National Park Service
US Department of the Interior

Natural Resource Stewardship and Science

Arkansas Post National Memorial

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2013/731

ON THE COVER
View of Park Lake from the south shoreline within Arkansas Post National Memorial.

THIS PAGE
French Cross exhibit near the park visitor center. A cabin and large cross were erected at the post Henri de Tonti established as the "Poste de Arkansea" in 1686.

National Park Service photographs courtesy Ed Wood (Arkansas Post National Memorial).

Arkansas Post National Memorial

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National Park Service
Geologic Resources Division
PO Box 25287
Denver, CO 80225

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

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

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Printed copies of this report are produced in a limited quantity and they are only available as long as the supply lasts. This report is available from the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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Executive Summary

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service Inventory and Monitoring Program. The Geologic Resources Division held a Geologic Resources Inventory (GRI) scoping meeting for Arkansas Post National Memorial in New Jersey and Pennsylvania on 23 April 2007 and a follow-up conference call on 10 April 2013 to discuss geologic resources, the status of geologic mapping, and resource management issues and needs. This report synthesizes those discussions and is a companion document to the previously completed GRI digital geologic map data.

This Geologic Resources Inventory (GRI) report was written for resource managers to assist in resource management and science-based decision making, but it may also be useful for interpretation. The report was prepared using available geologic information. The Geologic Resources Division did not conduct any new fieldwork in association with this report. The report discusses distinctive geologic features and processes within Arkansas Post National Memorial, geologic issues facing resource managers at the memorial, and the geologic history leading to the memorial's present-day landscape. Geologic maps by the Arkansas Geological Survey (Ausbrooks and Prior 2009a, 2009b) are the source maps for the GRI digital geologic data of Arkansas Post National Memorial. A geologic map graphic (in pocket) illustrates these geologic data; the Map Unit Properties Table (in pocket) summarizes the main features, characteristics, and potential management issues for all the unconsolidated deposits on the digital geologic map for the memorial. This report also provides a glossary and a geologic time scale.

The Arkansas River is *the* story at Arkansas Post National Memorial. Flowing within the Mississippi River Alluvial Plain province, the river is responsible for the landscape that shaped more than 8,000 years of human history. In 1686, French entrepreneur Henri de Tonti established the first semi-permanent French settlement in the lower Mississippi River valley, "Poste de Arkansea", at the American Indian Quapaw village of Osotouy. The site then changed hands between France, Spain, and the newly independent United States of America for the next 150 years. It was of strategic importance during both the American Revolution and Civil War. As early as the 1920s, the historical significance of the site inspired protective measures to ensure that the story of the post was not lost to time or the river. After a short tenure as a state park, Arkansas Post National Memorial was formally established as part of the National Park System in 1960. The memorial now includes two units—the Memorial and Osotouy.

With the exception of the deeply buried Eocene (56 million–34 million years ago) Jackson Group (geologic map unit Tj), the geologic units in the memorial and surrounding area are young, unconsolidated, clays, silts, sands, and gravels associated with the Arkansas River fluvial system deposited atop a foundation of glacial outwash deposits from the Pleistocene (2.6 million to 11,700 years ago) ice ages. The Arkansas River has meandered back and forth across its floodplain for millennia, leaving a complex pattern of abandoned channels, natural levees, point bars, and backswamp deposits. Human activities left their mark on the landscape and are recorded in the geologic record (and on the geologic map; scale 1:24,000) as artificial fill in the form of American Indian mounds, flood control structures, and agricultural fill.

This location factored heavily in the region's human history because it is the first high ground encountered on banks of the Arkansas River upstream from its confluence with the Mississippi River. Coarser-grained, Pleistocene terrace deposits (Qt) underlie the high ground at both units of the memorial. Almost annually, torrential floods of the Arkansas River would inundate any low ground along its banks, making higher ground a necessity for successful settlement. This lesson was hard-learned and the post's location changed many times over its history in an attempt to escape inundation. In the 1960s, much of Arkansas Post's relief was submerged beneath the Arkansas River behind the Wilbur D. Mills Dam and Lock #2, muting the topography so critical to the early history of the post.

Geologic features of particular significance for resource management at Arkansas Post National Memorial include the following:

- Geologic Connections with Memorial Stories. Human history overlaps the geologic history of the memorial. The Arkansas River has long been a transportation corridor for settlement and commerce. The river brought opportunities and challenges to a long line of local inhabitants, from American Indians to modern residents of eastern Arkansas.
- Fluvial Features and Processes. The landforms in the memorial and surrounding area are the result of the flow of the Arkansas River across its floodplain for thousands of years. It is a classic example of an alluvial meandering river. Water flow, erosion, sediment transport and deposition, and channel migration are constantly changing the local landscape.
- Paleontological Resources. No fossils are known from within the memorial. Petrified wood, vertebrate fossils, and invertebrate fossils are present in Pleistocene deposits outside the memorial, signifying some

potential for similar discoveries within the memorial. Eocene marine mollusk fossils are present deep in the subsurface within the Jackson Group (Tj).

- Lacustrine Features. Park Lake in the Memorial Unit, and Lake Dumond in the Osotouy Unit are the two most prominent lacustrine features within the memorial. Park Lake is an artificial lake dating to the memorial's history as a state park. Lake Dumond is an abandoned meander or oxbow lake that is currently filling with silt.

During the 2007 GRI scoping meeting and a 2013 follow-up conference call, participants (see Appendix A) identified geologic issues of particular significance for resource management at Arkansas Post National Memorial. They include the following:

- Flooding and Fluvial Geomorphology. Because the Arkansas River system figures so prominently in the landscape and history of the memorial, issues associated with its flow are of high priority for resource management. Engineering structures have mitigated some flood and erosion threats, but flooding still occurs regularly within both units. The primary slope movements are falls, topples, slumps, and debris flows along disturbed areas associated with shorelines.
- Groundwater Quality and Quantity. The memorial's water supply comes directly from a shallow alluvial aquifer. This aquifer may be prone to contamination and degradation from local agricultural activities.
- Past Land Use. Disturbances on the landscape result from centuries of settlement, channel diversion, levee construction, grazing and agricultural practices, dredging, recreation, and military activities. All of these have links to geologic features and processes at the memorial.
- Economic Resource Development. Sand and gravel extraction, as well as exploration for and development of both coal-bed methane and natural gas occur outside of the memorial. These activities may create disturbed lands near the park and could affect park viewshed in the future.
- Seismicity. Although large earthquakes are unlikely to affect the memorial in the next century, the New Madrid Seismic Zone, which produced the most powerful earthquakes recorded in the contiguous United States (1811–1812), touches the state. Arkansas has a recorded history of seismic activity dating back to 1699. Geologists recently discovered faults buried beneath the unconsolidated fluvial sediments. Seismic shaking can be amplified in unconsolidated substrates, and liquefaction is a hazard in areas such as the memorial where these sediments are water-saturated. Regional sand blows provide a valuable record of Quaternary (2.6 million years ago to the present) seismicity.

Acknowledgements

The GRI is administered by the Geologic Resources Division of the Natural Resource Stewardship and Science Directorate.

The Geologic Resources Division relies on partnerships with institutions such as Colorado State University, the US Geological Survey, state geological surveys, local museums, and universities to develop GRI products.

Special thanks to Arkansas Post National Memorial superintendent Ed Wood and resource manager Kirby McCallie for providing photographs and answering many requests for information as the report came together. Scott Ausbrooks and Bill Prior of the Arkansas Geological Survey not only mapped the memorial but also provided substantial information and facilitated review by the survey's staff. Arkansas Geological Survey mapping was partially supported by GRI funds and we acknowledge Bekki White of the survey for her support. Thank you to the scoping participants (Appendix A).

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Introduction

This section briefly describes the National Park Service Geologic Resources Inventory Program and the regional geologic and historic setting of Arkansas Post National Memorial.

Geologic Resources Inventory Program

The Geologic Resources Inventory (GRI) is one of 12 baseline natural resource inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The NPS Geologic Resources Division of the Natural Resource Stewardship and Science Directorate administers the GRI.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (section 204), the 2006 NPS Management Policies, and in the Natural Resources Inventory and Monitoring Guideline (NPS-75). Refer to the "Additional References" section for links to these and other resource management documents.

The objectives of the GRI are to provide geologic map data and pertinent geologic information to support resource management and science-based decision making in more than 270 natural resource parks throughout the National Park System. To realize these objectives, the GRI team undertakes three tasks for each natural resource park: (1) conduct a scoping meeting and provide a scoping summary, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps, develop a geologic mapping plan, and discuss geologic issues, features, and processes that should be included in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan into digital geologic map data in accordance with their data model. Refer to the "Geologic Map Data" section for additional map information. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the geologic report. This geologic report assists park managers in the use of the map, and provides an overview of the park geology, including geologic resource management issues, geologic features and process, and the geologic history leading to the park's present-day landscape.

For additional information regarding the GRI, including contact information, please refer to the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/). The current status and projected completion dates for GRI products are available on the GRI status website (http://www.nature.nps.gov/geology/GRI_DB/Scoping/Quick_Status.aspx).

Memorial Setting

Arkansas Post National Memorial is approximately 60 km (38 mi) southeast of Pine Bluff and 11 km (6 mi) south of Gillett, in southeastern Arkansas (fig. 1). The memorial tells the stories of Arkansas Post, which was established in 1686 as the first semi-permanent settlement in the lower Mississippi River valley. The memorial also preserves Civil War trenches, American Indian mounds, and adjacent lands within two separate units—the Memorial (main) Unit (figs. 2, 3, and 4) and the Osotouy (Menard-Hodges) Unit (figs. 2 and 5), 8 km (5 mi) to the southeast. The memorial includes 307 ha (758 ac) of grasslands and upland terraces along the Arkansas River—a major tributary of the Mississippi River. The memorial is approximately 15 km (9 mi) upstream of the rivers' confluence.

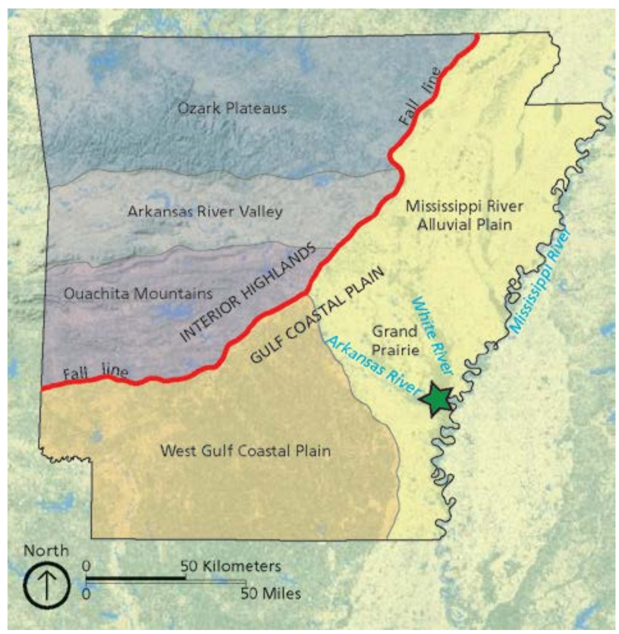


Figure 1. Physiographic provinces of Arkansas. Arkansas Post National Memorial (green star) is located within the Mississippi River Alluvial Plain province, which contains the youngest geologic units in the state. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using ESRI ArcMap basemap and information from the Arkansas Geological Survey (2012).

Interest in preserving the historical significance of Arkansas Post began in the 1920s when some 100 people still lived in the hamlet, within Arkansas County (Carrera 1976; Evans 2005). Over the next several decades, the State began development of a park at the site, culminating in the creation of Arkansas Post State Park in 1929 (Carrera 1976). Arkansas Congressman W. F. Norrell introduced the bill to establish Arkansas Post National Memorial on 26 March 1959; the bill was signed

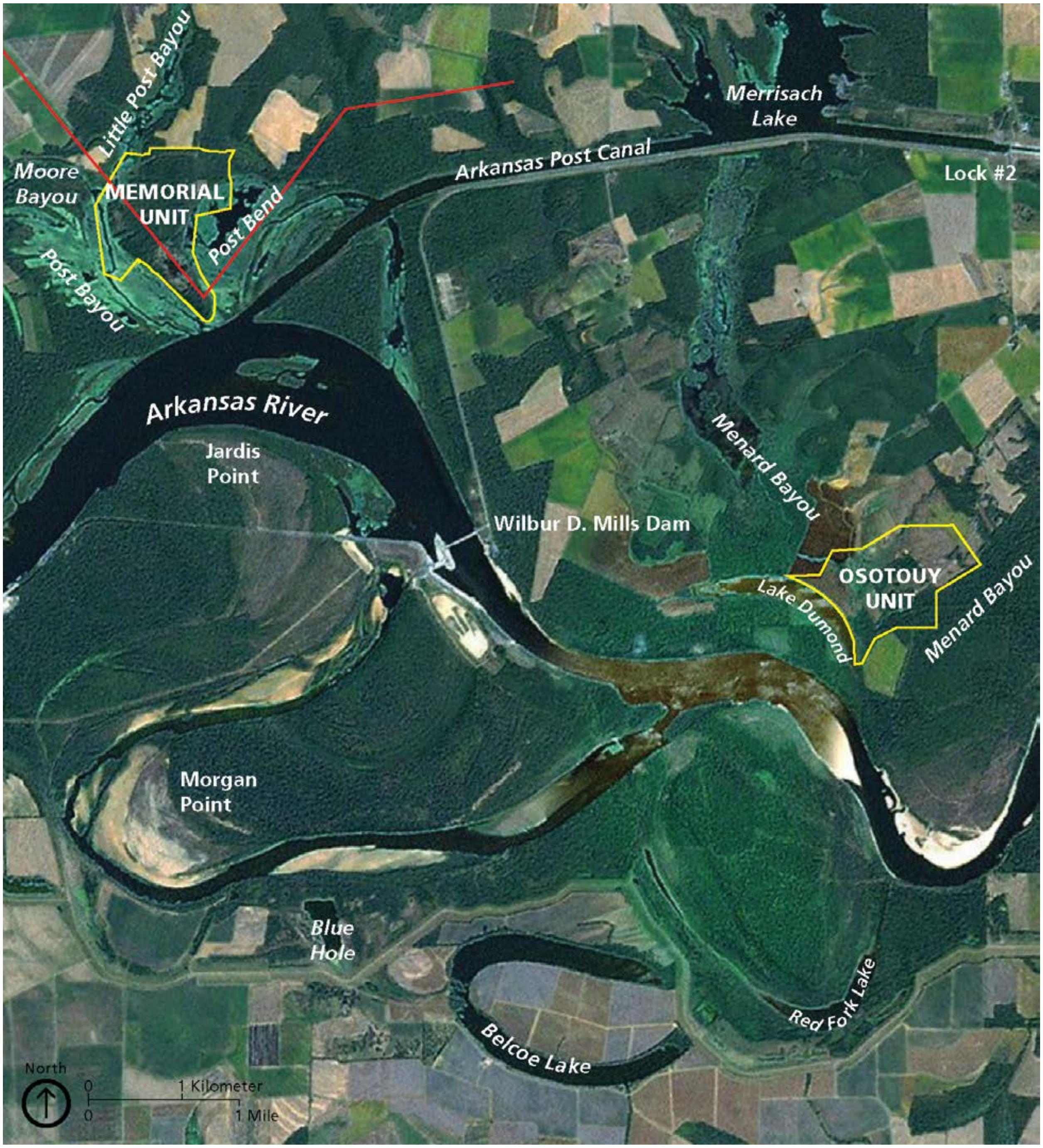


Figure 2. Memorial and Osotouy units of Arkansas Post National Memorial. Abandoned meanders are obvious as oxbow lakes and topographic differences, particularly around Morgan Point. Note the locations of Wilbur D. Mills Dam and Lock #2. Yellow lines mark the memorial boundaries. Red line is the trace of the cross section shown in figure 8. ESRI Bing Maps basemap with annotation by Trista L. Thornberry-Ehrlich (Colorado State University).

into law by President Eisenhower on 6 July 1960. Nearly 40,000 people visited Arkansas Post National Memorial in 2012.

The Memorial Unit is mostly an elevated plateau above the Arkansas River and flooded low-lying areas. It includes wooded areas, open lawns, an open prairie area, Park Lake, and infrastructure such as roads, trails, parking and picnic areas, and buildings (fig. 3; Evans 2005). The Osotouy Unit, adjacent to Lake Dumond, has undergone several boundary changes over the past several decades and currently includes approximately 160 ha (400 ac), of which 40–60 ha (100–150 ac) are part of the Wallace Bottoms—land that was cultivated until 2008. The unit is relatively low-lying with flat topography, typical of the area's floodplains. Only 30% of the unit is forested (primarily around the Menard Bayou and northern part of the unit) with the remaining 70% consisting of grasslands and perennially flooded lowlands in the northwestern corner (E. Wood and K.

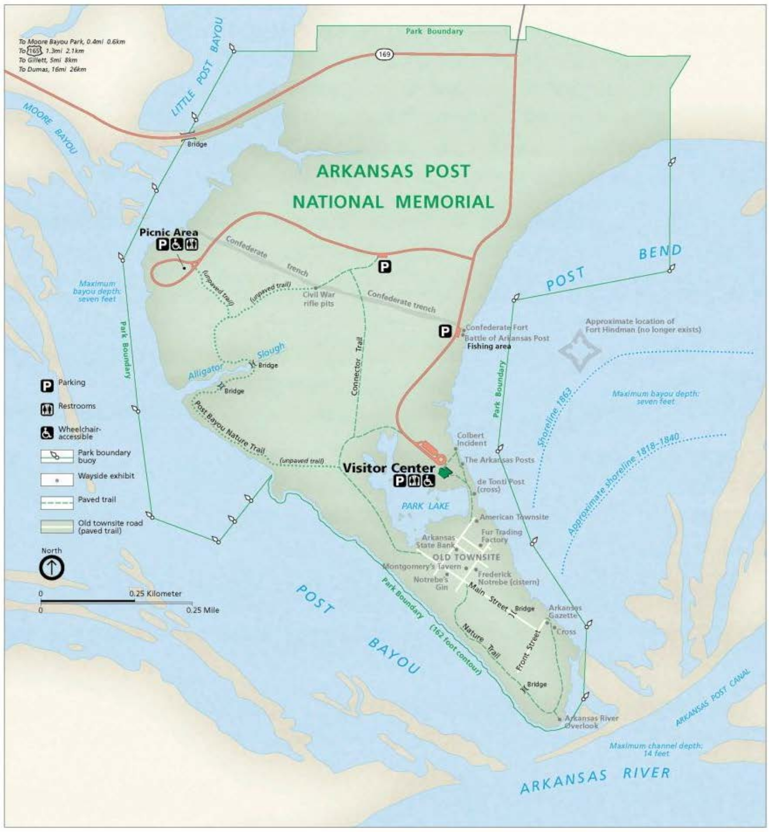


Figure 3. Location map for Arkansas Post National Memorial (Memorial Unit). Note the locations of previous shorelines (dashed blue lines), Fort Hindman (no longer exists) in Post Bend, the Confederate trend, Park Lake, Alligator Slough, and the Picnic Area. These locations are all relevant to resource management issues at the memorial. National Park Service graphic.

