. Water should be kept away from the base of the cut bank, either by berms or by offset drainage ditches to prevent these types of failures (Murphy and Albertson 1996).
- Where wetting has weakened the loess beside the toe (base) of the slope, shell-like slabs separate along tensile fractures and fail outward on new shears inclined down to the toe.
- The tensile fractures, which bound the shell-like slabs, are elements of a larger system of curved surfaces centered over and growing beyond the origin of weakening.
- Tensile fracturing starts at an approximately horizontal line of origin rather than a point of origin.

Comparison would allow a researcher to improve interpretation of the new inventory data by checking it against past findings. For example, both past work by Lutton (2009) and the summary of work by Ashland and DeWitt (2024) conclude that landslide occurrence is strongly influenced by precipitation. Indeed, learning about the moisture content of landslides in loess would be a significant outcome of the inventory (see, e.g., Wang et al. 2020). Also, Lutton (2009) demonstrates that human activity (i.e., road construction) strongly influences landslides. Analysis of the landslide inventory data at VICK may help to answer the 20-year-old question of whether slope failure is being exacerbated by park management actions (Cooper et al. 2004, Appendix B).

Guzzetti et al. (2012), which highlights the utility of landslide inventory maps, is another study with applicability to VICK. Also, Zhang et al. (2024) contributes to a better understanding of the reactivation behavior of landslides in a loess landscape, provides a scientific foundation for landslide hazard and risk management, and supplements understanding of the geomorphologic evolution of a loess landscape.

Erosion Management Plan

Although the foundation document (National Park Service 2014) identifies the need for a stormwater management plan, which is a primary cause of erosion at VICK, it does not identify the need for a parkwide erosion management plan. Addressing erosion caused by stormwater runoff along roads, parking areas, and bridges at VICK will likely continue into the foreseeable future, but this site-specific approach is not sustainable, and a parkwide plan is needed. Moreover, the plan needs to

consider the potential increase in the intensity and frequency of extreme precipitation events as a result of climate change (National Park Service 2014).

The GSRI suggests the development of an erosion management plan in conjunction with or following the development of a loess landscape conceptual model for VICK. That approach would apply a geomorphic perspective to erosion management, incorporating an understanding of the various types of landforms at VICK (e.g., ridge, slope, ravine, terrace, bluff, and bayou) as well as formulating an approach that addresses landform change over time.

Work by Zhu et al. (2021), which reviews soil erosion processes and control practices in the slope-gully system of the Chinese Loess Plateau, serves as an example of applying a geomorphic perspective to erosion of a loess landscape. That study identifies the inner gully area as the main sediment source, whereas runoff and sediment from the inter-gully (upland area) are found to significantly affect downslope erosion processes. Correspondingly, the protective vegetation pattern and coverage should be strategically designed for different erosion zones. Zhu et al. (2021) conclude that understanding the erosion processes and implementing erosion practices for the slope-gully system are of importance and require more research efforts that emphasize (1) the influence of upland runoff on erosion processes at downslope, (2) the relationship between hydraulic characteristics of overland flow and erosion processes at a slope-gully system scale, and (3) the physical mechanisms of different vegetation patterns on the slope-gully erosion process.

Monitoring of Soil Moisture and Nutrients

VICK staff is looking for proxies and predictive models to manage invasive plant species and choose where to focus efforts. The GULN monitors terrestrial vegetation at fixed 20 m × 20 m (33 ft × 33 ft) plots every three years (Carlson 2022), but no soil characteristics are currently monitored at VICK. Park staff members hypothesize that understanding soil moisture and soil nutrients may suggest areas for monitoring (and eradicating) invasive plants, even in areas rarely visited, difficult to access, and not systematically surveyed at present (Chuck Beightol, VICK, natural resources manager, Teams chat, 4 June 2024).

In the future, soil moisture could be monitored by park staff using existing equipment. However, a process and protocol for monitoring soil nutrients are needed (Chuck Beightol, VICK, natural resources manager, Teams chat, 4 June 2024).

Another application of soil moisture data would be to gain a better understanding of landslides in loess landscapes (see “Interpretation and Analysis of the Landslide Inventory”). Increasing moisture content results in a dramatic decrease in loess strength and can trigger loess landslides (Zhuang et al. 2018).

Preservation of Stratotypes

For a stratotype to be relevant, it must remain visible (e.g., not obscured by vegetation or infrastructure), accessible (e.g., via road or trail), and unaltered (i.e., maintain the integrity of the exposure as originally described). At present, the Mint Spring Formation type section is visible and

unaltered but not fully accessible. The area is no longer open to the public due to safety issues (i.e., unstable bluff grade, ground cracks, slough, and tall grass; National Park Service 2014).

The NPS geologic type section inventory (Henderson et al. 2022) makes the following recommendations for preserving stratotypes. Collaboration among park, region, network, GSRI, and GRD staff could address the following at VICK:

- Photograph all stratotypes at high resolution with a common object or scale bar included. GPS locations should also be recorded and kept in a database when the photographs are taken.
- Consider the collection and curation of geologic samples (new or extant) from stratotypes. 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.
- Consider photogrammetry for documenting and monitoring the Mint Spring Formation type section. Photogrammetry is an ideal documentation method for significant stratotypes, particularly where obscuring or destruction of the outcrop is necessary for other resource management priorities or where active geologic processes (e.g., rockfalls, landslides, bank erosion) may obscure or destroy the exposure. Designation of a reference section at a less threatened or dangerous exposure is another possibility.
- Clear exotic or invasive vegetation from stratotypes or manage native vegetation to maximize visibility and accessibility.
- Develop appropriate management actions based on the significance of the site and consideration of other resource management needs. For example, the Mint Spring Formation type section is known for its scenic location, waterfall, historic significance during the American Civil War, and fossils. It may also be a cave and an archeological resource.
- Utilize *Unstable Slope Management Program for Federal Land Management Agencies* (Beckstrand et al. 2019) to determine the stability of stratotype exposure and potential hazards to human safety.
- Consider using the Mint Spring Formation type section for interpretation and public education by installing wayside panels or developing virtual opportunities for visitors to explore the site.
- Establish appropriate monitoring protocols to regularly assess the Mint Spring Formation type section. Crofts et al. (2020) provide details on potential threats. Brocx et al. (2019) include examples of destroyed stratotypes and suggest protocols for conservation.

Preservation of Earthworks

Earthworks (dirt and log parapets with firing steps for infantry and embrasures for cannon), as well as earthen fortifications, trenches, and the remnants of other military defenses, are archeological resources and are considered an “other important resource and value” at VICK (National Park

Service 2014). Earthworks may also be considered geologic resources because they were built on, in, and of loess. From northwest to southeast, the surviving earthworks within VICK are Battery Selfridge, Fort Hill, Stockade Redan, Third Louisiana Redan, Great Redoubt, Battery De Golyer, Second Texas Lunette, Railroad Redoubt, and Fort Garrott (see poster). In addition, numerous earthen structures throughout VICK represent protected Confederate artillery positions along the defensive line established prior to the siege as well as Union battery positions established during the siege (Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009).

According to the resource management plan (Wells 1997), the main threat to earthworks is erosion. Moreover, earthworks are a concern for geologic resource management because they are affected by subsidence (sinking or downward settling; GSRI discussion, 22 May 2024).

Although considered “in fair to good condition” (National Park Service 2014, p. 15), the integrity of earthworks is threatened by activities such as mowing, digging by wildlife (i.e., feral hogs and armadillos), and improper visitor use such as social trails (National Park Service 2014). Also, tree fall, typically brought on by heavy precipitation, threatens earthworks at South Fort (National Park Service 2014). Tree fall breaches the surface of the earthwork, initiating a pathway for water to infiltrate and erode the loess. Moreover, slumping of loess occurs on steep slopes throughout VICK after heavy rains but is especially noticeable on the earthwork embankments (Wells 1997).

The section about earthworks (§5.3.5.1.6) in [Management Policies 2006](#) (National Park Service 2006) relies on the maintenance of native vegetation as the means for preventing erosion of earthworks. However, the outcome of well-intended plantings at VICK—for example, the planting of trees as erosion control by the Civilian Conservation Corps between 1933 and 1941, which now obscures key military features—should serve as a cautionary tale for future restoration efforts that rely solely on revegetation efforts. The GSRI suggests the application of a geomorphic perspective to erosion management of earthworks and elsewhere at VICK (see “Erosion Management Plan”).

Inventory of Commemorative Stones

Commemorative stones have geologic origins worthy of recognition and interpretation. An inventory would draw cultural–natural connections and promote the geologic heritage of commemorative stones and the commemorative landscape.

Because the traditional emphasis on commemorative stones has been as cultural resources, geologic information is rarely documented. Nevertheless, based on a cursory review of NPS information (conducted during preparation of this GSRI summary), most of the commemorative stones at VICK appear to be granite (Table 4).

Table 4. Geologic heritage of a selection of commemorative stones.

Sources of information: Miller (1976); Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. (2009); and National Park Service (2024a). In some cases, these sources of information contain the names of sculptors, designers, and/or organizations that commissioned works, which may be of use for tracking down the origin of the geologic material.

Note: Though not listed in the following table, most statuary rests on a granite base; for example, the statue of Major General Frederick Steele rests on Milford pink granite (Miller 1976). This granite—from the Proterozoic Eon (2.5 billion–538.8 million years ago)—is in and near the town of Milford, Massachusetts.

Monument/Memorial (Installation Date)	Geologic Material and Other Origin Information
Alabama State Memorial (1951)	Varying descriptions: • Miller (1976)—Base: Stone Mountain granite, Georgia • Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. (2009)—Large bronze statue rests on Weiblin gray granite from the Elberton City Quarries in Elberton, Georgia. These are the same quarries used in the construction of the Memorial Arch, located at the entrance of VICK, as well as the Jefferson Memorial in Washington, DC (National Park Service 2024a).
Arkansas State Memorial (1954)	Mount Airy marble, North Carolina. Erected by McNeel Company, Marietta, Georgia.
Cemetery Arch (old main gate entrance; 1880)	Alatawa (fossiliferous) limestone
Connecticut State Monument (2008)	Polished gray and black granites. Designed by Mathieu Memorial and Granite Works of Southington, Connecticut, in conjunction with Royal Melrose Granite of Cold Spring, Minnesota.
Florida State Memorial (1954)	Elberton granite, Georgia. Constructed by the Atlantic Memorials of Jacksonville, Florida.
Georgia State Monument (1962)	Gray granite
Illinois State Memorial (1906)	Base and long flight of steps are Stone Mountain granite, Georgia; the entire exterior above the base is white marble from Georgia. Atop the memorial sits a bronze bald eagle.
Iowa State Memorial (1906)	White granite, Vermont, and six bronze relief panels
Louisiana State Memorial (1920)	Base, Doric column topped by a brazier, and the sculpture of a pelican nest are all composed of granite.
Indiana State Memorial (1926)	Bronze statue on a granite base
Maryland State Monument (1914)	Bronze tablet mounted on a granite pedestal
Massachusetts State Monument (1903)	15-ton granite boulder from Massachusetts
Memorial Arch (1920)	Stone Mountain granite, Georgia
Michigan State Memorial (1916)	White Bethel granite
Minnesota State Monument (1907)	White granite, bronze statue
Missouri State Memorial (1914)	Missouri Red granite, Graniteville, Missouri

Monument/Memorial (Installation Date)	Geologic Material and Other Origin Information
Mississippi African American Memorial (2004)	Bronze sculpture standing on a pedestal of black granite from Africa. The polished granite block is set on a slab of granite flagstones (Note: “Flagstone” is typically sandstone, not granite).
Mississippi State Memorial (1909)	Mount Airy granite, North Carolina. The bronze work was fabricated in Rome, Italy, and shipped to New Orleans, Louisiana, in 1912.
New Hampshire State Memorial (1904)	Rough (i.e., unpolished) granite
New York State Memorial (1908)	Mount Airy granite, North Carolina, and bronze inscription tablets
North Carolina State Monument (1925)	Stone Mountain granite, Georgia
Ohio State Monuments (1905)	39 small, stone monuments (for the 39 units from Ohio that participated in the Vicksburg Campaign). Created by the Hughes Granite and Marble Company, Clyde, Ohio.
Pennsylvania State Memorial (1906)	Granite
Rhode Island State Memorial (1908)	Bronze statue on a granite pedestal with granite from Westerly, Rhode Island
South Carolina State Memorial (1935)	Winnsboro granite, South Carolina
Tennessee State Memorial (1996)	Unpolished granite
Texas State Monument (1961)	Red granite, Texas, installed by the Texas Granite Corporation
Union Navy Memorial (1911)	Granite
Virginia State Memorial (1907)	Bronze plaque mounted on a granite pedestal
West Virginia State Memorial (1922)	Bronze bust on a granite pedestal
Wisconsin State Memorial (1911)	Light gray granite from Winnsboro, South Carolina

Field verification by a geologist of the information in Table 4 is needed because the term “granite” is broadly used by non-geoscientists for rocks that are not actually granite; for example, quartz, travertine, and marble countertops are commonly referred to as “granite.” Moreover, the terms used by archeologists for particular stones (referred to as “lithics”) commonly differ from what geologists use for the same stones, so field verification may be needed.

An inventory could compile basic geologic information such as rock type and commercial origin (i.e., quarry). Based on a quarry’s location, a researcher could determine the geologic formation of the extracted material using a geologic map. Geologic connections could then be made to other NPS areas with the same rock formations and similar geologic settings. Furthermore, geologic heritage connections could be made among state, regional, national, and global stories. For example, granite is commonly representative of an orogeny (mountain-building event), so connections could be made to a particular mountain range—the Appalachian Mountains, the Black Hills of South Dakota, or the Wichita Mountains in Oklahoma. Making a mountain-building connection between a granite obelisk

pointing skyward or serving as the base of a heroic statue would be illuminating for geologic heritage and potentially inspiring for visitors.

Because VICK touts nearly 1,400 monuments and markers, compiling even a basic list of commemorative stones for use in an inventory may seem daunting. However, the foundation document (National Park Service 2014) indicates that the condition of monuments and sculptures throughout VICK is known and monitored, so a list or database may exist. As an alternative, the NPS Cultural Resources Inventory System (CRIS) may contain a list. Park managers are encouraged to contact the regional archeologist and/or anthropologist of NPS Interior Region 4 (Mississippi Basin) to determine what information is contained in CRIS.

Park managers could consider making an inventory of commemorative stones part of an updated survey of important features of the commemorative landscape (compatible with GIS), which is a high-priority data need, or as part of a historic structure report, including state memorials and other major monuments, which is a low-priority planning need (National Park Service 2014). Coordinating with other or ongoing cultural resource projects seems prudent.

Inventory of Quarries

No formal inventory of quarries has taken place at VICK. However, Dockery and Thompson (2016, p. 522–523) documents a quarry in the Catahoula Formation 4.0 km (2.5 mi) east of Raymond, which may be of interest due to the proximity of the Raymond Battlefield. In addition, a prominent outcrop of Glendon Limestone within VICK is a probable source of the material used in making effigy pipes (Rich et al. 2023a; see “Paleontological Resources”). Evidence of quarrying is not known to have been collected or documented at that site.