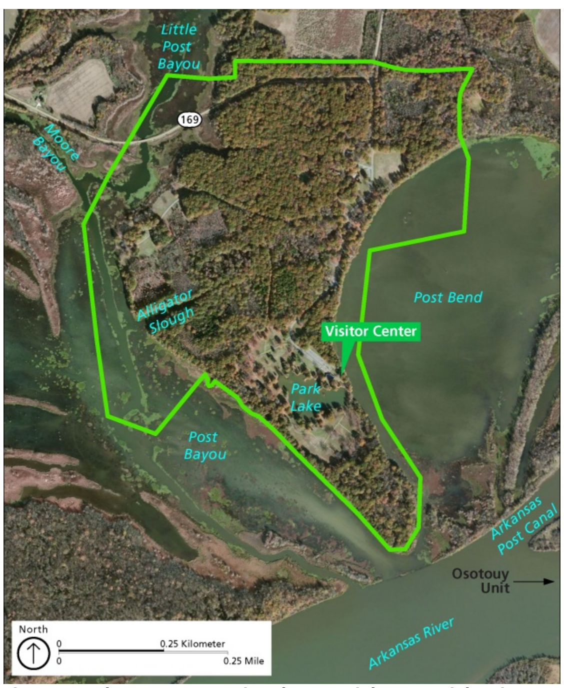


Figure 4. Arkansas Post National Memorial, Memorial Unit. Post Bayou and Post Bend are shallow. The original channel of the flooded Post Bayou is still visible. Upland areas of the memorial are forested and less prone to erosion. Note the locations of Park Lake; the flooded Post Bayou; and former Arkansas River channel, Post Bend. ESRI Bing Maps basemap with annotation by Trista L. Thornberry-Ehrlich (Colorado State University).

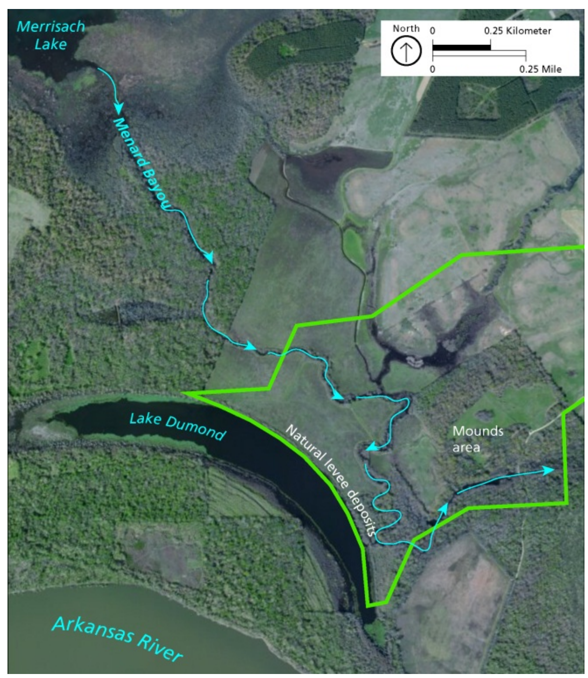


Figure 5. Arkansas Post National Memorial, Osotouy Unit. Most of the unit is undeveloped with the exception of the mounds area which is mowed. Note the location of Lake Dumond, a former meanderof the Arkansas River and the levee deposits that separate it from the Menard Bayou. Note the flow direction of the Menard Bayou (blue arrows). ESRI Bing Maps basemap with annotation by Trista L. Thornberry-Ehrlich (Colorado State University).

McCallie, superintendent and resource manager, Arkansas Post National Memorial, conference call, 10 April 2013).

Henri de Tonti established "Poste de Arkansea" in 1686 at the American Indian Quapaw village of Osotouy, solidifying France's claim to the Mississippi River, the most important waterway in North America (Coleman 1987). Over the next 150 years, the post played a role in the long struggle between France, Spain, England, and the United States for control of the Mississippi River valley. In 1783, the only Revolutionary War battle in Arkansas—the Colbert Raid—occurred at the post between Spanish soldiers and British partisans with their Chickasaw allies. Following the Louisiana Purchase of 1803, Arkansas Post was part of the United States. The Quapaws ceded the area surrounding the post to the federal government in 1818, and by 1819, it was a thriving river port and the largest city in the region. This prompted the naming of Arkansas Post as the first capital of the Arkansas Territory from 1819 to 1821 (Evans 2005).

The post also played a role in the American Civil War. The Confederate army attempted to maintain control of the confluence of the Arkansas and White rivers. In 1862, troops constructed the short-lived, massive earthen Fort Hindman to protect the approach to the upriver capital of Little Rock (Coleman 1987; McCutchen 2003). In January 1863, Union troops captured and destroyed the fort, removing another impediment to Union shipping on the Mississippi River (McCutchen 2003).

Geologic Setting

The geologic evolution of the Arkansas and Mississippi River valleys shaped the landscape that influenced the history at what is now Arkansas Post National Memorial.

Arkansas is divided into two primary physiographic regions: the Interior Highlands, which is underlain by ancient, erosion-resistant Paleozoic bedrock; and the Gulf Coastal Plain of young, unconsolidated sediments (e.g., clay, silt, sand, and gravel). The boundary between the two regions is called the "fall line"—a low, east-facing escarpment that parallels the Atlantic coastline from New Jersey to the Carolinas. It is an erosional scarp and the site of many waterfalls, which yielded flume- and waterwheel-powered industries in colonial times and thus helped determine the location of major cities such as Philadelphia, Baltimore, Washington DC, and Richmond (US Geological Survey 2000).

These two regions are further divided into five physiographic provinces based on bedrock geology and surficial geomorphology. The Interior Highlands includes the Ozark Plateaus, Arkansas River Valley, and Ouachita Mountains. The Gulf Coastal Plain includes the Mississippi River Alluvial Plain and West Gulf Coastal Plain (see fig. 1). Arkansas Post National Memorial is located within the unglaciated Mississippi River Alluvial Plain—a relatively level surface with elevations varying between 30 and 90 m (100 and 300 ft) above sea level (Arkansas Geological Survey 2012). The Arkansas River lowland (not far above sea level, also an area along a stream) forms a subdivision of the Mississippi Alluvial Valley, which is located between a low escarpment to the northeast (White River drainage divide) and another low divide to the southwest (Boeuf Basin) (Waterways Experiment Station 1951). The memorial lies at the far southeastern end of the Grand Prairie ridge or terrace—a broad plain between 3 and 6 km (2 and 4 mi) wide, lying between and 6 to 12 m (20 to 40 ft) higher than the courses of the Arkansas and White rivers.

The geologic foundation of Arkansas Post National Memorial is young, consisting of the Arkansas River floodplain that overlies older floodplain deposits (Waterways Experiment Station 1951). Only Quaternary-age (fig. 6), unconsolidated sedimentary units occur on the surface (figs. 7 and 8). At depths of more than 30 m (100 ft) below ground, the poorly consolidated Eocene-age Jackson Group (geologic map unit Tj) forms a wedge that is tilted (dips) slightly to the south. Mixed alluvial deposits from modern and older streams overlie the Jackson Group (Ausbrooks and Prior 2009a, 2009b; Arkansas Geological Survey 2012). For example, braided stream lower deposits (Qbsl) and terrace deposits (Qt) were deposited during the colder climates of the Pleistocene ice ages. At that time, massive amounts of Earth's water were locked up in continental ice caps. As a result, global sea level was hundreds of feet lower than today. Coarse glacial deposits washed down large rivers, and terraces (now perched above the modern rivers) developed along the flanks of ancient river courses (Ausbrooks and Prior 2009a, 2009b). The memorial is partly located on terrace deposits (Qt) approximately 3 to 8 m (10 to 25 ft) above the Arkansas River's lowlands.

Following the most recent glacial retreat at the beginning of the Holocene Epoch, sea levels rose as ice caps melted, decreasing stream gradients. The decreased gradient reduced the amount of material that could be transported by rivers, and finer grained material began to be deposited. Throughout the Holocene, the region's rivers meandered across the landscape leaving a complex pattern of overbank deposits such as levees and backswamps (Qsonl, Qsobs, and Qso) and channel meander deposits (Qcm, Qcmpb, and Qcmac) (Ausbrooks and Prior 2009a, 2009b). Natural levees (Osonl) occasionally diverted flow to new, distributary courses. As meanders become too sinuous, the river forged a new, straighter channel leaving the former channel abandoned as an oxbow lake (e.g., Lake Dumond at the Osotouy Unit). Oxbow lakes, shallow sloughs and bayous, gentle swells, flat floodplains, and sloping bluffs characterize the landscape at the memorial.

The youngest geologic units in the area are the lens-shaped, small stream deposits (Qalss) collecting today in drainages such as Menard Bayou at the Osotouy Unit (Ausbrooks and Prior 2009a, 2009b). Windblown silt (loess), paleosols (old, buried soils), and modern soils do not appear on the digital geologic map but are also locally present (Markewich 1993).

Anthropogenic modifications left a lasting legacy on the landscape in the Arkansas Post National Memorial area. Three artificial fill units—agricultural (Qafa), engineered/flood control/navigation (Qafe), and Native-American (Indian Mound) (Qafn)—are large enough to be mapped at 1:24,000 scale (Ausbrooks and Prior 2009a, 2009b).

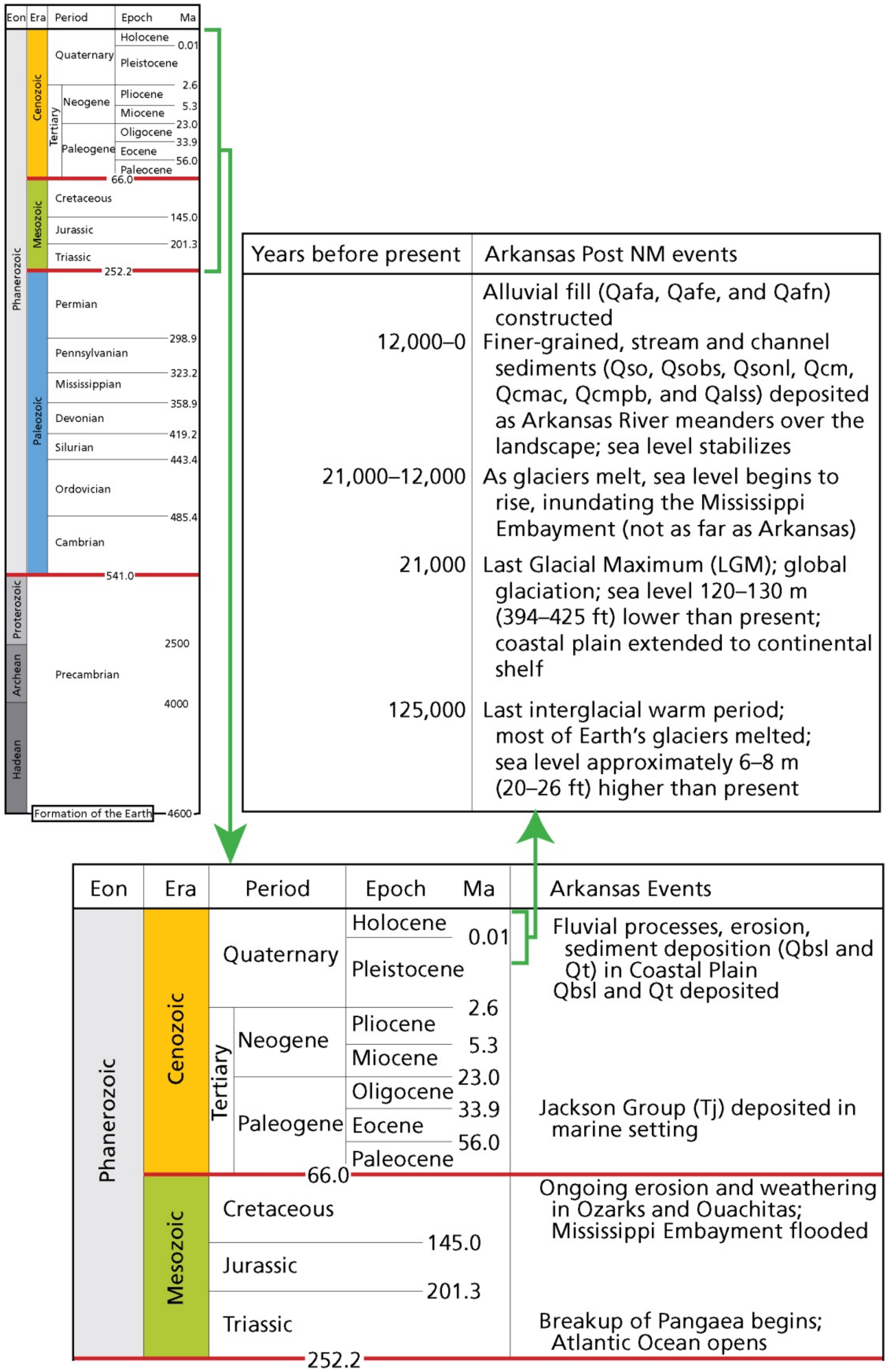
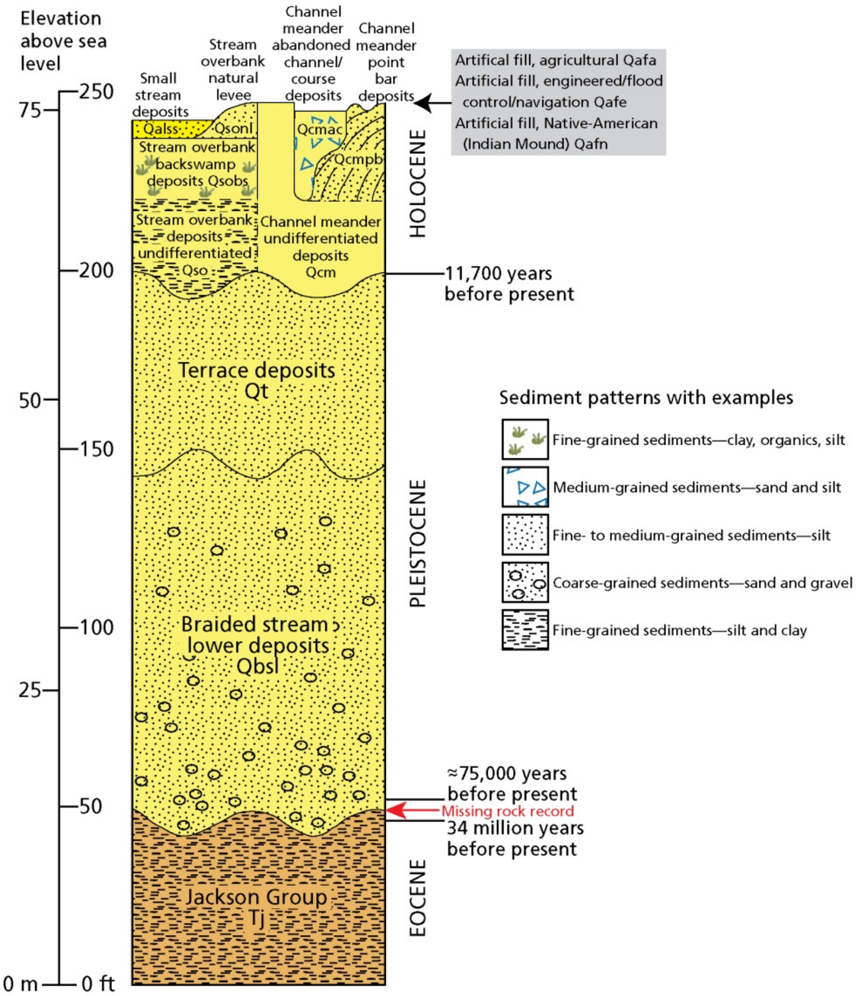


Figure 6. Geologic time scale. Geologic time and events included are limited to those most relevant to Arkansas Post National Memorial. The divisions of the geologic time scale are organized stratigraphically, with the oldest at the bottom and youngest at the top. Boundary ages are in millions of years (Ma). Red lines indicate major boundaries between eras. Graphic design by Trista Thornberry-Ehrlich (Colorado State University), using dates from the International Commission on Stratigraphy (http://www.stratigraphy.org/index.php/ics-chart-timescale).



** Age numbers indicate the time spanned by associated epoch or period. Rock/sediment units associated with those epochs or periods may not encompass the entire age range.*

Figure 7. General stratigraphic column for Arkansas Post National Memorial and adjacent areas. The Jackson Group (Tj) and braided stream lower deposits (Qbsl) are mapped in the subsurface of the memorial. Other units occur at the surface. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps; they also correspond to the colors on the Map Unit Properties Table (in pocket). Graphic by Trista L. Thornberry-Ehrlich after column presented in Ausbrooks and Prior (2009a, 2009b) with information from McFarland (2004) and geologists from the Arkansas Geological Survey, written communication (23 September 2012).

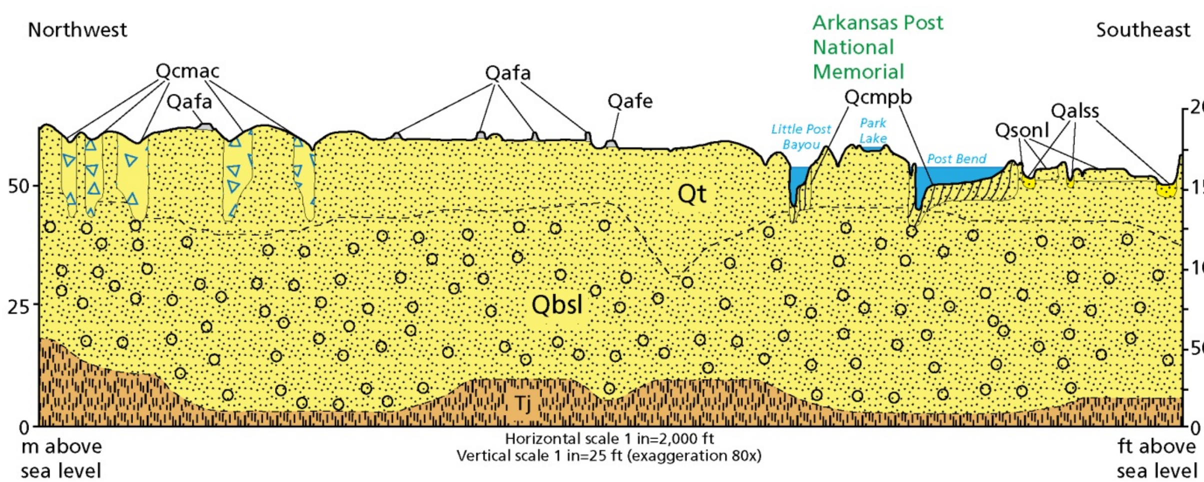


Figure 8. Geologic cross section through Arkansas Post National Memorial and adjacent areas. The red line on figure 2 marks the location of this cross section. Qafa=artificial fill, agricultural; Qafe=artificial fill, engineered/flood control/navigation; Qcmac=channel meander abandoned channel/course deposits; Qt=terrace deposits; Qcmpb=channel meander point bar deposits; Qsonl=stream overbank natural levee; Qalss=Small stream deposits; Qbsl=braided stream lower deposits; and Tj=Jackson Group. Cross section redrafted and modified by Trista L. Thornberry-Ehrlich (Colorado State University), after Ausbrooks and Prior (2009a, cross section A–A').