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The following lists reflect the names and affiliations of participants at the time of the meeting:

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Literature Cited

- Ackerman, D. J. 1989. Hydrology of the Mississippi River Valley alluvial aquifer, south-central United States—a preliminary assessment of the regional flow system. Water-Resources Investigations Report 88-4028. US Geological Survey, Washington, DC.
<https://doi.org/10.3133/wri884028>
- Ashland, F. X., and J. D. DeWitt. 2024. Map data for a landslide inventory of the northwestern part of Vicksburg National Military Park, Mississippi. US Geological Survey, Northeast Region, Reston, Virginia. <https://doi.org/10.5066/P13KDTBY>
- Baughman, W. T. 1971. Rankin County geology and mineral resources. Bulletin 115. Mississippi Geological, Economic, and Topographical Survey, Jackson, Mississippi.
<https://www.mdeq.ms.gov/geology/work-areas/publications-and-map-sales/categories/bulletins/rankin-county-geology-and-mineral-resources-19786/>
- Beckstrand, D., D. Stanley, P. Thompson, E. Bilderback, M. Wittie, U. Kanewala, E. Cuelho, and D. A. Anderson. 2019. Unstable slope management program for federal land management agencies. Publication number FHWA-FLH-19-002. Prepared for the Federal Highway Administration, Vancouver, Washington, by Western Transportation Institute, Bozeman, Montana.
<https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/federal-lands/tech-resources/31011/usmp-field-manual.pdf>
- Bentley, S. J. Sr., M. D. Blum, J. Maloney, L. Pond, and R. Paulsell. 2016. The Mississippi River source-to-sink system: perspectives on tectonic, climatic, and anthropogenic influences, Miocene to Anthropocene. *Earth-Science Reviews* 153:139–174.
<http://dx.doi.org/10.1016/j.earscirev.2015.11.001>
- Bettis, E. A. III, D. R. Muhs, H. M. Roberts, and A. G. Wintle. 2003. Last glacial loess in the conterminous USA. *Quaternary Science Reviews* 22(18–19):907–1946.
[https://doi.org/10.1016/S0277-3791\(03\)00169-0](https://doi.org/10.1016/S0277-3791(03)00169-0)
- Bicker, A. R. 1969. Geologic map of Mississippi (scale 1:500,000). Mississippi Geological Survey, Jackson, Mississippi. https://ngmdb.usgs.gov/Prodesc/proddesc_16555.htm
- Biek, R. F., and M. A. Gonzalez. 2001. The geology of Theodore Roosevelt National Park, Billings and McKenzie Counties, North Dakota (scale 1:24,000). Miscellaneous Series (MS) 86. North Dakota Geological Survey, Bismarck, North Dakota.
https://www.dmr.nd.gov/ndgs/Publication_List/miscells.asp
- Blum, M. D., and H. H. Roberts. 2012. The Mississippi Delta region: past, present, and future. *Annual Review of Earth and Planetary Sciences* 40(1):655–683.
<http://www.annualreviews.org/doi/10.1146/annurev-earth-042711-105248>

- Bobba, C. 2004. Subsurface field investigation for the Connecting Avenue slide. Project no. VICK-2004-SCI-0005. Investigator annual report profile. US Department of Transportation, Federal Highway Administration, Sterling, Virginia. <https://irma.nps.gov/RPRS/IAR/Profile/31500>
- Bograd, B. E., and [updated by] B. Yassin. 2021. Earthquakes in Mississippi. Fact Sheet 1. Mississippi Department of Environmental Quality, Jackson, Mississippi. <https://www.mdeq.ms.gov/geology/work-areas/publications-and-map-sales/categories/fact-sheets/earthquakes-in-mississippi-12509/>
- Bond, D., A. Edwards, D. Peele, H. Shriber, and N. Leber. 2022. Preserve Wisconsin state memorial: material investigation—collection and analysis of concrete, mortar, and soil samples. Permit number VICK-2022-SCI-0001. McMullan Consulting Engineers, Reston, Virginia, and Terracon, Olathe, Kansas. <https://irma.nps.gov/RPRS/Permit/Profile/571752> [Note: Only available on an NPS computer.]
- Brocx, M., C. Brown, and V. Semeniuk. 2019. Geoheritage importance of stratigraphic type sections, type localities and reference sites—review, discussion and protocols for geoconservation. *Australian Journal of Earth Sciences* 66(6):823–836. <https://doi.org/10.1080/08120099.2019.1593242>
- Burns Cooley Dennis, Inc. 2002. Geotechnical investigation: Cemetery wall, Vicksburg National Cemetery. Project no. 01520-I. Geotechnical Consultants, Vicksburg, Mississippi.
- Busacca, A. J., J. E. Begét, H. W. Markewich, D. R. Muhs, N. Lancaster, and M. R. Sweeney. 2004. Eolian sediments. Pages 275–309 *in* A. R. Gillespie, S. C. Porter, and B. R. Atwater, editors. *The Quaternary Period in the United States*. Elsevier, Amsterdam, The Netherlands.
- Carlson, J. E. 2022. Vicksburg National Military Park, project descriptions. Gulf Coast Network, Lafayette, Louisiana. <https://irma.nps.gov/DataStore/DownloadFile/678125>
- Central United States Earthquake Consortium [CUSEC]. n.d. Our earthquake risk. Online information. CUSEC, Memphis, Tennessee. <https://cusec.org/our-earthquake-risk/> (accessed 16 July 2025)
- Chapman, S. S., G. E. Griffith, J. M. Omernik, J. A. Comstock, M. C. Beiser, and D. Johnson. 2004. Ecoregions of Mississippi (scale 1:1,000,000). US Geological Survey, Reston, Virginia. <https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-state>
- Cole, W. A., and R. C. Carter. 1964. Soil survey of Warren County, Mississippi. Fieldwork by H. C. Lane and V. H. McGehee, Soil Conservation Service, and William Clarke, Mississippi Agricultural Experiment Station. United States Department of Agriculture, Soil Conservation Service, in Cooperation with the Mississippi Agricultural Experiment Station, Mississippi State, Mississippi. <https://archive.org/details/usda-soil-surveys>

- Cole, W. A., R. W. Smith, J. W. Keyes, F. T. Scott, and L. B. Walton. 1979. Soil survey of Hinds County, Mississippi. United States Department of Agriculture, Soil Conservation Service, Washington, DC, in cooperation with the Mississippi Agricultural and Forestry Experiment Station, Mississippi State, Mississippi. <https://archive.org/details/usda-soil-survey-of-hinds-county-mississippi-1979>
- Conrad, T. A. 1846a. Observations on the Eocene formation of the United States, with descriptions of species of shells, &c. occurring in it. The American Journal of Science and Arts, Second Series, Volume I, Number II, Article VII, p. 209–221. <https://www.biodiversitylibrary.org/page/15011479>
- Conrad, T. A. 1846b. Observations on the Eocene formation of the United States, with descriptions of species of shells occurring in it. The American Journal of Science and Arts, Second Series, Volume I, Number III, Article VIII, p. 395–405. <https://www.biodiversitylibrary.org/page/15011674>
- Conrad, T. A. 1846c. Tertiary of Warren Co., Mississippi. The American Journal of Science and Arts, Second Series, Volume II, Number IV, Chapter II: Mineralogy and Geology, Number 14, p. 124–125. <https://www.biodiversitylibrary.org/page/28135563>
- Conrad, T. A. 1847. Observations on the Eocene formation, and description of one hundred and five new fossils of that period, from the vicinity of Vicksburg, Mississippi. Academy of Natural Sciences of Philadelphia Proceedings 3(11):280–299. https://ngmdb.usgs.gov/Prodesc/proddesc_87746.htm
- Conrad, T. A. 1848a. Observations on the Eocene formation, and descriptions of one hundred and five new fossils of that period, from the vicinity of Vicksburg, Mississippi, with an Appendix. Proceedings of the Academy of Natural Sciences of Philadelphia, Volume III—1846 & 1847, p. 280–299. <https://www.biodiversitylibrary.org/page/26296675>
- Conrad, T. A. 1848b. Observations on the Eocene formation, and descriptions of one hundred and five new fossils of that period, from the vicinity of Vicksburg, Mississippi, with an Appendix. Journal of the Academy of Natural Sciences of Philadelphia, Volume I, Article IX, p. 111–134. <https://www.biodiversitylibrary.org/page/35780201>
- Cooke, C. W. 1918. Correlation of the deposits of Jackson and Vicksburg ages in Mississippi and Alabama. Washington Academy of Sciences Journal 8(7):186–198.
- Cooke, C. W., and J. A. Cushman. 1923. The correlation of the Vicksburg group and the foraminifera of the Vicksburg group. Professional Paper 133. US Geological Survey, Washington, DC. <https://doi.org/10.3133/pp133>

- Cooper, R. J., S. B. Cederbaum, and J. J. Gannon. 2004. Natural resource summary for Vicksburg National Military Park (VICK). University of Georgia, Warnell School of Forest Resources, Athens, Georgia. <https://irma.nps.gov/DataStore/Reference/Profile/590838>
- Crofts, R., J. E. Gordon, J. Brilha, M. Gray, J. Gunn, J. Larwood, V. L. Santucci, D. Tormey, and G. L. Worboys. 2020. Guidelines for geoconservation in protected and conserved areas. Best Practice Protected Area Guidelines 31. International Union for Conservation of Nature (IUCN), Gland, Switzerland. <https://portals.iucn.org/library/node/49132>
- Cruden, D. M., and D. L. Varnes. 1996. Landslide types and processes. Pages 36–75 (chapter 3) *in* A. K. Turner and R. L. Schuster, editors. Landslides: investigation and mitigation. Special Report 247. Transportation Research Board, National Research Council, Washington, DC.
- Darrah, W. C. 1951. Powell of the Colorado. Princeton University Press, Princeton, New Jersey.
- Desai, V., N. Leber, T. Lyons, S. Ravizza, Z. Romeo, R. Steiner, E. Turcotte, and R. Warren. 2016. Topographic/geotechnical surveys at RR Redoubt/TX memorial bluff. Permit number VICK-2016-SCI-0003. VHB, Williamsburg, Virginia. <https://irma.nps.gov/RPRS/Permit/Profile/56860> [Note: Only available on an NPS computer.]
- Desai, V., A. Ulschmid, and B. Armstrong. 2022. Stabilize Mint Spring Bayou redesign services—geotechnical investigation & wetland investigation. Permit number VICK-2021-SCI-005. VHB, Williamsburg, Virginia. <https://irma.nps.gov/RPRS/Permit/Profile/571607> [Note: Only available on an NPS computer.]
- DeWitt, J. D. 2024. UAS-borne Lidar 0.5m DTM for parts of Vicksburg National Military Park, December 2022. Data release. US Geological Survey, Northeast Region, Reston, Virginia. <https://doi.org/10.5066/P93OY5HH>
- Dockery, D. T. III. 1982a. Lower Oligocene Bivalvia of the Vicksburg Group in Mississippi. Bulletin 123. Mississippi Department of Natural Resources, Bureau of Geology, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/bulletins/
- Dockery, D. T. III. 1982b. Lesueur’s Walnut Hills fossil shells. Mississippi Geology 2(3):7–13. https://www.mdeq.ms.gov/geology_publication_categories/mississippi-geology/
- Dockery, D. T. III. 1986. Punctuated succession of Paleogene mollusks in the northern Gulf Coastal Plain. *Palaios* 1(6):582–589. <https://doi.org/10.2307/3514708>
- Dockery, D. T. III, J. E. Starnes, D. E. Thompson, and L. Beiser. 2008. Rocks and fossils found in Mississippi’s gravel deposits. Circular 7. Mississippi Department of Environmental Quality, Office of Geology, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/circulars/

- Dockery, D. T. III, and D. E. Thompson. 2016. *The geology of Mississippi*. University Press of Mississippi, Jackson, Mississippi.
- Dyke, A. S., J. T. Andrews, P. U. Clark, J. H. England, G. H. Miller, J. Shaw, and J. I. Veillette. 2002. The Laurentide and Innuitian ice sheets during the last glacial maximum. *Quaternary Science Reviews* 21:9–31. [https://doi.org/10.1016/S0277-3791\(01\)00095-6](https://doi.org/10.1016/S0277-3791(01)00095-6)
- Feng, L., M. Zhang, H. Liu, B. Zhang, Z. Du, P. Sun, J. Bi, L. Wang, and T. Gu. 2024. The general patterns of water flow in loess slope system and implications for slope geological security. *Science of the Total Environment* 945:174041. <https://doi.org/10.1016/j.scitotenv.2024.174041>
- Fisk, H. N. 1944. *Geological investigation of the alluvial valley of the lower Mississippi River*. US Army Corps of Engineers, Vicksburg, Mississippi.
- Flint, R. F. 1971. *Glacial and Quaternary geology*. John Wiley & Sons, Inc., New York, New York.
- Galloway, W. E., T. L. Whiteaker, and P. Ganey-Curry. 2011. History of Cenozoic North American drainage basin evolution, sediment yield, and accumulation in the Gulf of Mexico basin. *Geosphere* 7:938–73. <https://doi.org/10.1130/GES00647.1>
- Gandl, L. A. 1979. The Oligocene aquifer system in Mississippi. Water-Resources Investigations Report 79-28. US Geological Survey, Washington, DC. <https://doi.org/10.3133/wri7928>
- Grabau, W. E. 2000. *Ninety-eight days: a geographer's view of the Vicksburg Campaign*. The University of Tennessee Press, Knoxville, Tennessee.
- Guzzetti, F., A. C. Mondini, M. Cardinali, F. Fiorucci, M. Santangelo, and K. T. Chang. 2012. Landslide inventory maps: new tools for an old problem. *Earth-Science Reviews* 112 (1–2):42–66. <https://doi.org/10.1016/j.earscirev.2012.02.001>
- Henderson, S. W. 2000. The significance of meander bends in military history: Three examples from the southern United States. *Geological Society of America Abstracts with Programs* 32(2):25.
- Henderson, T. C., V. L. Santucci, T. Connors, and J. S. Tweet. 2022. National Park Service, geologic type section inventory: Gulf Coast Inventory & Monitoring Network. Natural Resource Report NPS/GULN/NRR—2022/2454. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2294339>
- Hiatt, D. L. 2023. Vicksburg National Military Park, water quality brief CY2022. National Park Service, Gulf Coast Network, Lafayette, Louisiana. <https://irma.nps.gov/DataStore/Reference/Profile/2300809>
- Higgins, B. 2002. Viewing the Civil War through a geological window. *CRM* 25(4):21–25. <https://www.nps.gov/crps/CRMJournal/CRM.html>