Geologic Features and Processes

Geologic resources underlie park ecosystems and geologic processes shape the landscape of every park. This section describes the most prominent and distinctive geologic features and processes in Arkansas Post National Memorial.

During the 2007 scoping meeting and 2013 conference call, participants (see Appendix A) identified the following geologic features and processes:

- Geologic Connections with Memorial Stories
- Fluvial Features and Processes
- Paleontological Resources
- Lacustrine Features

Geologic Connections with Memorial Stories

Because the geologic units present in the memorial and surrounding area are so young, their history overlaps human history. Likewise the sciences of geology and archeology overlap. Archeological investigations often provide reliable ages for geologic landforms, and geologic studies support archeological efforts by showing how human settlement and land-use patterns have changed with the physical environment over time and space (Saucier 1994).

The story of the Arkansas River, which has long been a major transportation corridor for settlement and commerce, is *the* story of Arkansas Post (Carrera 1986; Coleman 1987; Evans 2005). The Arkansas River is the sixth longest river in the United States. From its headwaters along the Continental Divide in the Rocky Mountains near Leadville, Colorado, it flows southeast 2,364 km (1,469 mi) across Colorado, Kansas, Oklahoma, and Arkansas to its confluence with the Mississippi River 15 km (9 mi) southeast of the memorial. From there, the Mississippi River flows a "10-days journey" to the Gulf of Mexico (Coleman 1987). Throughout its long history, the ever-changing, land-to-water-to-land relationship of the river has characterized Arkansas Post National Memorial (Evans 2005).

American Indian History

The Arkansas, White, and Mississippi rivers have been major trade routes for thousands of years. Local archeological sites date back to at least 10,000 years before present (Dalton or Archaic through late Mississippian and early Quapaw periods). The sites include the first-recorded cemetery in the Americas and provide invaluable chronologic markers for geologic study (Saucier 1994; Evans 2005). These first inhabitants grew crops in the fertile floodplains of the Arkansas River and used local clays for pottery (Evans 2005). Flint for tools was among the early trade items. The unconsolidated surficial deposits made excellent material for Hopewellian burial mounds, flat-topped platform mounds, and wattle and daub houses (Evans 2005; see Thornberry-Ehrlich 2013 for a GRI report of Hopewell Culture NHP). Mounds at the Osotouy Unit are large enough to be mapped as artificial fill (Qafn) and were constructed during the Mississippian (pre-Quapaw) time period (Evans 2005; Ausbrooks and Prior 2009a, 2009b). The site includes two large mounds and several house mounds. Early excavations uncovered graves; a Hardin point found at the site dates to approximately 8,000 years ago, helping to establish the timing of occupation (Arkansas Archeological Survey 2007; E. Wood and K. McCallie, superintendent and resource manager, Arkansas Post National Memorial, conference call, 10 April 2013).

Early European Presence

In the 1670s, a French expedition led by a Jesuit missionary Jacques Marquette and a fur trader Louis Joliet fostered dreams of an all-water route between the Great Lakes and the Gulf of Mexico (Coleman 1987). Recognizing the strategic importance of the location, in 1686 Henri de Tonti—an Italian-born soldier, explorer, and fur trader in the service of France—established the first semi-permanent French settlement in the lower Mississippi River valley. The settlement, called the "Poste de Arkansea" was "half a musket shot" from the American Indian Quapaw village of Osotouy (Carrera 1986; Coleman 1987; Arkansas Archeological Survey 2007). Early in its history, Arkansas Post was a point of supply for trappers and traders bound for the upper Arkansas through numerous American Indian nations and into Spanish territory. Throughout the 1700s additional settlements at Ecores Rouge, Osotouy (Lake Dumond), and Fort Desha were established, and later abandoned, on bluffs above the Arkansas River (Coleman 1987; Arkansas Archeological Survey 2007). Poor weather, flooding, and near-constant changes to the river course doomed many of these settlements, including an attempt in the 1750s to establish a post closer to the Mississippi River—it almost immediately flooded (Coleman 1987; E. Wood and K. McCallie, conference call, 10 April 2013).

Successful settlement required a high-ground refuge from the river's constant migration. Arkansas Post is located on fluvial terrace deposits (Qt), which tend to be slightly more coarse grained than floodplain deposits. These deposits compose bluffs along the Arkansas River near the post (Ausbrooks and Prior 2009a, 2009b). At about 3 to 8 m (10 to 25 ft) above the river, the post's location was the first natural high ground encountered when ascending the Arkansas River from its confluence with the Mississippi River (Evans 2005). Although it was on relatively high ground, it was not immune to flooding, however. Nearly annual torrential floods inundated lands within 50 km (30 mi) of the river's mouth. At other times, the river was nearly dry (Carrera 1986). To attempt to escape the omnipresent threat of destruction, flood-weary inhabitants of Arkansas Post changed location at least five times, and possibly as many as 10 times, before 1779 (Carrera 1976; Coleman 1987; Evans 2005; Arkansas Archeological Society 2007).

Although destructive to settlements, floods renew nutrients and over time build up natural levees (Ausbrooks and Prior 2009a, 2009b). Fertile overbank deposits (Qsonl and Qsobs) were cultivated for cotton (Coleman 1987). During the middle 1800s, Arkansas Post was a major river port for steamboats transporting cotton (Coleman 1987). The unconsolidated deposits were also used as building materials for the French bousillage technique (timber frame with earth and clay fill) and clay or mud fireplaces. The excavation of building materials created trenches which would later serve as defensive structures (Waterways Experiment Station 1951; Evans 2005).

During the early 1800s, the river occupied a different channel than it does today (see figs. 3 and 9 and Geologic History section). River channel migration, bluff erosion, and gullying were nearly constant sources of problems for the various groups tenured at Arkansas Post. In just the 40 years between 1779 and 1820, the river migrated between 120 and 270 m (400 and 900 ft) northwest (Evans 2005).

Arkansas Post and Warfare

The relative high ground afforded to Arkansas Post by the river terraces and natural levees made it strategically important. Its location near the junction of the Arkansas and Mississippi rivers also meant the site was in high demand from both sides of conflicts. Prior to the American Revolution, the site experienced skirmishes among American Indians. The Colbert Raid—the only Revolutionary War battle in Arkansas—was fought at Arkansas Post in 1783. The raid may have been the last battle of the Revolutionary War (Coleman 1987). Fort San Carlos III (built by the Spanish as one of the post's first forts) was attacked by allied British and Chickasaw forces during the raid. Eroded ravines adjacent to the fort provided cover for the attacking forces, allowing them to approach within 40 to 50 m (40 to 50 yds) without being detected. The ravines also protected the attackers from Spanish canon fire (Coleman 1987). This fort washed away into the Arkansas River by 1790 following several high flows. In 1791–1792, a replacement fort, Fort San Esteban (renamed Fort Madison), was established downriver as much as 60 to 90 m (200 to 300 ft) from the banks of the river (Coleman 1987; Evans 2005). Fort Madison washed into the river by the 1820s or 1830s (Evans 2005).

During the Civil War, the Confederate Army feared a Union invasion of Arkansas and its capital, Little Rock, via the Arkansas River valley. Troops built Fort Hindman at Arkansas Post in 1862 atop bluffs 8 m (25 ft) above the river, affording a commanding view for more than a mile downstream (McCutchen 2003; Evans 2005). The fort was located between what Union witnesses described as two "very deep" and "impassable" eroded gullies or ravines (Evans 2005). Wooden pilings planted in the southern side of the river channel ensured any passing ships would be forced within range of Fort Hindman's cannons (Bearss and Brown 1971; Coleman 1987; Evans 2005). Marshy lowlands in the riparian zone prevented a large-scale, land-based assault (Coleman 1987). Despite these defenses, at approximately 210 m (690 ft) wide, the Arkansas River proved narrow enough for Union artillery across the river atop a series of point bars to shell the fort in January 1863. The river was also deep enough to permit Union ironclads to come upriver and shell the fort. The battle resulted in a costly but relatively rapid Confederate surrender and the destruction of the fort (fig. 9) (Coleman 1987; McCutchen 2003).

Post-Civil War Recovery

After the American Civil War ended in 1865, the local inhabitants were poor and their properties were devastated. In addition, natural resources for rebuilding were strapped. Nevertheless another community was constructed atop the bluffs (Evans 2005). However, the post's utility as a river port for the cotton trade suffered when the railroad arrived, and river trade effectively ceased in the early 1900s when the Arkansas River changed course from 1903 to 1912, meandering away from the port between 0.8 and 1.2 km (0.5 and 0.75 mi) to the east (Coleman 1987; Evans 2005). At that time, Post Bayou's course changed as well (fig. 3). For more than 130 years, the bayou emptied into the river several hundred meters south of the southeastern tip of the Grand Prairie bluffs between the Arkansas and White rivers. However, once the Arkansas River changed course, the bayou turned northward at the site of its former confluence and followed an old channel of the river to a confluence east of the Arkansas Post, where, today, it is inundated as Post Bend (Evans 2005). By the time the area was being considered for preservation in the 1920s, only 100 or so inhabitants clustered in the settlement, which consisted of farms, residences, and several stores (Evans 2005). The Great Depression left the historic area largely abandoned.

Over time, the small family farms were abandoned or consolidated into large agricultural endeavors. This style of agriculture continues today with rice fields throughout the area. This crop requires controlled flooding. Alluvial aquifers are the water source (E. Wood and K. McCallie, conference call, 10 April 2013). Controlled flooding was not possible along the Arkansas River for most of its history. In the 1960s and beyond, the Army Corps of Engineers (ACOE) sought to give the river system some stability with myriad engineering structures described in the "Flooding and River Control Structures" section. Creating stability involved raising the local river level. As a result, the relief and prominence of the historic bluffs at Arkansas Post were greatly lessened. However, the smaller bluffs still provide a distinct visual and physical, water-to-land edge (Evans 2005).

Figure 9. Battle of Arkansas Post. Positions superimposed over modern memorial map. Note the location of the Civil War era Arkansas River. At this time, the river was narrow enough to allow Union forces to shell Fort Hindman from the opposite bank. The river was also deep enough to permit the passage of Union ironclad ships. The modern Post Bend is a remnant of the mid-19th century Arkansas River channel. National Park Service graphic prepared by McCutchen (2003).

Fluvial Features and Processes

Virtually all landforms in the Arkansas Post area result from variations in the energy of the Arkansas River's flow and the quantity and physical characteristics of sediments derived from surrounding areas (Saucier 1994). Fluvial processes both construct (deposit) and erode landforms. Meandering river channels, oxbow lakes, point bars, natural levees, and backswamp deposits are the primary fluvial features within and near the memorial. Today, the river banks near Arkansas Post are heavily modified by ACOE river control structures.

Meandering River Channels

The characteristic meandering channels of the Arkansas River are a result of an exceptionally low gradient (slow flow) and high sediment load. Below Little Rock, the Arkansas River enters the alluvial valley of the Mississippi River and flows for 286 km (178 mi) with an average gradient of just 0.1 m/km (0.6 ft/mi). The river's low channel gradient reduces its sediment-carrying capacity, resulting in rapid sedimentation. The lower Arkansas transports many million tons of suspended material each year (Waterways Experiment Station 1951). The sediments characteristic of fluvial meandering present within and surrounding the memorial are described in detail in the Map Unit Properties Table (in pocket).

The Arkansas River forms a series of fairly uniform S-shaped curves that define a classic alluvial meander pattern. Nearly all stages of the pattern's development are visible in the lower Arkansas River valley (Waterways Experiment Station 1951). Because sedimentation rates are highest near an active channel, an alluvial ridge develops in the meander belt at a higher elevation than the adjacent floodplain (Saucier 1994). This elevated topography diverts the river's flow laterally, causing the channel to broaden, shallow, and meander.

As a river flows through its channel, around curves, the flow velocity (and thus erosive energy) is greatest on the outside of the bend (see "Point Bars" section). The river erodes into its bank on the outside of a curve and leaves point bar deposits on the inside of the bend. As the process continues, the outside bend retreats farther, while the inside bend migrates laterally, thus creating migrating meanders.

Oxbow Lakes

As meander bends migrate, the "neck" of land between two bends narrows (fig. 10, panel A). Eventually the neck may be cut through and the meander is abandoned by the stream (fig. 10). Abandoned meanders (Qcmac), commonly known as "oxbows," are prominent features on the regional landscape (Ausbrooks and Prior 2009a, 2009b). Water may periodically flow through the abandoned meander during floods or particularly high flow events. The oxbows hold water as ponds and lakes (e.g., Lake Dumond at the Osotouy Unit), but over time will fill in with very fine-grained sediment, often clay. Such "clay plugs" may be slightly more resistant to erosion than surrounding sediments, slowing channel migration (Waterways Experiment Station 1951).

Point Bars

Point bars (Qcmpb) are crescent-shaped ridges of sand, silt, and clay deposited on the inside of meander loops where the water's velocity is slowest (Waterways Experiment Station 1951; Ausbrooks and Prior 2009a, 2009b). A point bar's shape conforms to the curvature of the source channel, but bars may truncate each other forming a complex pattern as meandering continues (Waterways Experiment Station 1951). As a meander migrates, successive point bars build up laterally and may reach heights as much as 3 m (10 ft) above mean low water levels. The curved, sand- and silt-cored ridges are separated by low, clay- and silt-rich swales. The alternating ridges and swales, sometimes referred to as scroll-bar sequences, define classic point–bar accretionary topography (Waterways Experiment Station 1951; Saucier 1994). This topography is particularly well developed near the Memorial Unit and is easily visible in aerial imagery (see figs. 2 and 4).

Natural Levees

During high flows or floods, a river deposits natural levees (Qsonl) of sand and silt along its banks. These deposits represent the relatively coarse-grained component of a river's suspended sediment load and often form the highest areas of an alluvial region's land surface. Natural levees also create fertile farmland. For these reasons, they have been the most significant landforms in human-settlement patterns, influencing building locations, transportation routes, agriculture, and industry development (Saucier 1994).

The width of a natural levee is proportional to the size (volume) of the river responsible for its formation; the height of a natural levee is an indicator of the difference in water levels between normal flow and flood stage. Both dimensions increase as a function of age (Saucier 1994). In the lower Arkansas River, the thickest natural levees are approximately 5 m (15 ft) high with the coarsest sedimentary components at their crests grading landward into finer grained, backwater deposits (Waterways Experiment Station 1951; Ausbrooks and Prior 2009a, 2009b). They typically are largest on the outside of bends (Waterways Experiment Station 1951).

The modern Arkansas River channel lacks significant, flanking natural levees (Qsonl). This may be because it had not occupied its current position long enough to build up large levees prior to the installation of artificial levees (Qafe) (Waterways Experiment Station 1951).

Backswamp Deposits

Backswamps are low-lying areas that retain water during floods or high flow. They are separated from the river channel by natural levees (Qsonl) (Waterways Experiment Station 1951; Ausbrooks and Prior 2009a, 2009b). Low relief and dense vegetation characterize a backswamp. The relatively slack floodwaters lay down layers of (fine-grained) clays and organic material (Waterways Experiment Station 1951).

Paleontological Resources

Fossils have not yet been documented within Arkansas Post National Memorial. The young geologic units and rare outcrops preclude the possibility for significant amounts of paleontological resources. Nevertheless, fossils are occasionally discovered in the surrounding area. For instance, along the White River near Crocketts Bluff, 40 km (24 mi) north of the memorial, members of a hunting club discovered a Pleistocene bone bed during a period of very low water (fig. 11; Thornberry-Ehrlich 2007; S. Ausbrooks and B. Prior, geologists, Arkansas Geological Survey, conference call, 10 April 2013). Other local Pleistocene units contain petrified wood,

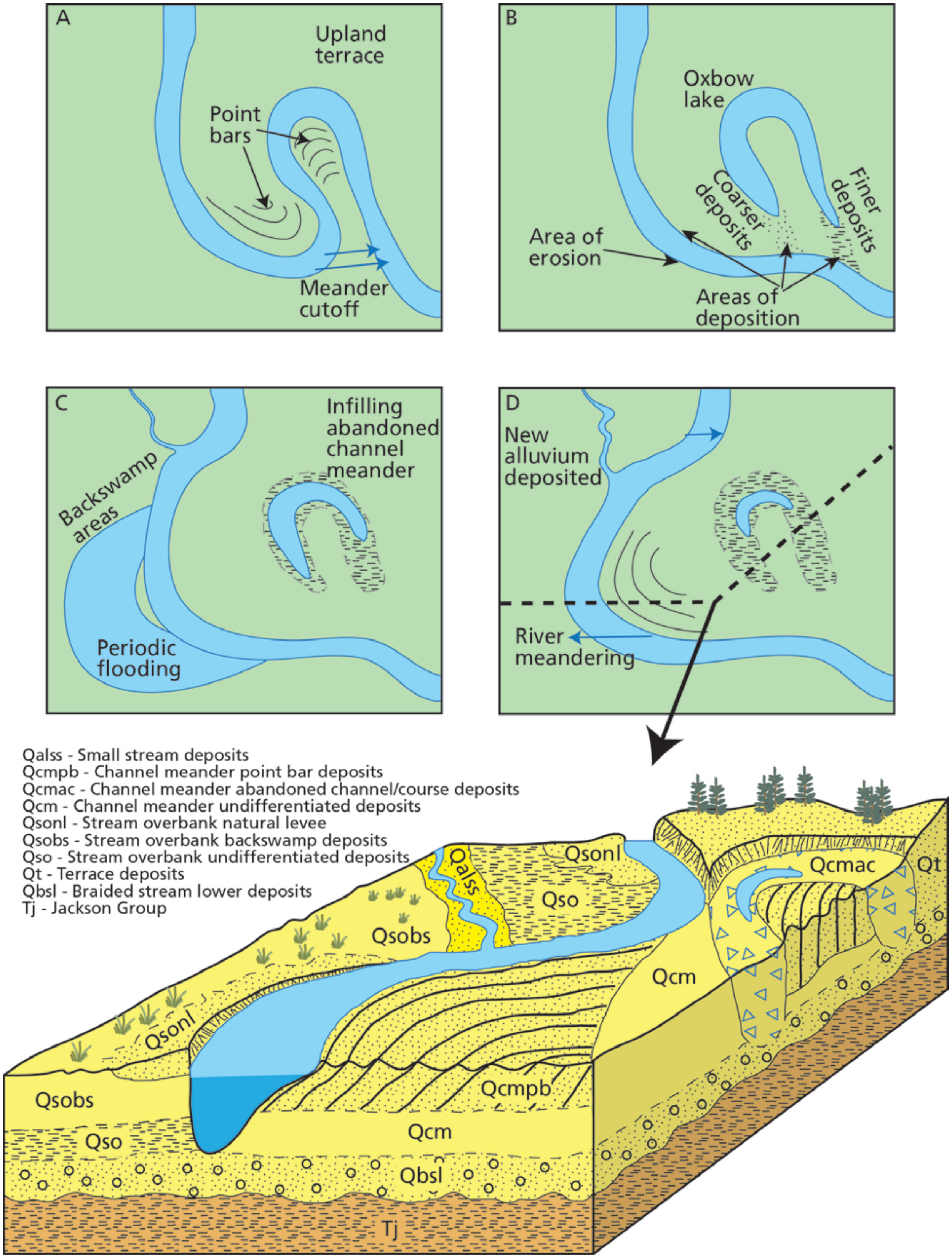


Figure 10. Fluvial evolution of the lower Arkansas River. River meandering causes the formation of abandoned channels that infill with fine-grained sediments. Dashed line on panel D indicates location of the block diagram. Graphic by Trista Thornberry-Ehrlich (Colorado State University) with information from Ausbrooks and Prior (2009a, 2009b) and Allen (1964).

invertebrate fossils, and vertebrate fossils (Hunt et al. 2008). Pleistocene terrace deposits (Qt) within both units of the memorial have the potential to yield fossils, particularly at low river levels or in disturbed areas where older sedimentary layers are exposed (Thornberry-Ehrlich 2007; S. Ausbrooks and B. Prior, conference call, 10 April 2013). Because the Wilbur D. Mills Dam and Lock #2 regulate river levels, they are not likely to be low enough to expose fossils within the Memorial Unit. However, the Osotouy Unit is downstream from the dam, so water levels may fluctuate more at this unit, exposing potential fossil discoveries. "Loess dolls" or concretions discovered along the Arkansas Post Canal between the Memorial and Osotouy units may be mineralized plant roots (S. Ausbrooks and B. Prior, conference call, 10 April 2013).