- Hilgard, E. W. 1879. The loess of the Mississippi Valley and the eolian hypothesis. *American Journal of Science*, s3-18(104):106–112. <https://doi.org/10.2475/ajs.s3-18.104.106>
- Hill, J., B. Dunaway, and J. Barone. 2019. Develop and implement a habitat management plan for prairie nymph. Permit no. VICK-2018-SCI-0002. Investigators Annual Report. Mississippi State University, Mississippi Entomological Museum, Mississippi State, Mississippi. <https://irma.nps.gov/RPRS/IAR/Profile/342406>
- Hu, S., Q. Haijun, N. Wang, Y. Cui, J. Wang, X. Wang, S. Ma, D. Yang, M. Caoa. 2020. The influence of loess cave development upon landslides and geomorphologic evolution: A case study from the northwest Loess Plateau, China. *Geomorphology* 359:107167. <https://doi.org/10.1016/j.geomorph.2020.107167>
- Huang, T., B. Ma, Z. Pang, Z. Li, Z. Li, and Y. Long. 2020. How does precipitation recharge groundwater in loess aquifers? Evidence from multiple environmental tracers. *Journal of Hydrology* 583:124532. <https://doi.org/10.1016/j.jhydrol.2019.124532>
- Jarvis, J. E. 2015. Addressing climate change and natural hazards for facilities. Policy Memorandum 15-01 to All Employees (National Park Service), 20 January 2015. US Department of the Interior, National Park Service, Washington DC Support Office, Washington DC.
- Joyner, E. H. 2024. Vicksburg National Cemetery. Images of America [series]. Arcadia Publishing, Mount Pleasant, South Carolina.
- KellerLynn, K. 2010a. Geologic resources inventory scoping summary, Natchez Trace Parkway, Mississippi, Alabama, Tennessee. NPS Geologic Resources Division, Lakewood, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2250381>
- KellerLynn, K. 2010b. Geologic resources inventory scoping summary, Vicksburg National Military Park, Mississippi and Louisiana. NPS Geologic Resources Division, Lakewood, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2251459>
- KellerLynn, K. 2011. Oregon Caves National Monument: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/457. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2176678>
- Kenworthy, J. P., V. L. Santucci, and C. C. Visaggi. 2007. Paleontological resource inventory and monitoring, Gulf Coast Network. Technical Information Center (TIC) document D-750. National Park Service, Geologic Resources Division, Lakewood, Colorado.
- Kerbo, R., and G. McDonald. 2005. Preliminary geological and paleontological resources assessment. Trip report: technical assistance to Vicksburg National Military Park, 19–21 September 2005. National Park Service, Geologic Resources Division, Lakewood, Colorado.

- Kious, W. J., and R. I. Tilling. 1996. This dynamic Earth: the story of plate tectonics. US Geological Survey, Washington, DC. <https://pubs.usgs.gov/gip/dynamic/dynamic.html>
- Kocher, A. E., and A. L. Goodman. 1918. Soil survey of Hinds County, Mississippi. US Department of Agriculture, Bureau of Soils, Washington, DC, in cooperation with the State of Mississippi, State Geological Survey, Jackson, Mississippi. <https://archive.org/details/usda-soil-survey-of-hinds-county-mississippi-1918>
- Kolb, C. R. 1967. Physical properties and engineering characteristics of Mississippi loess. Pages D-1–D-20 *in* C. R. Kolb and C. O. Durham Jr., editors. Field trip guidebook: Lower Mississippi alluvial valley and terraces. Geological Society of America, 1967 Annual Meeting, New Orleans, Louisiana. Geological Society of America, Boulder, Colorado.
- Kolb, C. R., E. E. Russell, and B. W. Johnson. 1976. Classic Tertiary and Quaternary localities and historical highlights of the Jackson-Vicksburg-Natchez area. Field trip guidebook. AAPG/SEPM Annual Convention, 24–26 May 1976, New Orleans, Louisiana. New Orleans Geological Society, New Orleans, Louisiana.
- Krinitzsky, E. L., and W. J. Turnbull. 1967. Loess deposits of Mississippi. Special Paper 94. Geological Society of America, Boulder, Colorado. <https://doi.org/10.1130/SPE94-p1>
- Lane, H. C., and W. A. Cole. 1963. Soil survey of Claiborne County, Mississippi. United States Department of Agriculture, Soil Conservation Service, Washington, DC, in cooperation with the Mississippi Agricultural Experiment Station, Mississippi State, Mississippi. <https://archive.org/details/usda-soil-surveys>
- Larsen, D., J. Bursi, B. Waldron, S. Schoefernacker, and J. Eason. 2020. Recharge pathways and rates for a sand aquifer beneath a loess mantled landscape in western Tennessee, USA. *Journal of Hydrology: Regional Studies* 28(April 2020),100667. <https://doi.org/10.1016/j.ejrh.2020.100667>
- Larson, R. J., W. M. Myers, and D. W. Harrelson. 2004. Mississippi loess and the siege of Vicksburg. *Geological Society of America Abstracts with Programs* 36(2):77.
- Leard, J. R., and J. E. Starnes. 2021. Geologic map of the Raymond quadrangle, Hinds County, Mississippi (scale 1:24,000). Open-File Report OF-313. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/open-file-reports/
- Leard, J. R., J. E. Starnes, and T. J. Palmer. 2023a. Geologic map of the Edwards quadrangle Hinds County, Mississippi (scale 1:24,000). Open-File Report OF-332. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/open-file-reports/

- Leard, J. R., J. E. Starnes, and T. J. Palmer. 2023b. Geologic map of the Phoenix 7.5-minute quadrangle, Yazoo, Warren, and Hinds Counties, Mississippi (scale 1:24,000). Open-File Report 329. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi.
https://www.mdeq.ms.gov/geology_publication_categories/open-file-reports/
- Leard, J. R., J. E. Starnes, and T. J. Palmer. 2025. Geologic map of the Mississippi River alluvial plain: Bolivar, Washington, Sunflower, Leflore, Coahoma, Tunica, Tallahatchie, Issaquena, Sharkey, Humphreys, Quitman, Yazoo, Warren, Holmes, Adams, Panola, Wilkinson, Desoto, Carroll, Jefferson, Grenada, Claiborne, and Tate Counties, Mississippi (scale 1:500,000). Open-File Report 354. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi. <https://www.mdeq.ms.gov/geology/work-areas/publications-and-map-sales/categories/open-file-reports/of-354-geologic-map-of-the-mississippi-river-alluvial-plain-bolivar-washington-sunflower-leflore-coahoma-tunica-tallahatchie-issaquena-sharkey-humphreys-quitman-yazoo-warren-holmes-adams-103123/>
- Lutton, R. J. 1969. Fractures and failure mechanics in loess and applications to rock mechanics. Research Report S-69-1. US Army Waterways Experiment Station, Vicksburg, Mississippi.
- Lutton, R. J. 2009. Sequential mass failure as detailed in steep cuts in loess. *Environmental Engineering & Geoscience* 15(1):1–12. <https://doi.org/10.2113/gseegeosci.15.1.1>
- Lyell, C. 1833. *Principles of geology*. Volume III. John Murray, London.
<https://www.gutenberg.org/cache/epub/33224/pg33224-images.html>
- Lyell, C. 1849. *A second visit to the United States of North America*. Volume II. Harper and Brothers Publishing Co., New York, New York.
<https://archive.org/details/asecondvisittou07lyelgoog>
- MacNeil, F. S., and D. T. Dockery III. 1984. Lower Oligocene Gastropoda, Scaphopoda, and Cephalopoda of the Vicksburg Group in Mississippi. Bulletin 124. Mississippi Department of Natural Resources, Bureau of Geology, Jackson, Mississippi.
https://www.mdeq.ms.gov/geology_publication_categories/bulletins/
- Meiman, J. 2012. Gulf Coast Network water quality report: status of water quality of Vicksburg National Military Park. Natural Resource Technical Report NPS/GULN/NRTR—2012/548. National Park Service, Lafayette, Louisiana.
<https://irma.nps.gov/DataStore/Reference/Profile/2183993>
- Mellen, F. F. 1941. Geology. Pages 9–88 in F. F. Mellen, T. E. McCutcheon, and M. R. Livingston, editors. Warren County mineral resources. Bulletin 43. Mississippi State Geological Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/bulletins/

- Miller, N. A. 1976. National register of historic places inventory—nomination form: Vicksburg National Military Park. National Park Service, Vicksburg National Military Park, Vicksburg, Mississippi. <http://npshistory.com/publications/vick/index.htm>
- Monroe, W. H. 1954. Geology of the Jackson area, Mississippi. Bulletin 986. US Geological Survey, Washington, DC. <https://pubs.er.usgs.gov/publication/b986>
- Moore, W. H. 1965. Hinds County geology. Pages 21–146 *in* W. H. Moore, A. R. Bicker, Jr., T. E. McCutcheon, and W. Parks, contributors. Hinds County geology and mineral resources. Bulletin 105. Mississippi Geological, Economic and Topographical Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/bulletins/
- Moore, C. M., A. Walker, and J. Mylroie. 2005. Progress report on the digital karst map of Mississippi. Geological Society of America Abstracts with Programs 37(2):41. <https://gsa.confex.com/gsa/2005SE/webprogram/Paper82696.html>
- Morse, W. C. 1935. Geologic history of the Vicksburg National Military Park area. Bulletin 28. Mississippi State Geological Survey, Jackson, Mississippi. <https://irma.nps.gov/DataStore/Reference/Profile/53093>
- Muhs, D. R. 2007. Loess deposits, origins and properties. Pages 1405–1418 *in* S. A. Elias, editor. Encyclopedia of Quaternary Science. Elsevier, Amsterdam, The Netherlands.
- Muhs, D. R. 2013. The geologic records of dust in the Quaternary. Aeolian Research 9:3–48. <https://doi.org/10.1016/j.aeolia.2012.08.001>
- Muhs, D. R., T. A. Ager, E. A. Bettis III, J. McGeehin, J. M. Been, J. E. Begét, M. J. Pavich, T. W. Stafford Jr., and D. Pinney. 2003. Stratigraphy and paleoclimatic significance of late Quaternary loess–paleosol sequences of the last interglacial–glacial cycle in central Alaska. Quaternary Science Reviews 22:1947–1986. [https://doi.org/10.1016/S0277-3791\(03\)00167-7](https://doi.org/10.1016/S0277-3791(03)00167-7)
- Muhs, D. R., S. R. Cattle, O. Crouvi, D. Rousseau, J. Sun, and M. A. Zárate. 2014. Loess records. Pages 411–441 *in* P. Knippertz and J. W. Stuut, editors. Mineral dust. Springer Netherlands, Dordrecht. https://doi.org/10.1007/978-94-017-8978-3_16
- Murphy, W. L., and P. E. Albertson. 1996. Engineering geological geographical information system of the Waterways Experiment Station. Mississippi Geology 17(2):25–39. https://www.mdeq.ms.gov/geology_publication_categories/mississippi-geology/
- Myers, W. M., D. W. Harrelson, and R. J. Larson. 2005. The impact of Vicksburg loess on the 1863 siege of Vicksburg, Mississippi. Geological Society of America Abstracts with Programs, Southeastern Section 37(2):46. <https://gsa.confex.com/gsa/2005SE/webprogram/Paper83021.html>

- National Park Service. n.d. Natural resources—backdrop to the battlefield. Site brochure. Vicksburg National Military Park, Vicksburg, Mississippi.
- National Park Service. 2006. Management policies 2006. US Department of the Interior, National Park Service, Washington, DC. <https://irma.nps.gov/DataStore/Reference/Profile/2219015>
- National Park Service. 2007. SRI—soil survey geographic (SSURGO) for Vicksburg National Military Park, Mississippi. National Park Service, Geologic Resources Division, Soil Inventory and Monitoring Program, Denver, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/1048992>
- National Park Service. 2014. Foundation document: Vicksburg National Military Park, Mississippi (October 2014). Vicksburg National Military Park, Vicksburg, Mississippi; Southeast Regional Office, Atlanta, Georgia; and Denver Science Center, Denver, Colorado.
<https://npshistory.com/publications/vick/index.htm>
- National Park Service. 2015a. Addressing climate change and natural hazards: facility planning and design considerations. Level 3 Handbook. National Park Service, Park Planning Facilities and Lands, Construction Program Management Division, Denver, Colorado.
- National Park Service. 2015b. Seeps and springs. Online information. Vicksburg National Military Park, Vicksburg, Mississippi. <https://www.nps.gov/vick/learn/nature/springs.htm> (accessed 17 July August 2025)
- National Park Service. 2023. Addressing climate change and natural hazards handbook: checklist for assessment of environmental change and effects on National Park Service facilities, version 2, April 2023. NPS Park Planning, Facilities, and Lands Directorate. Washington, DC.
- National Park Service. 2024a. Monument and memorials: explore the monuments and memorials. Online information. Vicksburg National Military Park, Vicksburg, Mississippi.
<https://www.nps.gov/vick/learn/historyculture/vnmp-state-memorials.htm> (accessed 17 July 2025)
- National Park Service. 2024b. USS *Cairo* gunboat and museum. Online information. Vicksburg National Military Park, Vicksburg, Mississippi. <https://www.nps.gov/vick/u-s-s-cairo-gunboat.htm> (accessed 17 July 2025)
- National Park Service. 2024c. Vicksburg National Military Park climate futures summary. National Park Service, Climate Change Response Program, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2304575>
- National Water Prediction Service. 2024. Mississippi River at Vicksburg. Online information. National Oceanic and Atmospheric Administration, National Water Prediction Service, Jackson, Mississippi. <https://water.noaa.gov/gauges/vckm6> (accessed 17 July 2025)

- Nayegandhi, A., J. C. Brock, C. W. Wright, M. Segura, and X. Yates. 2007. EAARL topography–Vicksburg National Military Park 2007: first surface. Data Series 388. Jacobs Technology Inc., St. Petersburg, Florida; USGS, Coastal and Marine Geology Program, Reston, Virginia; USGS, Florida Integrated Science Center, St. Petersburg, Florida; and NPS, Gulf Coast Network, Lafayette, Louisiana. <https://pubs.usgs.gov/ds/388/>
- Nayegandhi, A., J. C. Brock, C. W. Wright, M. Segura, and X. Yates. 2008. EAARL topography–Vicksburg National Military Park 2008: bare earth. Data Series 390. Jacobs Technology Inc., St. Petersburg, Florida; USGS, Coastal and Marine Geology Program, Reston, Virginia; USGS, Florida Integrated Science Center, St. Petersburg, Florida; and NPS, Gulf Coast Network, Lafayette, Louisiana. <https://pubs.usgs.gov/ds/390/>
- Palmer, T. J., J. R. Leard, J. E. Starnes, T. Smith, and N. Usachenko. 2025a. Geologic map of the Redwood 7.5-minute quadrangle, Warren and Issaquena Counties, Mississippi (scale 1:24,000). Open-File Report 352. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/open-file-reports/
- Palmer, T. J., J. R. Leard, J. E. Starnes, T. Smith, and N. Usachenko. 2025b. Geologic map of the Vicksburg East 7.5-minute quadrangle, Warren County, Mississippi (scale 1:24,000). Open-File Report 351. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/open-file-reports/
- Palmer, T. J., J. R. Leard, J. E. Starnes, T. Smith, and N. Usachenko. 2025c. Geologic map of the Vicksburg West 7.5-minute quadrangle, Warren County, Mississippi (scale 1:24,000). Open-File Report 350. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/open-file-reports/
- Peng, D., Q. Xu, F. Liu, Y. He, S. Zhang, X. Qi, K. Zhao, and X. Zhang. 2018. Distribution and failure modes of the landslides in Heitai terrace, China. *Engineering Geology* 236:97–110. <https://doi.org/10.1016/j.enggeo.2017.09.016>
- Pécsi, M. 1990. Loess is not just the accumulation of dust. *Quaternary International* 7–8:1–21. [https://doi.org/10.1016/1040-6182\(90\)90034-2](https://doi.org/10.1016/1040-6182(90)90034-2)
- Péwé, T. L. 1975. Quaternary geology of Alaska. Professional Paper 835. US Geological Survey, Washington, DC. <https://doi.org/10.3133/pp835>
- Pigati, J. S., J. McGeehin, D. R. Muhs, D. A. Grimley, and J. C. Nekola. 2014. Radiocarbon dating loess deposits in the Mississippi Valley using terrestrial gastropod shells (Polygyridae, Helicinidae, and Discidae). *Aeolian Research* 16:25–33. <https://doi.org/10.1016/j.aeolia.2014.10.005>