Although archeological resources are the primary resource, fossil potential may influence future boundary expansions and preservation efforts (Thornberry-Ehrlich 2007; E. Wood and K. McCallie, conference call, 10 April 2013). All paleontological resources are non-renewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act. Regulations associated with the Act are still (September 2013) being developed. Santucci et al. (2009)—the paleontological resources chapter in *Geological Monitoring*—described five methods and vital signs for monitoring in situ paleontological resources: (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use.

Lacustrine Features

Post Bayou, Post Bend, and Little Post Bayou surround the Memorial Unit (see figs. 2, 3, and 4). These are abandoned Arkansas River channels. The Memorial Unit also contains a 4-ha (9-ac) artificial lake, Park Lake (see cover). The lake formed by damming ravines in the 1930s (Evans 2005). Lake Dumond is an oxbow lake within the Osotouy Unit.

According to Evans (2005), overuse of shoreline areas at Lake Dumond and Park Lake causes soil compaction and erosion, which are management concerns.

Figure 11. Fossil display. A selection of fossils discovered from local river sands on display in the memorial visitor center. These primarily vertebrate fossils are primarily Pleistocene in age. Similar fossils are not known from the memorial. National Park Service photograph by Ed Wood (Arkansas Post National Memorial).

Geologic Issues

Geologic issues described in this section may impact park resources or visitor safety and could require attention from resource managers. Contact the Geologic Resources Division for technical or policy assistance.

During the 2007 scoping meeting and 2013 conference call, participants (see Appendix A) identified the following geologic resource management issues:

- Flooding and Fluvial Geomorphology
- Groundwater Quality and Quantity
- Past Land Use
- Economic Resource Development
- Seismicity

Resource managers may find *Geological Monitoring* (Young and Norby 2009; http://go.nps.gov/geomonitoring) useful for addressing these geologic resource management issues. The manual provides guidance for monitoring vital signs—measurable parameters of the overall condition of natural resources. Each chapter covers a different geologic resource and includes detailed recommendations for resource managers and suggested methods of monitoring.

Flooding and Fluvial Geomorphology

The fluvial system of the Arkansas River dominates the landscape within and surrounding Arkansas Post National Memorial. Flooding, erosion, dredging, and sedimentation are important resource management issues. The Memorial Unit is located on terrace deposits (geologic map unit Qt) that provide high ground northwest of the main channel of the Arkansas River. Post Bend, Post Bayou, and Little Post Bayou surround the Memorial Unit on three sides. The bayous are abandoned channels of the Arkansas River. The 49 m (162 ft) elevation (above sea level) contour line is designated as the memorial boundary.

Flooding and River Control Structures

Nearly 1,600,000 ha (4,000,000 ac) of the lower Arkansas River basin is subject to flooding by the Arkansas, White, and/or Mississippi rivers. The Arkansas and White rivers experience water-flow exchange during high flows. When the Arkansas River is high, some of its flow goes into the White River, above the confluence, and vice versa.

Because three major rivers could inundate the area singly or in combination, the memorial area experienced frequent major floods prior to the construction of Army Corps of Engineers (ACOE) river control structures (Waterways Experiment Station 1951). At least five large floods occurred between 1833 and 1872. From 1872 to 1950, 13 major floods took place (Waterways Experiment Station 1951). The 1927 flood was particularly devastating, inundating the entire Arkansas Post site, and destroying or damaging much of the post-Civil War community (Coleman 1987; Evans 2005).

To promote river navigation, mitigate flooding, and maintain the current channel location, the ACOE constructed extensive levees, canals, locks, and dams throughout the Arkansas and Mississippi river valleys during the middle 20th century. Engineered artificial fill (Qafe) is so extensive that it appears on 1:24,000-scale data (Ausbrooks and Prior 2009a, 2009b). Artificial levees were constructed along both sides of the river as far north as Little Rock, more than 120 km (75 mi) northwest of Arkansas Post, which itself is 27 km (17 mi) northwest of the Arkansas and Mississippi river confluence. The Arkansas Post Canal passes Arkansas Post and is part of the ACOE McClellan-Kerr Arkansas River Navigation System connecting Tulsa to the Mississippi River along the Arkansas River. The Wilbur D. Mills Dam—visible from an overlook on the memorial's nature trail—is located on the Arkansas River between the two units of the memorial (see fig. 2). Lock #2 is located on the Arkansas Post Canal between the Arkansas and White rivers. As part of the Mills dam and lock project, the ACOE constructed a stone revetment (riprap) between elevations 49 and 50 m (160 and 165 ft) within Arkansas Post National Memorial, along the peninsula's shoreline (fig. 12; Carrera 1976; Evans 2005; E. Wood and K. McCallie, superintendent and resource manager, Arkansas Post National Memorial, conference call, 10 April 2013). A levee system was proposed but rejected due to its impact on the historical integrity of the site (Evans 2005).

The reversal of flow between the Arkansas and White rivers can cause severe erosion along the exchange channel (E. Wood and K. McCallie, conference call, 10 April 2013). To facilitate the flow exchange without eroding the landscape, the ACOE installed a permanent exchange channel downriver from the Memorial Unit. However, erosion impacts and temporary flooding from the exchange are still experienced upriver (E. Wood and K. McCallie, conference call, 10 April 2013). The engineered structure has suffered damage in recent years and the ACOE is installing riprap along the shorelines to maintain the status quo. Stabilization of the area may not be possible (E. Wood and K. McCallie, conference call, 10 April 2013).

The engineered structures artificially raised the base river level to 49 m (162 ft) above sea level, flooding lower elevations. Low-lying areas adjacent to the river such as Post Bayou and Post Bend are now approximately 2 m (7 ft) deep (navigable for shallow-draft boats). The memorial map shows locations of Arkansas River

Figure 12. Revetment along shoreline near the memorial's visitor center. The revetment was installed by the Army Corps of Engineers as part of the Wilbur D. Mills Dam project. National Park Service photograph by Ed Wood (Arkansas Post National Memorial).

shorelines in 1818–1840 and 1863, and Evans (2005) presented channel locations through 1963, but the memorial's archive does not have a photograph of the landscape immediately before the completion of Wilbur D. Mills Dam and Lock #2 in 1967 for reference (E. Wood and K. McCallie, conference call, 10 April 2013). Significantly, the construction of the Mills dam inundated the 8-m- (25-ft-) high bluffs crucial to the original location and history of Arkansas Post (Evans 2005). The western bank of Post Bend approximates the river's pre-1912 shoreline (Evans 2005).

Without the 8 m (25 ft) bluffs that historically provided some flood protection, a rise of less than 1 m (2 ft) behind the Mills dam will now inundate the lowest areas of the memorial, including the picnic area. Flooding has occurred twice in the past 15 years (E. Wood and K. McCallie, written communication, 29 July 2013). Such rises occur during peak flow when the ACOE restricts Arkansas River flow to limit flooding on the Mississippi River. At the memorial's picnic area in the Memorial Unit, a 2 to 3 m (6 to 8 ft) high metal seawall structure attempts to mitigate flooding and shoreline loss (E. Wood and K. McCallie, conference call, 10 April 2013).

As climate continues to change, precipitation patterns will also change and storm intensity will likely increase (Karl et al. 2009). Both of these changes have the potential to exacerbate flooding issues along the Arkansas River. For additional climate change information refer to Schramm and Loehman (2011) and the NPS Climate Change Response Program website: http://nature.nps.gov/climatechange/ (accessed 5 June 2013).

Dredging

Dredging for sand and gravel resources, flood control, or to maintain current navigation routes, deepens channels. Initially, the ACOE routinely dredged channels for navigation, but have not recently dredged (at least not within the last 15 years) because of the dam (E. Wood and K. McCallie, conference call, 10 April 2013).

Impacts of dredging along the Arkansas and White rivers on the memorial's natural resources are not known. At the very least, however, dredging will affect the sediment budget of the area's waterways, resulting in a net loss, thus impacting channel morphology (Thornberry-Ehrlich 2007).

Flooding and Sedimentation of Lake Dumond and Park Lake

Lake Dumond at the Osotouy Unit is a classic example of an abandoned meander (oxbow lake). Menard Bayou connects Lake Dumond to Lake Merrisach outside the memorial. Both Lake Dumond and Lake Merrisach are filling in with sediment. If and when siltation fills in the lakes, flow will back up into Menard Bayou and the system will lose two natural catch basins for high water situations. Memorial managers might consider cutting a channel through the natural levee (Qsonl) to allow the system to drain back to its natural level (S. Ausbrooks and B. Prior, conference call, 10 April 2013). Natural levee deposits (Qsonl) just southeast of the American Indian mounds (Qafn) within the Osotuoy Unit are more erosion resistant and deflect the flow of the Menard Bayou toward the northeast (S. Ausbrooks and B. Prior, conference call, 10 April 2013). Local beaver dams disrupt flow through the system and are mitigated to lessen impacts on adjacent landholdings (E. Wood and K. McCallie, conference call, 10 April 2013).

High water in the Arkansas River or Menard Bayou can flood all but the highest elevations (i.e., the mounds [Qafn]) of the Osotouy Unit and can also flood the bridge over Menard Bayou (E. Wood and K. McCallie, conference call, 10 April 2013).

After recent land acquisitions, the National Park Service now manages approximately half of Lake Dumond's northern shoreline. Resource managers seek additional information regarding the natural and cultural history of Lake Dumond, including influences on the story at Arkansas Post and the history of river courses through the former channel (E. Wood and K. McCallie, conference call, 10 April 2013).

Aside from dredging, the best method to maintain Lake Dumond's current shoreline is unclear. Because so much of the fluvial system surrounding the memorial is controlled by artificial structures, the National Park Service cannot make changes without involving the ACOE and considering the entire system.

Park Lake is an artificial lake within the Memorial Unit. The lake, impounded by an earthen dam constructed in the 1930s and fed by precipitation, is slowly filling in by siltation. Shoreline erosion (exacerbated by a burrowing alligator) was a problem, but current water levels preclude extensive shoreline erosion. Memorial managers are considering dredging the lake to maintain its current morphology (E. Wood and K. McCallie, conference call, 10 April 2013).

Fluvial Issues Management

Memorial managers have an interest in identifying and dating the old river courses and accurately charting the river's evolution through time. Paleochannel studies would also include dating river terraces to determine the timing of channel abandonment. Clues to this history exist in the meander patterns evident on geologic, hydrologic, topographic, and other landform maps. The ACOE office in Vicksburg, Mississippi, has some maps available (S. Ausbrooks and B. Prior, geologists, Arkansas Geological Survey, conference call, 10 April 2013). This knowledge may also serve to focus archeological inventories and studies, particularly at the Osotouy Unit.

Lord et al. (2009)—the chapter in *Geological Monitoring* about fluvial geomorphology—described methods for inventorying and monitoring vital signs, including: (1) watershed landscape (vegetation, land use, surficial geology, slopes, and hydrology), (2) hydrology (frequency, magnitude, and duration of stream flow rates), (3) sediment transport (rates, modes, sources, and types of sediment), (4) channel cross-section, (5) channel planform, and (6) channel longitudinal profile.

Slope Movements

Shoreline erosion is a natural process, particularly in a meandering river system. The geologic units underlying the memorial and surrounding area are unconsolidated clays, muds, silts, sands, and some gravels deposited during a long history of fluvial-system evolution over the lower Mississippi Embayment (Ausbrooks and Prior 2009a, 2009b). Although topographic relief within the memorial is minimal, the unconsolidated deposits are susceptible to slope movements (gravity-driven processes) when exposed in even moderate slopes, terrace scarps, natural levees, and unvegetated or disturbed areas (Thornberry-Ehrlich 2007). A notable disturbance occurs where nutria burrow into river banks (Evans 2005).

The Memorial Unit is located atop a slight bluff and cutbank. This relief was reduced significantly from its previous height of 8 m (25 ft) following the construction of the Wilbur D. Mills Dam and Lock #2, which caused inundation up to 49 m (162 ft) elevation (above sea level). That contour line was designated as the memorial boundary. Any rise in river level above this contour will flood memorial lands to varying degrees.

The bluffs, particularly at the southeastern point of the Memorial Unit, are eroding into the river. Erosion occurs gradually as occasional slumps, falls, or topples (fig. 13) (Waterways Experiment Station 1951). In addition, erosion is occurring along the eastern edge of the peninsula at the Memorial Unit, where runoff is undercutting riprap on the landward side, which was installed to stabilize the shoreline (E. Wood and K. McCallie, conference call, 10 April 2013).

Because of the long human history of the Arkansas Post area, slope movements and erosion threaten a variety of cultural resources. These impacts are greatest along the memorial's shorelines. For example, the Old Townsite located on the peninsula of the Memorial Unit is particularly vulnerable to continued erosion. The American Indian mounds at the Osotouy Unit are largely vegetated and stable but experience some erosion. As described in the "Past Land Use" section, a farm road crosses one of the mounds, exposing archeological resources. Another mound (Mound A) experienced local erosion associated with a large, toppled tree root-ball (E. Wood and K. McCallie, conference call, 10 April 2013). The Arkansas River is meandering toward the Osotouy Unit, which may accelerate erosion at this unit. Small, localized gullies and washes are the only indication of slope movements within the upland areas of the memorial (S. Ausbrooks and B. Prior, conference call, 10 April 2013).

Managing Slope Movements and Erosion

Mitigating the natural erosive processes of a meandering river system is an ongoing management challenge.

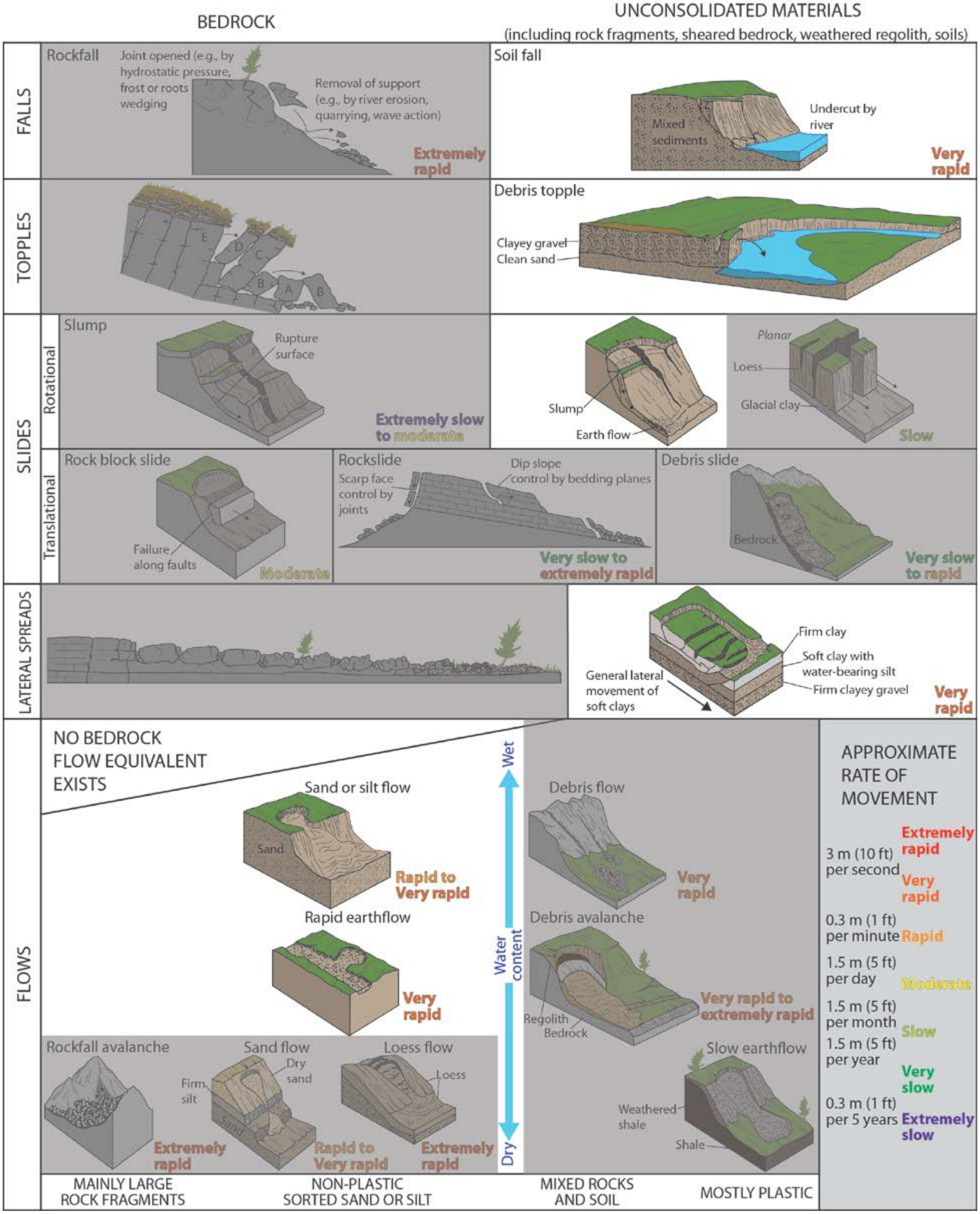


Figure 13. Types of slope movements. Grayed boxes refer to conditions that do not exist at Arkansas Post National Memorial. Graphic by Trista Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978).