- Pindell, J. L. 1985. Alleghenian reconstruction and subsequent evolution of the Gulf of Mexico, Bahamas, and proto-Caribbean. *Tectonics* 4:1–39. <https://doi.org/10.1029/TC004i001p00001>
- Pizarro, M. G., J. N. Gifford, J. E. Starnes, and B. F. Platt. 2024. Bedrock origins from petrology and geochemistry: volcanic gravel clasts from the Rawhide Terrace in the Pleistocene ancestral Mississippi River pre-loess terrace deposits. *Geosciences* 14(12), article number 340. <https://doi.org/10.3390/geosciences14120340>
- Priddy, R. R., J. Y. Christmas III, and J. G. Ward. 1964. Pseudoanticlines in Vicksburg loess. *Journal of the Mississippi Academy of Sciences* 10:178–179. <https://msacad.org/past-journals>
- Priddy, R. R., J. O. Snowden Jr., and L. L. McDonald. 1966. Radiocarbon stratigraphy of Vicksburg loess. *Journal of the Mississippi Academy of Sciences* 12:130–131. <https://msacad.org/past-journals>
- Prokocki, E. 2009. Holocene evolution and avulsion history of the lower Mississippi River, Yazoo Basin. Thesis. Louisiana State University, Baton Rouge, Louisiana. https://digitalcommons.lsu.edu/gradschool_theses/2070/
- Rabbitt, M. C. 1980. John Wesley Powell: soldier, explorer, scientist. Unnumbered general interest publication. US Geological Survey, Washington, DC. https://www.nps.gov/parkhistory/online_books/geology/publications/inf/74-24/sec1.htm
- Reimer, P., W. E. N. Austin, E. Bard, A. Bayliss, P. G. Blackwell, C. Bronk Ramsey, M. Butzin, R. L. Edwards, M. Friedrich, P. M. Grootes, T. P. Guilderson, I. Hajdas, T. J. Heaton, A. Hogg, B. Kromer, S. W. Manning, R. Muscheler, J. G. Palmer, C. Pearson, J. van der Plicht, D. A. Reim Richards, E. M. Scott, J. R. Southon, C. S. M. Turney, L. Wacker, F. Adolphi, U. Büntgen, S. Fahrni, A. Fogtman-Schulz, R. Friedrich, P. Köhler, S. Kudsk, F. Miyake, J. Olsen, M. Sakamoto, A. Sookdeo, and S. Talamo. 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62(4):725–757. <https://doi.org/10.1017/RDC.2020.41>
- Rich, M. M., C. V. Beightol, C. C. Visaggi, J. S. Tweet, and V. L. Santucci. 2023a. The historical record of paleontological and geological investigations within Vicksburg National Military Park, Mississippi. Pages 547–557 in S. G. Lucas, G. S. Morgan, A. P. Hunt, and A. J. Lichtig, editors. *Fossil Record 9. Bulletin 94*. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. <https://irma.nps.gov/DataStore/DownloadFile/692617>
- Rich, M. M., C. V. Beightol V, C. C. Visaggi, J. S. Tweet, and V. L. Santucci. 2023b. Vicksburg National Military Park: paleontological resource inventory (public version). Natural Resource Report NPS/VICK/NRR—2023/2516. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2299268>

- Richthofen, E. V. 1882. On the mode of origin of loess. *Geological Magazine* 9(7):293–305.
<https://doi.org/10.1017/S001675680017164X>
- Russell, R. J. 1944. Lower Mississippi valley loess. *Geological Society of America Bulletin* 55(1):1–40. <https://doi.org/10.1130/GSAB-55-1>
- Schmidt, J., P. C. Almond, L. Basher, S. Carrick, A. E. Hewitt, I. H. Lynn, and T. H. Webb. 2005. Modelling loess landscapes for the South Island, New Zealand, based on expert knowledge. *New Zealand Journal of Geology and Geophysics* 48:117–133.
<https://doi.org/10.1080/00288306.2005.9515103>
- Sherman, W. C. 1962. Results of investigations of slide area at Mint Springs Bayou bridge, Vicksburg National Military Park. US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.
- Skates, J. R. 1990. Mississippi's old capitol: biography of a building. Mississippi Department of Archives and History, Jackson, Mississippi.
- Smalley, I. J., I. F. Jefferson, T. A. Dijkstra, and E. Derbyshire. 2001. Some major events in the development of the scientific study of loess. *Earth-Science Reviews* 54(1–3):5–18.
[https://doi.org/10.1016/S0012-8252\(01\)00038-1](https://doi.org/10.1016/S0012-8252(01)00038-1)
- Smith, T. 2016. Surficial geologic mapping of the Vicksburg National Military Park and surrounding areas in Vicksburg, Mississippi. Thesis. Mississippi State University, Department of Geosciences, Mississippi State, Mississippi. <https://scholarsjunction.msstate.edu/td/4163>
- Smith, T. E., and D. W. Schmitz. 2016a. Geologic map of the Long Lake quadrangle, Warren County, Mississippi, and Madison Parish, Louisiana (scale 1:24,000). Unpublished map and GIS data. Mississippi State University, Department of Geosciences, Mississippi State, Mississippi. <https://irma.nps.gov/DataStore/Reference/Profile/2231845>
- Smith, T. E., and D. W. Schmitz. 2016b. Geologic map of the Redwood quadrangle, Warren and Issaquena Counties, Mississippi (scale 1:24,000). Unpublished map and GIS data. Mississippi State University, Department of Geosciences, Mississippi State, Mississippi. <https://irma.nps.gov/DataStore/Reference/Profile/2231845>
- Smith, T. E., and D. W. Schmitz. 2016c. Geologic map of the Vicksburg East quadrangle, Warren County, Mississippi (scale 1:24,000). Unpublished map and GIS data. Mississippi State University, Department of Geosciences, Mississippi State, Mississippi. <https://irma.nps.gov/DataStore/Reference/Profile/2231845>

- Smith, T. E., and D. W. Schmitz. 2016d. Geologic map of the Vicksburg West quadrangle, Warren County, Mississippi, and Madison Parish, Louisiana (scale 1:24,000). Unpublished map and GIS data. Mississippi State University, Department of Geosciences, Mississippi State, Mississippi. <https://irma.nps.gov/DataStore/Reference/Profile/2231845>
- Snowden, J. O. Jr., and R. R. Priddy. 1968. Geology of Mississippi loess. Pages 13–203 in *Loess Investigations in Mississippi*. Bulletin 111. Mississippi Geological, Economic and Topographical Survey, Jackson, Mississippi. <https://www.mdeq.ms.gov/geology/work-areas/publications-and-map-sales/categories/bulletins/loess-investigations-in-mississippi-19386/>
- Sprafke, T., and I. Obreht. 2016. Loess: rock, sediment or soil—what is missing for its definition? *Quaternary International* 399:198–207. <https://doi.org/10.1016/j.quaint.2015.03.033>
- Starnes, J. E., and J. R. Leard. 2021. Geologic map of the Widows Creek quadrangle, Claiborne County, Mississippi (scale 1:24,000). Open-File Report OF-314. Mississippi Department of Environmental Quality, Office of Geology, Mississippi Geological Survey, Jackson, Mississippi. https://www.mdeq.ms.gov/geology_publication_categories/open-file-reports/
- Stegner, W. 1954. *Beyond the hundredth meridian: John Wesley Powell and the second opening of the West*. Penguin Books, New York, New York.
- Steponaitis, V. P., and D. T. Dockery III. 2011. Mississippian effigy pipes and the Glendon Limestone. *American Antiquity* 76(2):345–354. <https://doi.org/10.7183/0002-7316.76.2.345>
- Sullivan, T. J. 2016. Air quality related values (AQRVs) for Gulf Coast Network (GULN) parks: effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/SCPN/NRR—2016/1158. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2227863>
- Sundin, G., L. Worsham, N. Nibbelink, M. Mengak, and G. Grossman. 2014. Natural resource condition assessment for Vicksburg National Military Park. Natural Resource Report NPS/VICK/NRR—2014/769. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2207798>
- Surratt, J. 2022. Faith of our forefathers: program to discuss Methodism, Newitt Vick. Online information. Vicksburg Post, Vicksburg, Mississippi. <https://www.vicksburgpost.com/2022/08/21/faith-of-our-forefathers-program-to-discuss-methodism-newitt-vick/> (accessed 17 July 2025)
- Tonti, E. C. 1955. Certain disconformities and lithology of the Vicksburg Stage of southeastern United States. Dissertation. Louisiana State University, Baton Rouge, Louisiana. https://repository.lsu.edu/gradschool_disstheses/113

- Tucker, D., and J. Ling. 2017. Hydrographic and impairment statistics database: VICK. National Park Service, Water Resources Division, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2249646>
- Tucker, D., and J. Ling. 2025. Hydrographic and Impairment Statistics Database: VICK. National Park Service, Water Resource Division, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2313701>
- Tweet, J. S., V. L. Santucci, and H. G. McDonald. 2016. Name-bearing fossil type specimens and taxa named from National Park Service areas. Pages 277–288 *in* R. M. Sullivan and S. G. Lucas, editors. Fossil Record 5. Bulletin 73. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico.
- US Army Corps of Engineers. 2013. 2009–2010 USACE Vicksburg District Lidar: Mississippi River Delta; collected 2009-02-19 to 2010-08-02. Point Cloud. GUID: gov.noaa.nmfs.inport:49819 (updated 9 August 2022). <https://www.fisheries.noaa.gov/inport/item/49819> (accessed 14 August 2024)
- US Board on Geographic Names. 1981. Summary report, feature details [for] Mint Spring Branch, Warren County, Mississippi. Feature ID: 673682. Online information. Geographic Names Information System (GNIS), maintained by the US Geological Survey, Washington, DC.
<https://edits.nationalmap.gov/apps/gaz-domestic/public/search/names/673682> (accessed 17 July 2025)
- US Geological Survey. 2014. USGS Lidar Point Cloud MS_MSDELTAYAZOO_PHASE1_2009; collected between February 2009 and August 2010.
<https://www.sciencebase.gov/catalog/item/641dd4b0d34e807d39b784de> (accessed 17 July 2025)
- US Geological Survey. 2017. 2016–2017 USGS Lidar: Mississippi NRCS; collected January and February 2016 and January 2017. Point Cloud. <https://www.fisheries.noaa.gov/inport/item/53850> (accessed 17 July 2025)
- US Geological Survey. 2020. 2018–2020 USGS Lidar: Mississippi Delta, MS; collected 2018-02-18 to 2019-02-08. US 3D Elevation Program Point Cloud.
<https://www.fisheries.noaa.gov/inport/item/70397> (accessed 17 July 2025)
- USGS Earthquake Hazards Program. 2022. National seismic hazard model, 9 March 2022. Online information. US Geological Survey, National Earthquake Information Center, Golden, Colorado.
<https://www.usgs.gov/programs/earthquake-hazards/science/national-seismic-hazard-model> (accessed 17 July 2025)
- Wailles, B. L. C. 1854. Report on the agriculture and geology of Mississippi. E. Barksdale, State Printer, Jackson, Mississippi.
<https://archive.org/details/reportonagricult00miss/page/n5/mode/2up>

- Wang, X. G., J. D. Wang, H. B. Zhan, P. Li, H. J. Qiu, and S. Hu. 2020. Moisture content effect on the creep behavior of loess for the catastrophic Baqiao landslide. *Catena* 187:104371. <https://doi.org/10.1016/j.catena.2019.104371>
- Webb, C. 1971. Archaic and Poverty Point zoomorphic locust beads. *American Antiquity* 36(1):105–114. <https://doi.org/10.2307/278028>
- Weems, T. A., E. F. Reynolds, R. L. Venson, E. T. Allen, and T. J. Smith. 1982. Soil survey of Madison Parish, Louisiana. United States Department of Agriculture, Soil Conservation Service, Washington, DC, in cooperation with the Louisiana Agricultural Experiment Station, Baton Rouge, Louisiana. <https://archive.org/details/usda-soil-surveys>
- Wells, C. 1997. Vicksburg National Military Park, resource management plan. Vicksburg National Military Park, Vicksburg, Mississippi. <https://irma.nps.gov/DataStore/Reference/Profile/2169566>
- Williams, R., G. Jones, J. Price, J. Mason, and M. Volk. 2021. Slope failure study, Logue Circle. Permit number VICK-2020-SCI-0001. SoilTech Consultants, Inc., Jackson, Mississippi. <https://irma.nps.gov/RPRS/Permit/Profile/357214> [Note: Only available on an NPS computer.]
- Winschel, T. 2017. The engineers at Vicksburg, part 28: Ransom's Approach. Online information. US Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, Mississippi. <https://www.erc.usace.army.mil/Media/News-Stories/Article/1302649/the-engineers-at-vicksburg-part-28-ransoms-approach/> (accessed 17 July 2025)
- Wiss, Janney, Elstner Associates, Inc., and John Milner Associates, Inc. 2009. Cultural landscape report: Vicksburg National Military Park, Vicksburg, Mississippi. Prepared for NPS Southeast Regional Office, Atlanta, Georgia. <https://irma.nps.gov/DataStore/Reference/Profile/2186021>
- Worster, D. 2001. *A river running west: the life of John Wesley Powell*. Oxford University Press, New York, New York.
- Zhang, Y., A. Wang, K. Ma, M. Zhang, X. Meng, K. Zhu, D. Qiao, T. Liu, Y. Li, and W. Liu. 2024. Geomorphic understanding of loess landslides activity on the loess tableland: a case study in the Bailu Tableland, China. *Catena* 234:107641. <https://doi.org/10.1016/j.catena.2023.107641>
- Zhu, B., Z. Zhou, and Z. Li. 2021. Soil erosion and controls in the slope-gully system of the Loess Plateau of China: a review. *Frontiers in Environmental Science* 9, article 657030. <https://doi.org/10.3389/fenvs.2021.657030>
- Zhuang, J., J. Peng, G. Wang, I. Javed, Y. Wang, and W. Li. 2018. Distribution and characteristics of landslide in Loess Plateau: a case study in Shaanxi province. *Engineering Geology* 236:89–96. <https://doi.org/10.1016/j.enggeo.2017.03.001>