Wilbur D. Mills Dam and Lock #2 on the Arkansas River and Arkansas Post Canal, respectively, mitigate some of the potential slope movements by reducing shoreline relief. However, this creates additional issues associated with flooding. Riprap installed along the shorelines of the Memorial Unit also attempted to minimize shoreline erosion and associated slope movements. However, rainwater runoff washed out a section of riprap on the eastern side of the peninsula, near the old mason's cross. Thus memorial managers installed additional rocks, 15–20 cm (6–8 in) in diameter, to mitigate erosion (E. Wood and K. McCallie, conference call, 10 April 2013). At the Memorial Unit's picnic area, a 2 to 3 m (6 to 8 ft) high metal seawall structure attempts to stabilize the shoreline and lessen flood impacts. Memorial managers have considered installing concrete shoreline armoring, although that would further detract from the cultural landscape and may not reduce shoreline erosion (E. Wood and K. McCallie, conference call, 10 April 2013).

Wieczorek and Snyder (2009)—the chapter in *Geological Monitoring* about slope movements—described five vital signs for understanding and monitoring slope movements: (1) types of landslides, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessing landslide hazards and risks.

Groundwater Quality and Quantity

Alluvial sediments strongly influence the groundwater-bearing properties of aquifers. Where rivers meander across a landscape, they leave a complicated pattern of deposits, resulting in alluvial aquifers that can be highly spatially variable (Ausbrooks and Prior 2008). For instance, fine-grained deposits (clay plugs) that settle in abandoned meanders (Qcmac) commonly form thick, confining layers for aquifers (Gonthier and Mahon 1994). By contrast, coarse grained point bar deposits (Qcmpb) readily transmit water and act as productive aquifers.

Groundwater flow in the region is to the south and east (Schrader 2010). The series of alluvial clay, silt, sand, and gravel deposits present throughout the memorial and surrounding area are part of the Mississippi Valley Alluvial Aquifer, one of the most productive aquifers in Arkansas (Kilpatrick and Ludwig 1990; Ausbrooks and Prior 2008). Shallow alluvial aquifers are rapidly recharged from precipitation and seepage of water from the Arkansas and White rivers. For this reason, the construction of dams and flood control structures raises local groundwater levels in proximity to the river (Kilpatrick and Ludwig 1990; Gonthier and Mahon 1994).

The alluvial aquifer is increasingly relied upon for agriculture and aquaculture in eastern Arkansas during periods of sporadic rainfall (Schrader 2010). Groundwater withdrawals for agriculture—in particular rice farming—dominate aquifer use in the vicinity of the memorial, and extraction is increasing. Withdrawal amounts increased 582% between 1965 and 2005 (Schrader 2010). A study by the US Geological Survey documented an elongated and deepening cone of depression, which is evidence of groundwater use far outpacing recharge, throughout the Mississippi Valley Alluvial Aquifer (Shrader 2010).

The memorial's water source is from a 60-m- (200-ft-) deep well that penetrates the alluvial aquifer (E. Wood and K. McCallie, conference call, 10 April 2013). Given its close proximity to the Arkansas River the well is not likely to go dry. The local depth to the water table is less than 15 m (50 ft).

Decreased water availability will be a major issue as climate continues to change over the next century. Climate models project a decrease in precipitation in winter and spring and thus the frequency, duration, and intensity of droughts are likely to continue to increase throughout the southeast (Karl et al. 2009). At the same time demand will also increase, exacerbating the issue.

The potential for contamination from pesticide use on adjacent agricultural lands is very high (Ausbrooks and Prior 2008). A deeper aquifer exists in the Tertiary Sparta Sand, below the oldest geologic unit (Jackson Group; Tj) mapped near Arkansas Post, and is less likely to be contaminated. However, the deep aquifer is a limited (or slowly replenished) resource, and a new well would have to be drilled to tap into the deeper, confined aquifer in the Sparta Sand (S. Ausbrooks and B. Prior, geologists, Arkansas Geological Survey, conference call, 10 April 2013).

The NPS Water Resources Division (http://www.nature.nps.gov/water/) can provide technical and regulatory assistance to resource managers at the memorial regarding water-related issues.

Past Land Use

Arkansas Post National Memorial has a long history of human presence. Most, if not all, of the landscape within the memorial has been disturbed at some point, as detailed in the cultural landscape report for the memorial (Evans 2005). Three map units consisting of artificial fill (Qafa, Qafe, and Qafn) attest to the scale of anthropogenic activities on the landscape within and surrounding the memorial (Ausbrooks and Prior 2009a, 2009b).

Early European settlers clear-cut forests at the post. Removal of vegetation decreased the stability of the substrate and exacerbated erosion. Erosion increased by orders of magnitude from the 1690s through state park establishment in 1929 (Saucier 1994). Following the establishment of Arkansas Post as a state park, the landscape was again altered to provide visitor access and infrastructure (Carrera 1976; Evans 2005). For example, Park Lake was impounded in the 1930s; the gullies within the memorial that played a role in the Spanish history of the post were lost as a result.

A long history of agriculture is visible on the landscape at the Osotouy Unit. Several fields, as well as access roads and fences are present. No NPS infrastructure exists at the unit (E. Wood and K. McCallie, conference call, 10 April 2013). Feral pigs frequent the area, burrowing and creating wallows in open, fallow fields (E. Wood and K. McCallie, conference call, 10 April 2013). A farm road (now gated and locked) crosses the unit that still provides access to local users (permitted, all-terrain vehicles only) as part of a land grant agreement (Thornberry-Ehrlich 2007; E. Wood and K. McCallie, conference call, 10 April 2013). This road traverses a mound site. Associated erosion exposed archeological resources, including pottery shards and animal bones (E. Wood and K. McCallie, conference call, 10 April 2013).

Monument managers strive to protect the remaining significant cultural features, characteristics, and landscapes (Evans 2005). With such a multi-layered historical record, deciding which resources warrant preservation is challenging. Documenting and protecting what remains of the post's colonial period (now mostly buried and constructed of vulnerable building materials such as wood) is essential (Evans 2005). Memorial staff members are presently considering management alternatives that include restoration of native forests or maintaining (via mowing) artificially open areas within the Osotouy Unit.

Economic Resource Development

Beyond memorial boundaries, but of concern to memorial resource managers, are potential impacts from sand and gravel extraction, as well as coal–bed methane and natural gas exploration and development. Not surprising for a state with significant river systems, sand and gravel are among the most important natural resources (S. Ausbrooks and B. Prior, conference call, 10 April 2013). Abandoned channel meanders (Qcmac) and point bar deposits (Qcmpb) (Ausbrooks and Prior 2009a, 2009b) provide material for four sand pits south of the memorial, across the Arkansas River. These pits are identified in the GRI geologic map data.

The ACOE issues permits to developers to remove sand and gravel for construction projects. This activity is typically focused upriver (particularly where sand accumulations impede barge navigation), near Little Rock, but potential for this activity exists in the memorial area (S. Ausbrooks and B. Prior, conference call, 10 April 2013).

The memorial is on the northern edge of the Desha Basin, which hosts abundant Tertiary and Cretaceous lignite (low grade coal). Coal-bed methane and natural gas exploration is underway in the Desha Basin south of the memorial (Saucier 1994; Hackley et al. 2006; Ratchford 2007). The Eocene Jackson Group (Tj) also contains lignite; deeper exposures may have higher-grade coal. Coal-bed methane is also of interest (Ratchford 2007).

Depending on gas prices, exploration efforts could reach the memorial area in 15 years, and some test wells already exist in the area (S. Ausbrooks and B. Prior, conference call, 10 April 2013). A dry/abandoned well is located immediately adjacent to the Osotouy Unit (maps available online at http://www.geology.ar.gov/fossilfuel_maps/eastark_county_wells.htm). Although drilling cannot occur within the memorial, local coal and gas development could create additional disturbed lands in the area, impacting the memorial's viewshed.

Seismicity

Earthquakes are uncommon in eastern Arkansas. However, the region shook during epic earthquakes 200 years ago. In 1811–1812, the largest earthquakes ever recorded in the continental United States (approximately magnitude 8.0) occurred along the New Madrid fault. The massive earthquakes were felt throughout an area of 130,000 km^2 (50,000 mi^2). The New Madrid Seismic Zone is centered along the Mississippi River valley where Arkansas, Missouri, Illinois, Kentucky, and Tennessee converge, about 260 km (160 mi) northeast of Arkansas Post.

Although the New Madrid Seismic Zone is the most recent to deliver a large earthquake, it is not the only fault zone in the area. The Saline River fault zone (centered southwest of Little Rock) and Marianna fault zone (centered about 80 km [50 mi] northeast of Arkansas Post) produced strong earthquakes about 5,000 years ago (Cox et al. 2000, 2012; Al-Shukuri 2011). Additional active fault zones that pose seismic hazards may be concealed by Coastal Plain sediments (Cox et al. 2000, 2012).

Large earthquakes leave lasting marks on the landscape, particularly in wet, unconsolidated sediments, such as those that underlie the Arkansas Post area. Wet, unconsolidated sediments are vulnerable to damaging shaking, seismically induced landslides, land fissures, widespread liquefaction, and the development of sand boils. All of these effects were noted after the New Madrid earthquakes. Because the memorial is underlain by unconsolidated deposits, earthquakes, even from a great distance such as New Madrid Seismic Zone, could be felt at the memorial (S. Ausbrooks and B. Prior, conference call, 10 April 2013). A moderate earthquake could have significant impacts on infrastructure, trigger sloughing along the shoreline, and affect the courses of the Arkansas and White rivers (Thornberry-Ehrlich 2007).

Liquefaction and sand boils are two primary hazards from large earthquakes. Liquefaction causes the loss of strength and ability of an unconsolidated substrate to withstand the weight of overlying structures or sediments (Ausbrooks and Prior 2008). According to Ausbrooks and Prior (2008), the depth to the alluvial aquifer beneath the memorial is less than 12 m (40 ft). Because liquefaction primarily occurs within areas where depth to groundwater is less than 15 m (50 ft) and saturated, unconsolidated material is present, the memorial area is at risk of liquefaction should a large earthquake occur in the vicinity. Geologists with the Arkansas Geological Survey are currently measuring the depth to the alluvial aquifer across eastern Arkansas to determine the threat of liquefaction (S. Ausbrooks and B. Prior, conference call, 10 April 2013).

Sand blows are patches of sand that erupt out of the ground when seismic waves pass through wet, loose sand. Typically a magnitude 6 earthquake is necessary to trigger sand blows. These features—low, roughly circular, sandy mounds—are a lasting record of strong seismic activity in surficial deposits. They serve a critical role in the study of paleoseismology. The presence of stretches of fine sand alerted geologists to the presence of the Marianna fault (Al-Shukuri 2011). Geologists are searching for evidence of sand boils in addition to other paleoseismic data in the Arkansas Post area from the 1811–1812 earthquakes (S. Ausbrooks and B. Prior, conference call, 10 April 2013). Researchers with the University of Memphis are currently mapping and dating the locations of ancient sand blows along the Mississippi River corridor. Seven-thousand-year-old sand blows near Marianna, Arkansas, 80 km (50 mi) northeast of the memorial, and elsewhere suggest possible recurrence intervals and the potential for large quakes to occur in the future (S. Ausbrooks and B. Prior, conference call, 10 April 2013).

According to the USGS earthquake probability map (https://geohazards.usgs.gov/eqprob/2009/index.php; accessed 3 June 2013), the probability of a magnitude 5.5 earthquake striking Arkansas Post is exceedingly low (<1%). However, the probability increases to between 30% and 40% for the area surrounding New Madrid. Smaller, less damaging earthquakes (in some cases, imperceptible to humans) are more common in Arkansas. In 1976, magnitude 4–5 earthquakes occurred near Marked Tree, Arkansas, 160 km (100 mi) northeast of the memorial. In the early 2000s, a magnitude 2.2 earthquake occurred near Earle, Arkansas, 60 km (40 mi) northeast of the memorial.

Small-scale faults may be active throughout the area, cutting young alluvial deposits (Waterways Experiment Station 1951). However, no faults are noted in the GRI digital geologic map data and no earthquakes larger than magnitude 3.0 have occurred in the immediate vicinity of the memorial since 1699, when historical records began (Ausbrooks and Prior 2009a, 2009b; Ausbrooks et al. 2012).

The Arkansas Geological Survey maintains a website on earthquake activity and seismic hazards for the state at http://www.geology.ar.gov/geohazards/earthquakes.htm. The US Geological Survey also provides online information for the state at http://earthquake.usgs.gov/. Cane Creek State Park, 40 km (25 mi) west of the memorial, contains the nearest seismic monitoring station (S. Ausbrooks and B. Prior, conference call, 10 April 2013).

Braile (2009)—the chapter in *Geological Monitoring* about earthquakes and seismic activity—described the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Arkansas Post National Memorial, the environment in which those units were deposited, and the timing of geologic events that formed the present landscape.

The geologic history of Arkansas Post National Memorial is relatively young, with most geologic map units no older than about 12,000 years (see fig. 6). In some cases the deposits are only decades-old (e.g., engineered artificial fill, Qafe) or still being deposited (e.g., small stream deposits, Qalss). Terraces developed during the ice ages (no more than 2.6 million years ago). A large gap of more than 35 million years separates terrace deposits from the Eocene Jackson Group (see fig. 7). However, the geologic story of the memorial spans as far back as the Mesozoic Era when the Mississippi Embayment began to form. The story includes the evolution of the Mississippi River, ice ages, and modern human history. Refer to Saucier (1994) for a comprehensive study and bibliography of the geomorphology and Quaternary geologic history of the lower Mississippi River valley, including the Arkansas River valley below Little Rock.

Mesozoic Era (251 million–65.5 million years ago): Pangaea Separation, Appalachian Mountains Erosion, and Mississippi Embayment Subsidence

At the dawn of the Mesozoic Era, all landmasses on Earth were assembled into the supercontinent Pangaea (fig. 14). During the Triassic and Jurassic periods, rifting began to pull apart Pangaea: Africa and South America separated from North America, forming the still-widening Atlantic Ocean. This rifting also opened the Gulf of Mexico basin in the Upper Triassic or Lower Jurassic (Saucier 1994). The Gulf of Mexico continued to expand through the Cretaceous Period. As the gulf expanded, the Earth's crust between the southern Appalachians and Ouachita Mountains subsided creating the Mississippi Embayment—a northward synclinal (concave) structure of the Coastal Plain. As sea levels fluctuated during the Upper Cretaceous, the embayment alternated between shallow marine and fluvial environments. Sediments shed from the Ouachita Mountains collected within the synclinal embayment. Weathering, erosion, and marine and fluvial deposition were the dominant geologic processes operating in the memorial by the end of the Mesozoic, continuing throughout the following Cenozoic Era.

Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation

Throughout the early Cenozoic Era, periodic incursions from the Gulf of Mexico inundated the lower Mississippi Embayment. Thick layers of clay—such as the marine clays of the Jackson Group (Tj) mapped deep beneath the memorial—and silt were deposited across the region. The Mississippi Embayment was largely filled by these sediments during the Paleocene and Eocene epochs (Saucier 1994). Also at this time, the courses of the ancestral Arkansas and Red rivers, which flowed into the embayment, were relatively close to today's patterns (Saucier 1994). However, the ancestral Mississippi River was relatively small (Saucier 1994).

At the beginning of the Pleistocene Epoch, the system experienced a major change. Ice age glaciation was the single most significant geologic process to affect the geomorphology and geologic history of the lower Mississippi River valley (Saucier 1994). During repeated continental glaciations (ice ages) of the Pleistocene Epoch (between 2.6 million years ago and approximately 12,000 years ago) thick sheets of ice advanced and retreated over more than half of North America. Glacial ice never reached as far south as Arkansas, but the global effects of their presence are recorded in the geologic units in the memorial area. East Arkansas' climate was much cooler. As recently as 11,200 years ago, cool temperate vegetation was present.

Ice advance and retreat rearranged the preexisting drainages in the midcontinent, and the Mississippi, Ohio, and Missouri rivers emerged as the continent's major drainage systems (Fisk 1944; Saucier 1994). The Mississippi River valley repeatedly functioned as a sluiceway, funneling vast quantities of glacial meltwater and outwash sediments to the Gulf of Mexico (Saucer 1994). During glacial intervals, vast amounts of water were entrained as ice, resulting in a lower global sea level. Erosional processes dominated the exposed landscape, causing breaks in the stratigraphic record (Saucier 1994). Rivers carved canyons onto the continental shelves. The entrenched valleys of the Mississippi, Arkansas, and White rivers formed during the most recent glaciation—termed the Wisconsinan (Fisk 1944; Waterways Experiment Station 1951).

As glacial ice sheets retreated, rivers swelled to accommodate immense amounts of meltwater. Following the most recent glacial retreat, the Mississippi River experienced flows up to 5 times greater than at present (Saucier 1994). The swollen river transported heavy sediment loads and often developed braided channels. The Arkansas River also was loaded with sediment, flowing as a braided stream. Coarse gravels of braided stream lower deposits (Qbsl) and terrace deposits (Qt) collected atop the Eocene Jackson Group (Tj) during this time in the memorial area. The surface between these braided-stream deposits and the marine deposits of the Jackson Group represent an approximately 30-million-year gap in the geologic record (Markewich 1993; Ausbrooks and Prior 2009a, 2009b). The braided stream and terrace deposits were a source of loess (windblown silt) deposited over broad areas of the

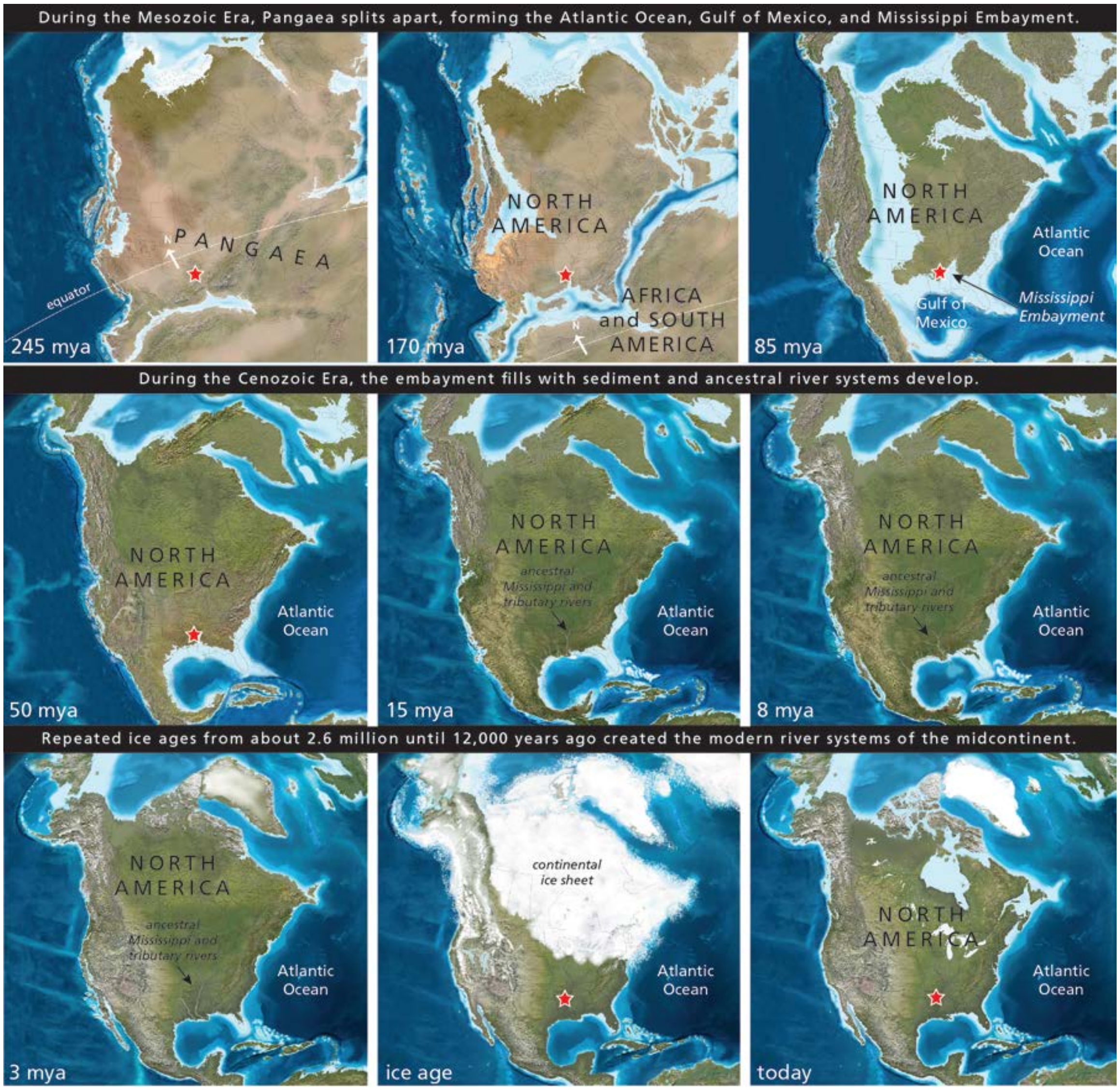


Figure 14. North American paleogeography. The geologic history of Arkansas Post (indicated by red star) includes the separation of a supercontinent; formation of the Atlantic Ocean and Gulf of Mexico; and development of the Mississippi Embayment, ancestral river drainages, and the modern drainage after establishment during ice ages. Graphic compiled and annotated by Jason Kenworthy (NPS Geologic Resources Division). Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems), available at http://cpgeosystems.com/paleomaps.html (accessed 3 June 2013).

greater Mississippi River valley throughout the Pleistocene Epoch (Markewich 1993).

Between about 14,000 and 12,000 years ago, water and sediment volume decreased and the rivers transitioned from a braided, sediment-choked system to a meandering one with significant floodplains and overbank areas (Saucier 1994). Much of the clays and silty clays of the Grand Prairie (uplands between the Arkansas and White rivers) were deposited as overbank deposits atop the glacial outwash (Saucier 1994; Evans 2005).

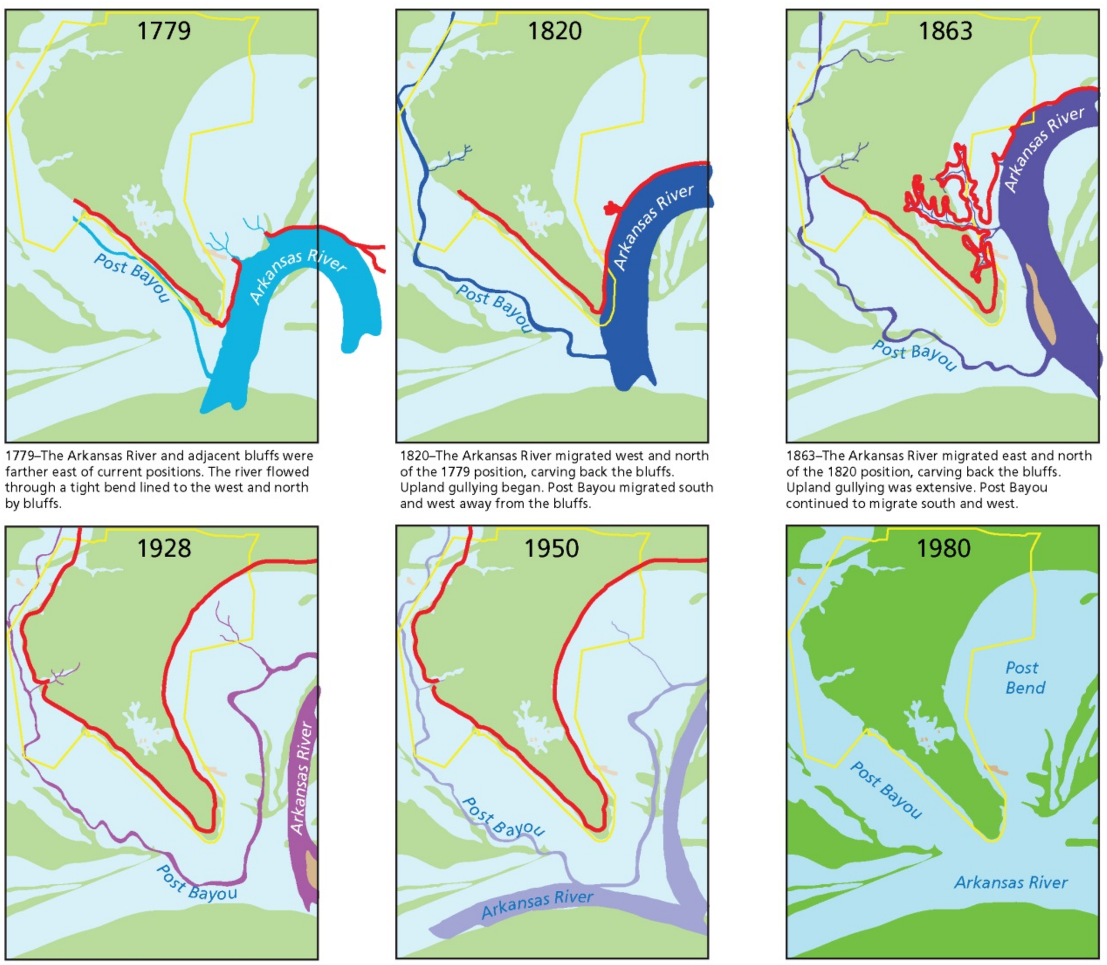
About 6,000 years ago, rising sea levels drowned the formerly fluvial canyons (Fisk 1944). When sea level approached its present position, the Arkansas River established a meandering course that changed almost annually carving new courses as indicated by oxbow lakes, channel fillings, natural levee deposits, and successive point bars laid down on the inside of meander loops. These units represent modern alluvial system atop a Pleistocene-era framework (Waterways Experiment Station 1951; S. Ausbrooks and B. Prior, conference call, 10 April 2013).

Pollen records extending back 11,200 years before present indicate the presence of cool-temperate vegetation in contrast with the modern warm-temperate climate (Markewich 1993). Just prior to the mid-1800s, Earth was experiencing the last remnants of a period of fluctuating climate known as the Little Ice Age, which was probably caused by volcanism and subsequent sea-ice formation (Miller et al. 2012). In southern Arkansas, different local vegetation consisting of colder-weather species (Markewich 1993), longer winters, and increased precipitation may represent colder climate. Colder climatic conditions may explain the propensity for large-scale flooding that caused the post's location to frequently change (see "Geologic Connections with Memorial Stories" section).

The modern Arkansas River system continues to meander across the floodplain, abandoning channels. Stream overbank deposits (Qso, Qsobs, and Qsonl) and channel meander deposits (Qcm, Qcmac, and Qcmpb) record these processes over the past few thousand years. Older, natural levee deposits (Qsonl) reveal that the slopes of earlier Arkansas River courses were considerably greater than the present slope, less than 1 m/km (1 ft/mi) vs. 0.33 m/km (0.52 ft/mi), respectively. This change occurred between about 1,000 and 900 years ago. Widespread sedimentation within the valley caused base level to rise (Waterways Experiment Station 1951; Evans 2005).

Based on historical maps and accounts, the location of Arkansas River channels near Arkansas Post are known for at least the past 220 years (fig. 15) (Evans 2005). Streams and tributaries such as Menard Bayou contribute small stream deposits (Qalss) of clays, silts, sands, and gravels to the greater Arkansas River system (Ausbrooks and Prior 2009a, 2009b). Prominent gullies (now submerged beneath Park Lake) were carved by small streams northeast of the post hundreds of years ago (Evans 2005). These are the youngest geologic units in the memorial area that record natural geomorphological processes.

The struggle between humans and the Arkansas River shaped much of the Arkansas Post's history and continues to have lasting effects on the landscape. The abundance of artificial fill such as Native-American (Indian Mound) (Qafn), agricultural (Qafa), and engineered/flood control/navigation (Qafe) reflects a long history of human settlement in the area with attempts to control flooding and natural meandering of the lower Arkansas River.



1779–The Arkansas River and adjacent bluffs were farther east of current positions. The river flowed through a tight bend lined to the west and north by bluffs.

1820–The Arkansas River migrated west and north of the 1779 position, carving back the bluffs. Upland gullying began. Post Bayou migrated south and west away from the bluffs.

1863–The Arkansas River migrated east and north of the 1820 position, carving back the bluffs. Upland gullying was extensive. Post Bayou continued to migrate south and west.

1928–The Arkansas River continued to migrate east of the 1863 position. Post Bayou lengthened flowing across the riparian zone at some distance from the abandoned bluffs.

1950–Prior to the construction of ACOE engineering structures, the Arkansas River was migrating west and cut off a meander. Post Bayou joined the river near its present position.

1980–ACOE engineering structures raised the river level, inundating all the low ground in the memorial area and greatly diminishing the prominence of the historical bluffs.

Figure 15. Arkansas River courses through time (1779–1980). Old river courses are superimposed on the river's 1980 position (light blue). The yellow outline delineates the boundary of the Memorial Unit. Bold red lines indicate bluff positions. Graphic by Trista L. Thornberry-Ehrlich after exhibits 1–7 in Evans (2005).

Geologic Map Data

This section summarizes the geologic map data available for Arkansas Post National Memorial. The Geologic Map Graphic (in pocket) displays the geologic map data draped over a shaded relief image of the memorial and surrounding area. The Map Unit Properties Table (in pocket) summarizes this report's content for each geologic map unit. Complete GIS data are included on the accompanying CD and are also available at the GRI publications website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Geologic Maps

Geologic maps facilitate an understanding of an area's geologic framework and the evolution of its present landscape. Using designated colors and symbols, geologic maps portray the spatial distribution and relationships of rocks and unconsolidated deposits. They also show age relationships. There are two primary types of geologic maps: surficial and bedrock. Surficial geologic maps encompass deposits that are frequently unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, generally more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type. Surficial geologic map data are provided for Arkansas Post National Memorial.

Geologic maps also may show geomorphic features, structural interpretations, and locations of past geologic hazards that may be prone to future activity. Additionally, anthropogenic features such as mines and quarries may be indicated on geologic maps.

Source Maps

The Geologic Resources Inventory (GRI) team converts digital and/or paper source maps into GIS formats that conform to the GRI GIS data model. The GRI digital geologic map product also includes essential elements of the source maps, including unit descriptions, map legend, map notes, references, and figures. The GRI team used the following source maps to produce the digital geologic data for Arkansas Post National Memorial. These source maps provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report.

Ausbrooks, S. M., and W. L. Prior. 2009a. Geologic map of the Arkansas Post 7.5′ quadrangle, Arkansas and Desha counties, Arkansas (scale 1:24,000). Digital geologic map DGM-AR-00026. Arkansas Geological Survey, Little Rock, Arkansas, USA. http://www.geology.ar.gov/maps_pdf/geologic/24k_maps/Arkansas%20Post.pdf.

Ausbrooks, S. M., and W. L. Prior. 2009b. Geologic map of the Watson 7.5′ quadrangle, Arkansas and Desha counties, Arkansas (scale 1:24,000). Digital geologic map DGM-AR-00894. Arkansas Geological Survey, Little Rock, Arkansas, USA. http://www.geology.ar.gov/maps_pdf/geologic/24k_maps/Watson.pdf.

Geologic GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is included on the enclosed CD and is also available online (http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm). This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI team digitized the data for Arkansas Post National Memorial using data model version 2.1.

GRI digital geologic data are included on the attached CD and are available through the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/App/Reference/Search?SearchType=Q). Enter "GRI" as the search text and select Arkansas Post National Memorial from the unit list.

The following components and geology data layers are part of the data set:

- Data in ESRI geodatabase and shapefile GIS formats
- Layer files with feature symbology (see table below)
- Federal Geographic Data Committee (FGDC)–compliant metadata
- A help file (.pdf) document that contains all of the ancillary map information and graphics, including geologic unit correlation tables, and map unit descriptions, legends, and other information captured from source maps
- An ESRI map document file (.mxd) that displays the digital geologic data

Geology data layers in the Arkansas Post National Memorial GIS data

Data Layer	Data Layer Code	On Map Graphic?
Geologic cross section lines	SEC	No
Surface wells and sand pits	MIN	Yes
Structure contour lines (elevation of top of Jackson Group)	CN1	No
Geologic contacts	GLGA	Yes
Geologic units	GLG	Yes

Geologic Map Graphic

The Geologic Map Graphic (in pocket) displays the GRI digital geologic data draped over an aerial image of the memorial and surrounding area. For graphic clarity and legibility, not all GIS feature classes may be visible on the graphic, as indicated in the above table. Cartographic elements and basic geographic information have been added to overview. Digital elevation data and geographic information, which are part of the map graphic, are not included with the GRI digital geologic GIS data for the memorial, but are available online from a variety of sources.

Map Unit Properties Table

The geologic units listed in the Map Unit Properties Table (in pocket) correspond to the accompanying digital geologic data. Following the structure of the report, the table summarizes the geologic issues, features and processes, and geologic history associated with each map unit. The table also lists the geologic time period, map unit symbol, and a simplified geologic description of the unit. Connections between geologic units and memorial stories are also summarized.

Use Constraints

Graphic and written information provided in this section is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the map graphic. Based on the source map scale (1:24,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are horizontally within 12 m (40 ft) of their true location.

Please contact GRI with any questions.

Glossary

This glossary contains brief definitions of geologic terms used in this report. Not all geologic terms used are listed. Definitions are based on those in the American Geological Institute Glossary of Geology *(fifth edition; 2005). Additional definitions and terms are available at: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.*

alluvial fan. A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows into a hydraulically unconfined area (commonly from a mountainous area into a valley or plain).
alluvium. Stream-deposited sediment.
anticline. A convex ("A"-shaped) fold. Older rocks are found in the center. Compare with "syncline."
aquiclude. See "confining bed."
aquifer. A rock or sedimentary unit that is sufficiently porous to hold water, sufficiently permeable to allow water to move through it, and currently saturated to some level.
base level. The lowest level to which a stream channel can erode. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.
basin (structural). A doubly plunging syncline in which rocks dip inward from all sides.
basin (sedimentary). Any depression, from continental to local scale, into which sediments are deposited.
beach. A gently sloping shoreline covered with sediment, commonly formed by the actions of waves and tides.
bed. The smallest sedimentary stratigraphic unit, commonly ranging in thickness from about 1 cm (0.4 in) to 1 to 2 m (39.4 to 78.7 in) and distinguishable from beds above and below.
bedding. Depositional layering or stratification of sediments.
bedrock. A general term for the rock that underlies soil or other unconsolidated surficial material.
braided stream. A sediment-clogged stream that forms multiple channels that divide and rejoin.
cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.
channel bar. An elongate deposit of sand and gravel located in the course of a stream. Common in braided streams.
chert. An extremely hard sedimentary rock with conchoidal (smooth, curved surface) fracturing. It consists chiefly of interlocking crystals of quartz. Also called "flint."
clast. An individual grain or rock fragment in a sedimentary rock, produced by the physical disintegration of a larger rock mass.
clastic. Describes rock or sediment made of fragments of pre-existing rocks (clasts). Also see "epiclastic."
clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).
concordant. Describes a stratum with contacts parallel to the orientation of adjacent strata.
confining bed. A body of relatively impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers. Replaced the term "aquiclude."
continental rifting. Process by which a region of crust undergoes extension (pulling apart), resulting in the formation of many related normal faults, and often associated with volcanic activity.
continental rise. Gently sloping region from the foot of the continental slope to the deep ocean abyssal plain; it generally has smooth topography but may have submarine canyons.
continental shelf. The shallowly submerged part of a continental margin extending from the shoreline to the continental slope, with water depths of less than 200 m (660 ft).
continental shield. A continental block of Earth's crust that has remained relatively stable over a long period of time and has undergone minor warping in contrast to the intense deformation of bordering crust.
continental slope. The relatively steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.
creep. The slow, imperceptible downslope movement of mineral, rock, and soil particles under gravity.
cross section. A graphic interpretation of geology, structure, and/or stratigraphy based on mapped and measured geologic extents and attitudes, depicted in a vertical plane (i.e., a cut or profile view).
crust. Earth's outermost compositional shell, 10 to 40 km (6 to 25 mi) thick, consisting predominantly of relatively low-density silicate minerals. Also see "oceanic crust" and "continental crust."
cutbank. A steep, bare slope formed by lateral erosion of a stream.
delta. A sediment wedge deposited where a stream flows into a lake or sea.
depocenter. An area or site of maximum deposition; the thickest part of any specified stratigraphic unit in a depositional basin.
detritus. A collective term for loose rock and mineral material that is worn off or removed by mechanical processes.
differential erosion. Erosion that occurs at irregular or varying rates due to differences in the resistance and hardness of surface material.
dip. The angle between a bed or other geologic surface and the horizontal plane.
discordant. Describes a contact between strata that cuts across or is set at an angle to the orientation of adjacent rocks.

dome. General term for any smoothly rounded landform or rock mass. More specifically, refers to an elliptical uplift in which rocks dip gently away in all directions.
downcutting. Stream erosion process in which cutting is directed primarily downward, as opposed to lateral erosion.
drainage basin. The total area from which a stream system receives or drains precipitation runoff.
entrainment. The process of picking up and transporting sediment, commonly by wind or water.
epicenter. The point on Earth's surface directly above the focus (location) of an earthquake.
escarpment. A steep cliff or topographic step resulting from vertical displacement on a fault or mass movement. Also called a "scarp."
fan delta. An alluvial fan that builds into a standing body of water. A fan delta differs from a delta in that it forms next to a highland, typically at an active margin.
fault. A break in rock characterized by displacement of one side relative to the other.
floodplain. The surface or strip of relatively smooth land adjacent to a river channel and formed by the river. Covered with water when the river overflows its banks.
formation. Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts.
geology. The study of Earth, including its origin, history, physical processes, components, and morphology.
geomorphology. The study of the general configuration of surface landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.
gully. A small channel produced by running water in earth or unconsolidated material (e.g., soil or a bare slope).
highstand. The time during which sea level is above the shelf edge in a given locality in one or more cycles of relative change in sea level. Compare with "lowstand."
hydrogeologic. Describes geologic influences on groundwater and surface water composition, movement, and distribution.
hydrology. The study of liquid and solid water properties, circulation, and distribution, on and under the Earth's surface and in the atmosphere.
incision. The process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley.
lacustrine. Describes a process, feature, or organism pertaining to, produced by, or inhabiting a lake or lakes.
landslide. Any process or landform resulting from rapid, gravity-driven mass movement.
lens. A sedimentary deposit characterized by converging surfaces, thick in the middle and thinning out toward the edges, resembling a convex lens.
levee. Raised ridge lining the bank of a stream. May be natural or artificial.
lignite. A brownish-black coal that is intermediate in coalification between peat and subbituminous coal.
liquefaction. The transformation of loosely packed sediment into a more tightly packed fluid mass.
lithification. The conversion of sediment into solid rock.
lithify. To change to stone or to petrify; especially to consolidate from a loose sediment to a solid rock through compaction and cementation.
loess. Windblown silt-sized sediment, generally of glacial origin.
lowstand. The time during which sea level is below the local shelf edge in one or more cycles of relative change in sea level Compare with "highstand."
mass wasting. A general term for the downslope movement of soil and rock material under the direct influence of gravity.
matrix. The fine-grained material between coarse (larger) grains in an igneous rock or poorly sorted clastic sediment or rock. Also refers to rock or sediment in which a fossil is embedded.
meander. Sinuous lateral curve or bend in a stream channel; a meander's original pattern is preserved with little modification. An entrenched meander is incised (carved downward) into the surface of its valley.
mechanical weathering. The physical breakup of rocks without change in composition. Synonymous with physical weathering.
mineral. A naturally occurring inorganic crystalline solid with a definite chemical composition or compositional range.
mold. An impression made in the surrounding earth or rock material by the exterior or interior of a fossil shell or other organic structure.
normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall. Compare with "reverse fault" and "thrust fault."
oblique fault. A fault in which motion includes both dip-slip and strike-slip components.
oil field. A geographic region rich in petroleum resources and containing one or more wells that produce, or have produced, oil and/or gas.
outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.
outwash. Glacial sediment transported and deposited by meltwater streams.
overbank deposit. Alluvium deposited outside a stream channel during flooding.
oxbow. A closely looping stream meander resembling the U-shaped collar of an ox yoke; its extreme curvature leaves only a neck of land between two parts of the stream.
paleogeography. The study, description, and reconstruction of the physical landscape in past geologic periods.
paleontology. The study of the life and chronology of Earth's geologic past based on the fossil record.
Pangaea. A supercontinent that existed during the Permian and Triassic periods and included much of Earth's continental crust. Split into Gondwana and Laurasia.
pebble. Generally, a small rounded rock particle with a diameter of 4 to 64 mm (0.16 to 2.52 in).
perched aquifer. An aquifer containing unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

permeability. A measure of the relative ease with which a fluid moves through the pore spaces of a rock or sediment.

plateau. A broad, flat-topped topographic high (terrestrial or marine) of great extent and elevation above the surrounding plains, canyons, or valleys.

point bar. A low ridge of sand and gravel deposited in a stream channel on the inside of a meander, where flow velocity slows.

porosity. The proportion of void space (i.e., pores or voids) in a volume of rock or sediment deposit.

progradation. The seaward building of land area due to sedimentary deposition.

recharge. Infiltration process that replenishes groundwater.

regression. Long-term seaward retreat of the shoreline or relative fall of sea level.

rift. A region of crust where extension results in formation of many related normal faults, often associated with volcanic activity.

riprap. A layer of large, durable, broken rock fragments irregularly thrown together in an attempt to prevent erosion by waves or currents and thereby preserve the shape of a surface, slope, or underlying structure.

rock. A solid, cohesive aggregate of one or more minerals.

rockfall. The most rapid mass-wasting process, in which rocks are dislodged and move downslope rapidly.

sand. A clastic particle smaller than a granule and larger than a silt grain, with a diameter ranging from 1/16 to 2 mm (0.0025 to 0.08 in).

scarp. A steep cliff or topographic step resulting from displacement on a fault or by mass movement or erosion. Also called an "escarpment."

sediment. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.

sedimentary. Describes a consolidated and lithified rock consisting of clastic and/or chemical sediment(s). One of the three main classes of rock—igneous, metamorphic, and sedimentary.

silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256 to 1/16 mm [0.00015 to 0.002 in]).

slope. The inclined surface of any geomorphic feature or measurement thereof. Synonymous with "gradient."

slump. A generally large, coherent mass movement with a concave failure surface and subsequent backward rotation relative to the slope.

soil. The unconsolidated mineral or organic matter on the surface of the earth that has been affected by climate (water and temperature) and organisms (macro and mico), conditioned by relief, acting on parent material over a period of time. Soil differs from the material from which it is derived in many ways.

spring. A site where water issues from the surface due to the intersection of the water table with the ground surface.

stade. An interval of a glacial stage marked by glacial readvance.

stratification. The accumulation, or layering, of sedimentary rocks in strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.

stream. Any body of water moving under gravity flow in a clearly confined channel.

stream channel. A long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

stream terrace. Step-like bench surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).

strike. The compass direction of the line of intersection of an inclined surface with a horizontal plane.

structure. The attitudes and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusion.

subaerial. Describes a condition or process that exists or operates in the open air on or immediately adjacent to the land surface.

subbituminous. Describes black coal, intermediate in rank between lignite and bituminous coal. It is distinguished from lignite by higher carbon and lower moisture content.

subsidence. The gradual sinking or depression of part of Earth's surface.

syncline. A downward-curving (concave) fold with layers that dip inward; stratigraphically younger rocks are found in its core. Compare with "anticline."

tectonic. Describes a feature or process related to large-scale movement and deformation of Earth's crust.

terrace. A relatively level bench- or step-like surface breaking the continuity of a slope. Also see "stream terrace."

terrestrial. Describes a feature, process, or organism related to land, Earth, or its inhabitants.

thrust fault. A contractional dip-slip fault with a shallowly dipping (less than 45°) fault surface where the hanging wall moves up and over relative to the footwall. Compare with "normal fault" and "reverse fault."

topography. The general morphology of Earth's surface, including relief and locations of natural and human-made features.

trace (fault). The exposed intersection of a fault with Earth's surface.

trace fossil. A fossilized feature or material, such as a track, trail, burrow, or coprolite (dung), that preserves evidence of an organism's life activities, rather than the organism itself.

transcurrent fault. A continental strike-slip fault that does not terminate at lithospheric plate boundaries.

transform fault. A strike-slip fault that links two other faults or plate boundaries (e.g., two segments of a mid-ocean ridge). A type of plate boundary at which lithosphere is neither created nor destroyed, and plates slide past each other.

transgression. Landward migration of the sea as a result of a relative rise in sea level.

trend. The direction or azimuth of elongation of a linear geologic feature.

unconfined groundwater. Groundwater that has a water table; i.e., water not confined under pressure beneath a confining bed.

undercutting. The removal of material at the base of a steep slope or cliff or other exposed rock by the erosive action of falling or running water (such as a meandering stream), of sand-laden wind in the desert, or of waves along the coast.

underfit stream. A stream that appears to be too small to have eroded the valley in which it flows; a stream whose whole volume is greatly reduced or whose meanders show a pronounced shrinkage in radius.

uplift. A structurally high area in the crust produced by movement that raises the rocks.

water table. The upper surface of the saturated zone; the zone of rock in an aquifer saturated with water.

weathering. The physical, chemical, and biological processes by which rock is broken down.

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Additional References

This section lists additional references, resources, and websites that may be of use to resource managers. Web addresses are current as of April 2013.

Geology of National Park Service Areas

National Park Service Geologic Resources Division (Lakewood, Colorado): http://nature.nps.gov/geology/

NPS Geologic Resources Inventory: http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

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NPS Geoscientist-in-the-Parks (GIP) internship and guest scientist program: http://www.nature.nps.gov/geology/gip/index.cfm

NPS Views Program (geology-themed modules are available for Geologic Time, Paleontology, Glaciers, Caves and Karst, Coastal Geology, Volcanoes, and a wide variety of geologic parks): http://www.nature.nps.gov/views/layouts/main.html.

NPS Resource Management Guidance and Documents

1998 National Parks Omnibus Management Act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf

NPS 2006 Management Policies (Chapter 4; Natural Resource Management): http://www.nps.gov/policy/mp/chapter4.htm

NPS-75: Natural Resource Inventory and Monitoring Guideline: http://www.nature.nps.gov/nps75/nps75.pdf

NPS Natural Resource Management Reference Manual #77: http://www.nature.nps.gov/Rm77/

Geologic Monitoring Manual:
Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado, USA. http://nature.nps.gov/geology/monitoring/index.cfm

NPS Technical Information Center (TIC) (Denver, Colorado; repository for technical documents): http://etic.nps.gov/

Geological Surveys and Societies

Arkansas Geological Survey: http://www.geology.ar.gov/home/index.htm

US Geological Survey: http://www.usgs.gov/

Geological Society of America: http://www.geosociety.org/

American Geological Institute: http://www.agiweb.org/

Association of American State Geologists: http://www.stategeologists.org/

US Geological Survey Reference Tools

US Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

US Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

US Geological Survey Geographic Names Information System (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/

US Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")

US Geological Survey Publications Warehouse (USGS publications, many available online): http://pubs.er.usgs.gov

US Geological Survey Tapestry of Time and Terrain (descriptions of physiographic provinces): http://tapestry.usgs.gov/Default.html

Other Park-Relevant Sources

Historical Maps of the Mississippi River Corridor: http://alabamamaps.ua.edu/historicalmaps/MississippiRiver/

Appendix A: Scoping Meeting Participants

The following people attended the GRI scoping meeting for Arkansas Post National Memorial, held on 23 April 2007, or the follow-up report writing conference call, held on 10 April 2013. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

2007 Scoping Meeting Participants

Name	Affiliation	Position
Leo Acosta	NPS Arkansas Post NM	Resource Management
Angela Chandler	Arkansas Geological Survey	Geologist
Tim Connors	NPS Geologic Resources Division	Geologist
Deanna Greco	NPS Geologic Resources Division	Geologist
Doug Hanson	Arkansas Geological Survey	Geologist
Philip Hays	US Geological Survey	Geologist
Bruce Heise	NPS Geologic Resources Division	Geologist
Mark Hudson	US Geological Survey	Geologist
Tim Kress	US Geological Survey	Hydrologist
Bill Prior	Arkansas Geological Survey	Geologist
Steve Rudd	NPS Hot Springs NP	Geologist
Trista Thornberry-Ehrlich	Colorado State University	Geologist, Report Writer
Bekki White	Arkansas Geological Survey	State Geologist

2013 Conference Call Participants

Name	Affiliation	Position
Scott Ausbrooks	Arkansas Geological Survey	Geologist
Jason Kenworthy	NPS Geologic Resources Division	Geologist, GRI Reports Coordinator
Kirby McCallie	NPS Arkansas Post NM	Resource Manager
Bill Prior	Arkansas Geological Survey	Geologist
Trista Thornberry-Ehrlich	Colorado State University	Geologist, Report Writer
Ed Wood	NPS Arkansas Post NM	Superintendent

Appendix B: Geologic Resource Laws, Regulations, and Policies

The Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to National Park Service minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available. Information is current as of February 2013. Contact GRD for detailed guidance.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**National Parks Omnibus Management Act of 1998, 16 USC. § 5937** protects the confidentiality of the nature and specific location of paleontological resources and objects. **Paleontological Resources Preservation Act of 2009**, **16 USC. § 470aaa *et seq.***, provides for the management and protection of paleontological resources on federal lands.	**36 C.F.R. § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof. **36 C.F.R. § 13.35** prohibition applies even in Alaska parks where the surface collection of other geologic resources is permitted. Regulations in association with 2009 PRPA are being finalized (February 2013).	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.1** emphasizes I & M, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.
Rocks and Minerals	**NPS Organic Act**, **16 USC. § 1 *et seq.*** directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law. **Exception: 16 USC. § 445c (c) – Pipestone National Monument enabling statute**. Authorizes Native American collection of catlinite (red pipestone).	**36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units. **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Mining Claims	**Mining in the Parks Act of 1976, 16 USC. § 1901 *et seq.*** authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC. § 21 *et seq.*** Allows US citizens to locate mining claims on Federal lands. Imposes administrative & economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 C.F.R. § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 C.F.R. Part 6** regulates solid waste disposal sites in park units. **36 C.F.R. Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability. **43 C.F.R. Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at 36 C.F.R. Parts 6 and 9A. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.
Nonfederal Oil and Gas	**NPS Organic Act, 16 USC. § 1 *et seq.*** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). Individual Park Enabling Statutes: 16 USC. § 230a (Jean Lafitte NHP & Pres.) 16 USC. §450kk (Fort Union NM), 16 USC. § 459d-3 (Padre Island NS), 16 USC. § 459h-3 (Gulf Islands NS), 16 USC. § 460ee (Big South Fork NRRA), 16 USC. § 460cc-2(i) (Gateway NRA), 16 USC. § 460m (Ozark NSR), 16 USC.§698c (Big Thicket N Pres.), 16 USC. §698f (Big Cypress N Pres.)	**36 C.F.R. Part 6** regulates solid waste disposal sites in park units. **36 C.F.R. Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights to: - Demonstrate bona fide title to mineral rights; - Submit a plan of operations to NPS describing where, when, how they intend to conduct operations; - Prepare/submit a reclamation plan; and - Submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.	**Section 8.7.3** requires operators must comply with 9B regulations.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Federal Mineral Leasing (Oil & Gas, Salable Minerals, and Non-locatable Minerals)	**The Mineral Leasing Act, 30 USC. § 181 *et seq.***, and the **Mineral Leasing Act for Acquired Lands, 30 USC. § 351 *et seq.*** do not authorize the BLM to lease federally owned minerals in NPS units. **Exceptions**: Glen Canyon NRA (16 USC. § 460dd et seq.), Lake Mead NRA (16 USC. § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC. § 460q et seq.) authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration. **Exceptions**: Native American Lands Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, (25 USC. § 396), and the Indian Leasing Act of 1938 (25 USC. §§ 396a, 398 and 399) and Indian Mineral Development Act of 1982 (25 USC.S. §§ 2101-2108), all minerals are subject to lease and apply to Native American trust lands within NPS units. **Federal Coal Leasing Amendments Act of 1975, 30 USC. § 201** does not authorize the BLM to issue leases for coal mining on any area of the national park system.	**36 C.F.R. § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law. **BLM regulations at 43 C.F.R. Parts 3100, 3400, and 3500** govern Federal mineral leasing. **Regulations re: Native American Lands within NPS Units:** 25 C.F.R. pt. 211 governs leasing of tribal lands for mineral development. 25 C.F.R. pt. 212 governs leasing of allotted lands for mineral development. 25 C.F.R. pt. 216 governs surface exploration, mining, and reclamation of lands during mineral development. 25 C.F.R. pt. 224 governs tribal energy resource agreements. 25 C.F.R. pt. 225 governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938 (codified at 25 USC.S. §§ 2101-2108). 30 C.F.R. §§ 1202.100-1202.101 governs royalties on oil produced from Indian leases. 30 C.F.R. §§ 1202.550-1202.558 governs royalties on gas production from Indian leases. 30 C.F.R. §§ 1206.50-1206.62 & §§ 1206.170-1206.176 governs product valuation for mineral resources produced from Indian oil and gas leases. 30 C.F.R. § 1206.450 governs the valuation coal from Indian Tribal and Allotted leases. 43 C.F.R. pt. 3160 governs onshore oil and gas operations, which are overseen by the Bureau of Land Management	**Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Nonfederal minerals other than oil and gas	**NPS Organic Act, 16 USC. §§ 1 and 3** **Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 *et. seq.*** prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.	**NPS regulations at 36 C.F.R. Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a § 5.3 business operation, and § 5.7 – Construction of buildings or other facilities, and to comply with the solid waste regulations at Part 6. **SMCRA Regulations at 30 C.F.R. Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation , and employee protection. Part 7 of the regulations states that National Park System lands are unsuitable for surface mining.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with 36 CFR Parts 1 and 5.
Park Use of Sand and Gravel	**Materials Act of 1947, 30 USC. § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Exception:** 16 USC. §90c 1(b) the non-wilderness portion of Lake Chelan National Recreation Area, where sand, rock and gravel may be made available for sale to the residents of Stehekin for local use as long as such sale and disposal does not have significant adverse effects on the administration of the National Recreation Area.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: - Only for park administrative uses. - After compliance with NEPA & other federal, state, and local laws, and a finding of non-impairment. - After finding the use is park's most reasonable alternative based on environment and economics. - Parks should use existing pits and create new pits only in accordance with park-wide borrow management plan. - Spoil areas must comply with Part 6 standards - NPS must evaluate use of external quarries. Any deviations from this policy require written waiver from the Secretary, Assistant Secretary, or Director.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC. § 403** prohibits the construction of any obstruction, on the waters of the united states, not authorized by congress or approved by the USACE. **Clean Water Act 33USC. § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US (including streams)). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also D.O. 77-2) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also D.O. 77-1)	None Applicable.	**Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems. **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human- caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes. **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Soils	**Soil and Water Resources Conservation Act, 16 USC. §§ 2011 – 2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC. § 4201 *et. seq.*** requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**7 C.F.R. Parts 610 and 611**are the US Department of Agriculture regulations for the Natural Resources Conservation Service. Part 610 governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. Part 611 governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.	**Section 4.8.2.4** requires NPS to: - Prevent unnatural erosion, removal, and contamination. - Conduct soil surveys. - Minimize unavoidable excavation. - Develop/follow written prescriptions (instructions).

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National Park Service
US Department of the Interior

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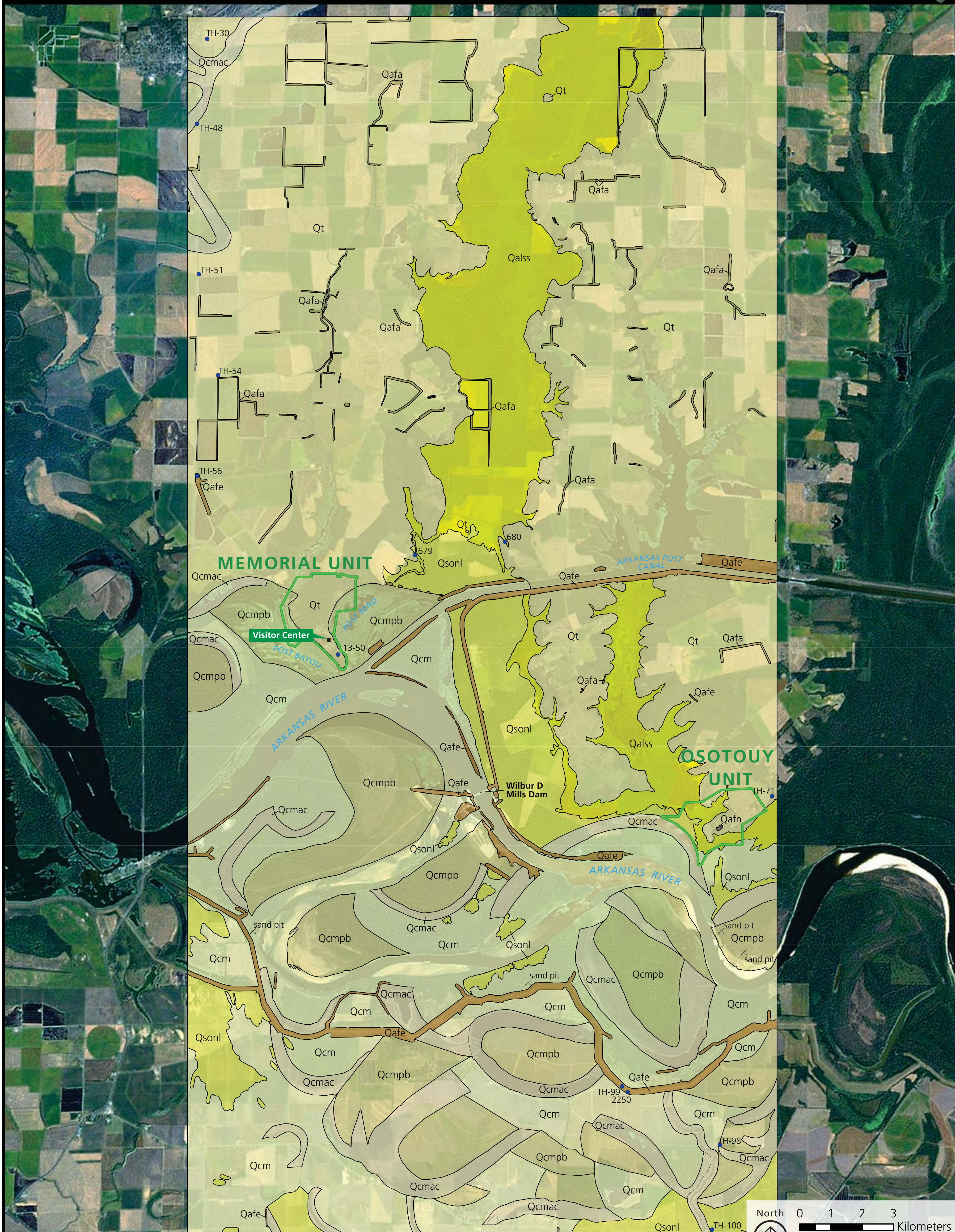
Geologic Map of Arkansas Post National Memorial

Arkansas

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science



NPS Boundary

Infrastructure

- structure

Surface Wells and Sand Pits

- well
- sand pit

Geologic Contacts

- known or certain
- quadrangle boundary

Geologic Units

Qafa	Artificial fill, agricultural
Qafe	Artificial fill, engineered/flood control
Qafn	Artificial fill, Native-American (Indian Mounds)
Qalss	Small stream deposits
Qcmpb	Channel meander point bar deposits
Qcmac	Channel meander abandoned channel/course deposits
Qcm	Channel meander undifferentiated deposits
Qsonl	Stream overbank natural levee
Qsobs	Stream overbank backswamp deposits
Qt	Terrace deposits

This map was produced by Georgia Hybels (National Park Service) in May 2013. It is an overview of compiled geologic data prepared as part of the NPS Geologic Resources Inventory. This map is not a substitute for site-specific investigations.

The source maps used in creation of the digital geologic data were:

Ausbrooks, S. M. and Prior, W.L. 2009. Geologic Map of the Arkansas Post 7.5' Quadrangle, Arkansas and Desha Counties, Arkansas (1:24,000 scale). Digital Geologic Map DGM-AR-00026. Arkansas Geological Survey.

Ausbrooks, Scott M. and Prior, W.L. 2009. Geologic Map of the Watson 7.5' Quadrangle, Arkansas and Desha Counties, Arkansas (1:24,000 scale). Digital Geologic Map DGM-AR-00894. Arkansas Geological Survey.

As per source map scale and U.S. National Map Accuracy Standards, geologic features represented here are within 12 m (40 ft) of their true location.

All digital geologic data and publications prepared as part of the Geologic Resources Inventory are available at the NPS Integrated Resource Management Applications Portal (IRMA): https://irma.nps.gov/App/Reference/Search. Enter “GRI” as the search text and select a park from the unit list.

Map Unit Properties Table: Arkansas Post National Memorial

Colored units are mapped within Arkansas Post National Memorial.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Recent)	Artificial fill, agricultural (Qafa)	**Qafa** appears as long, linear topographic highs composed of a mixture of locally derived clays, silts, sands, and some gravels. Individual ridges are 6 to 15 m (20 to 50 ft) wide and 2 to 3 m (5 to 10 ft) high. These features serve as levees that are frequently modified, enlarged, or obliterated. Artificial units were mapped to prevent confusion for future mappers after years of weathering, vegetation, and land-use changes.	Geologic Connections with Memorial Stories—Agriculture accelerated during the mid 1800s through the early 1900s. Fertile soils of the floodplains attracted farmers whereas seasonal floods often destroyed crops.	Past Land Use—**Qafa** is an anthropogenic unit.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—Part of the long history of human settlement in the area.
QUATERNARY (Recent)	Artificial fill, engineered/flood control/navigation (Qafe)	Similar in composition to **Qafa**, **Qafe** may also contain a core or be capped with rock riprap from distant sources. The topographic high ground formed by **Qafe** serves as highway and railroad beds, and engineered levees for flood control and navigation. The latter type of feature is 15 to 150 m (50 to 500 ft) long and 2 to 9 m (5 to 30 ft) high. **Qafe** is more permanent in purpose than **Qafa**. Artificial units were mapped to prevent confusion for future mappers after years of weathering, vegetation, and land-use changes.	Fluvial features and processes—**Qafe** mimics a natural levee (**Qsonl**) with more extreme slopes.	Flooding and Fluvial Geomorphology—**Qafe** is associated with controlling the morphology of the Arkansas River and dredging practices. Past Land Use—**Qafe** is an anthropogenic unit.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—Representative of the ongoing struggle between human activities and the Arkansas River. Levees attempt to protect adjacent areas from flooding, and navigational channels need to be consistently passable.
QUATERNARY (Recent)	Artificial fill, Native-American (Indian Mound) (Qafn)	**Qafn** is similar in composition to **Qafa** and **Qafe**, but appears are distinct, high mounds above the natural land surface. The mounds are typically round to oblong and range from 15 to 60 m (50 to 200 ft) across and as much as 8 m (25 ft) high. Artificial units were mapped to prevent confusion for future mappers after years of weathering, vegetation, and landuse changes. **Qafn** is mapped within memorial boundaries at the Osotouy Unit.	Geologic Connections with Memorial Stories—Mounds occur throughout the area (and within the Osotouy Unit). Provide evidence of early American Indian inhabitation. The Quapaw tribe did not construct the mounds. Paleontological Resources—Modern bison remains were collected at the mound complex within the Osotouy Unit.	Past Land Use—An access road crosses a mound at the Osotouy Unit causing exposure of archeological resources.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—Part of the long history of human settlement in the area.
QUATERNARY (Holocene)	Small stream deposits (Qalss)	**Qalss** comprises mixtures of clays, silts, sands, and gravels in modern streams and small rivers. Individual deposits of **Qalss** are lenticular (lens-shaped) and discontinuous in outcrop with variable layer-thickness. **Qalss** is mapped within park boundaries at the Osotouy Unit.	Fluvial features and processes—**Qalss** is the youngest naturally occurring unit within the memorial area, accumulating on smaller streams and bayous.	Flooding and Fluvial Geomorphology—Menard Bayou is depositing **Qalss** within the Osotouy Unit. Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qalss** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qalss** is the youngest, naturally occurring geologic unit in the map area.
QUATERNARY (Holocene)	Channel meander point bar deposits (Qcmpb)	**Qcmpb** occurs in crescent-shaped ridges of silt and sand as much as 3 m (10 ft) high. These ridges are separated by lower swales that trap clay, silt, and organic matter. Thickness of **Ocmpb** is variable, but ranges from 9 to 27 m (30 to 90 ft). **Qcmbp** is mapped within memorial boundaries at the Memorial Unit.	Geologic Connections with Memorial Stories—Coarser grained deposits of **Qcmpb** and **Qt** are more resistant to erosion and form high ground above the lowlands flanking the Arkansas River. This high ground was the reason Arkansas Post was established at this location. Fluvial Features and Processes—**Qcmpb** is part of a complex zone in which sedimentation rates are highest near the active river channel. This difference causes the development of an alluvial ridge (meander belt) that is elevated above an adjacent floodplain (overbank). As a stream migrates laterally and downstream, a succession of bar deposits truncate one another forming a complex landform—point bar accretionary topography. The morphology of **Qcmpb** conforms to the curvature of the source channel.	Flooding and Fluvial Geomorphology—Coarser deposits of **Qcmpb** readily transmit groundwater flow, making them productive aquifers. Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Past Land Use—Sand pits are located within **Qcmpb**. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qcmpb** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qcmpb** accumulated on the landscape throughout the Holocene Epoch as rivers meandered across their valleys.

Colored units are mapped within Arkansas Post National Memorial.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Holocene)	Channel meander abandoned channel/course deposits (Qcmac)	**Qcmac** is of variable composition. The lower arm of the meander fills with fine-grained silts, sands, and clays, whereas the upper arm of the abandoned meander contains coarser sand and silt deposits. As the inactive, cutoff channel slowly fills, a uniform clay "plug" forms. Thickness of **Qcmac** varies from 8 to 24 m (25 to 80 ft). **Qcmac** is mapped within memorial boundaries at the Osotouy Unit.	Fluvial Features and Processes—**Qcmac** is part of a complex zone in which sedimentation rates are highest near the active river channel. This difference causes the development of an alluvial ridge (meander belt) that is elevated above an adjacent floodplain (overbank). **Qcmac** forms after a meander loop is cut off from the active river channel, resulting in an oxbow lake that slowly fills with sediment.	Flooding and Fluvial Geomorphology—Finer grained material in **Qcmac** act as aquicludes or confining layers to groundwater flow. Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Past Land Use—Sand pits are locally located within **Qcmac**. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qcmac** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qcmac** accumulated on the landscape throughout the Holocene Epoch as rivers meandered across their valleys.
	Channel meander undifferentiated deposits (Qcm)	**Qcm** is a mixture of unconsolidated sands, silts, and clays with some gravel deposited by streams and rivers that meander and shift laterally across the landscape over time. Locally variable thickness, ranging from 9 to 27 m (30 to 90 ft).	Fluvial Features and Processes—**Qcm** is part of a complex zone in which sedimentation rates are highest near the active river channel. This difference causes the development of an alluvial ridge (meander belt) that is elevated above an adjacent floodplain (overbank). **Qcm** typically contains meander scars, point bars, and abandoned channels.	Flooding and Fluvial Geomorphology—Complex patterns of **Qcm** cause spatial variances in the hydrogeologic system. Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qcm** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qcm** accumulated on the landscape throughout the Holocene Epoch as rivers meandered across their valleys.
	Stream overbank natural levee (Qsonl)	**Qsonl** typically features reworked (homogenized) clay, silt, and fine-sand deposits and forms the highest elevations within the meander belt system. Locally, thickness is variable, but ranges from a thin veneer to approximately 5 m (15 ft). **Qsonl** is mapped within memorial boundaries at the Osotouy Unit.	Geologic Connections with Memorial Stories—Fertile overbank deposits provided ample substrate for agricultural development throughout the area. Fluvial Features and Processes—**Qsonl** is part of a complex zone in which sedimentation rates are highest near the active river channel. This difference causes the development of an alluvial ridge (meander belt) that is elevated above an adjacent floodplain (overbank). **Qsonl** builds up as areas of higher elevation along the river banks during times of flooding. Natural levees form as incrementally deposited sedimentary laminates (layers) during successive overbank flood events. In older levees, plant roots and burrowing fauna have obliterated much of the original layering features. Levees are highly variable, but typically overlie other fluvial deposits such as **Qsobs**, **Qcmpb**, **Qcmac**, **Qcm**, and **Qso** with gradational contacts (i.e. not separated by an erosional surface).	Flooding and Fluvial Geomorphology—Deposits of **Qsonl** at the Osotouy Unit affect the course of Menard Bayou. Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qsonl** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qsonl** accumulated on the local landscape as the Arkansas River established at least seven meander belts during the Holocene Epoch.
	Stream overbank backswamp deposits (Qsobs)	**Qsobs** contains fine-grained clays and silts as well as abundant organic matter, such as woody fragments. The clays are mottled in colors such as grays, browns, and tans. Abundant ferruginous (iron-bearing) and calcareous (containing calcium carbonate) nodules occur within this unit. **Qsobs** is of variable thickness, but averages 6 m (20 ft).	Geologic Connections with Memorial Stories—Fertile overbank deposits provided ample substrate for agricultural development throughout the area. Fluvial Features and Processes—**Qsobs** is part of a complex zone in which sedimentation rates are highest near the active river channel. This difference causes the development of an alluvial ridge (meander belt) that is elevated above an adjacent floodplain (overbank). **Qsobs** occupies the low-lying areas between natural levees (**Qsonl**) adjacent to the meander belts of large streams and rivers. Staining and striations within **Qsobs** results from shrink-and-swell cycles associated with periodic wetting and drying.	Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qsobs** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qsobs** accumulated on the local landscape as the Arkansas River established at least seven meander belts during the Holocene Epoch.

Colored units are mapped within Arkansas Post National Memorial.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Holocene)	Stream overbank undifferentiated deposits (Qso)	**Qso** contains varying mixtures of sands, silts, and clays that were deposited by larger streams and rivers. **Qso** typically displays flat, featureless topography with natural levees. **Qso** is not exposed at the surface in the memorial area, but appears on regional cross sections.	Geologic Connections with Memorial Stories—Fertile overbank deposits provided ample substrate for agricultural development throughout the area. Fluvial Features and Processes—**Qso** is part of a complex zone in which sedimentation rates are highest near the active river channel. This difference causes the development of an alluvial ridge (meander belt) that is elevated above an adjacent floodplain (overbank).	Flooding and Fluvial Geomorphology— Complex patterns of **Qso** cause spatial variances in the hydrogeologic system. Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qso** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qso** accumulated on the local landscape as the Arkansas River established at least seven meander belts during the Holocene Epoch.
QUATERNARY (Pleistocene)	Terrace deposits (Qt)	**Qt** contains clays and silts with some sands and gravels in deposits approximately 15 m (50 ft) thick with local variations. **Qt** occurs as both narrow benches along modern stream valleys and as broad plains. **Qt** is mapped within memorial boundaries at the Memorial and Osotouy units.	Geologic Connections with Memorial Stories—Coarser grained deposits of **Qt** and **Qcmpb** are more resistant to erosion and form high ground above the lowlands flanking the Arkansas River. This high ground was the reason Arkansas Post was established at this location. Fluvial features and processes—**Qt** is part of an evolving fluvial system. **Qt** was deposited on a relatively level to slightly inclined surface bounded on one side by a steeply ascending slope (e.g., a dissected upland surface), and bounded on the other side by a steeply descending slope (an erosional scarp), which drops to a lower level (e.g., a younger stream floodplain surface). Paleontological resources—Petrified wood, invertebrate fossils, and vertebrate fossils are found regionally in Pleistocene terrace deposits.	Flooding and Fluvial Geomorphology—Memorial Unit is located on **Qt** rising above the active floodplain of the Arkansas River. Slope Movements—Unconsolidated units may be prone to mass wasting when exposed on slopes. Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking. **Qt** could be prone to liquefaction.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qt** accumulated during the colder climates of the Pleistocene ice ages. **Qt** is older than recent channel meander (**Qcmpb**, **Qcmac**, **Qcm**) and overbank (**Qsonl**, **Osobs**, and **Qso**) deposits, but younger than underlying braided stream deposits (**Obsl**).
QUATERNARY (Pleistocene)	Braided stream lower deposits (Qbsl)	Glacial outwash gravels dominate the lower portions of **Qbsl** overlain by well-sorted sands. This upward fining in the sedimentary grainsize indicates the progressive lowering of stream (and sedimentation) velocity during sea level rise upon glacial melting. Thickness of **Qbsl** ranges from 12 to 40 m (40 to 130 ft). Like **Qso**, **Qbsl** is not exposed at the surface in the memorial area but appears on regional cross sections.	Paleontological Resources—Petrified wood, invertebrate fossils, and vertebrate fossils are found regionally in Pleistocene braided stream deposits.	Seismicity—Unconsolidated materials transmit seismic waves and amplify shaking.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Qbsl** accumulated during the colder climates of the Pleistocene ice ages.
PALEOGENE (Eocene)	Jackson Group (Tj)	**Tj** consists of rather homogenous blue-gray to dark gray clay and some silty clay layers. Thickness ranges from 80 to 130 m (270 to 420 ft). Like **Qso** and **Qbsl**, **Tj** is not exposed at the surface in the memorial area but appears on regional cross sections.	Paleontological Resources—**Tj** can be rich in molluscan fossils, other invertebrate fossils, and some invertebrate molds.	Flooding and Fluvial Geomorphology—Fine-grained clays in **Tj** act as aquicludes or confining layers to groundwater flow. Economic Resource Development—**Tj** contains lignite and may be a source of coal-bed natural gas or methane.	Cenozoic Era (the past 65.5 million years): River Valley Evolution and Ice Age Glaciation—**Tj** formed during an Eocene marine incursion into the Mississippian Embayment.