National Park Service
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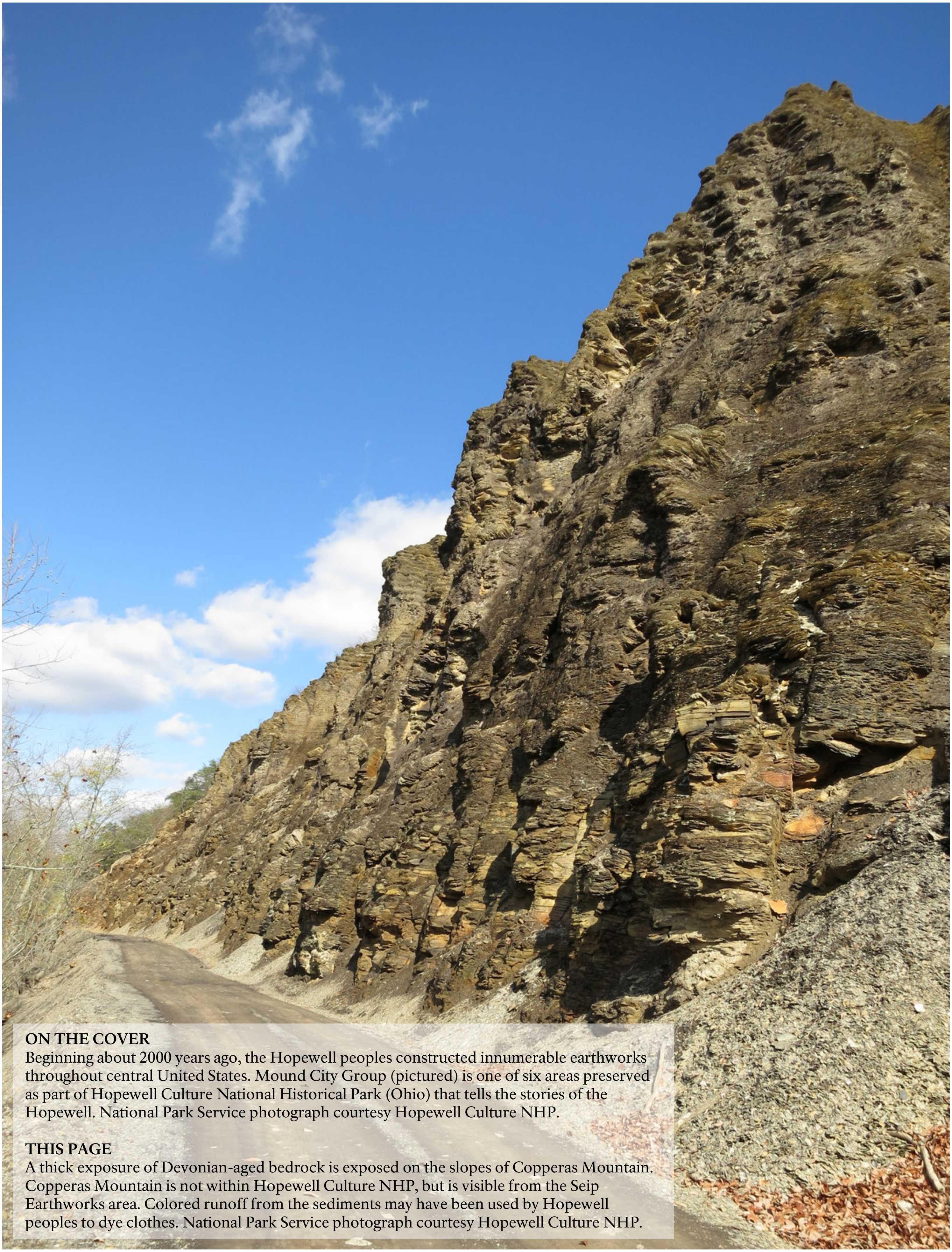
Natural Resource Stewardship and Science

Hopewell Culture National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2013/640



ON THE COVER
Beginning about 2000 years ago, the Hopewell peoples constructed innumerable earthworks throughout central United States. Mound City Group (pictured) is one of six areas preserved as part of Hopewell Culture National Historical Park (Ohio) that tells the stories of the Hopewell. National Park Service photograph courtesy Hopewell Culture NHP.

THIS PAGE
A thick exposure of Devonian-aged bedrock is exposed on the slopes of Copperas Mountain. Copperas Mountain is not within Hopewell Culture NHP, but is visible from the Seip Earthworks area. Colored runoff from the sediments may have been used by Hopewell peoples to dye clothes. National Park Service photograph courtesy Hopewell Culture NHP.

Hopewell Culture National Historical Park

Geologic Resources Inventory Report

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National Park Service
Geologic Resources Division
PO Box 25287
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March 2013

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics 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/).

Please cite this publication as:

Thornberry-Ehrlich, T. L. 2013. Hopewell Culture National Historical Park: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2013/640. National Park Service, Fort Collins, Colorado.

NPS 653/120138, March 2013

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Executive Summary

This report accompanies the digital geologic map data for Hopewell Culture National Historical Park in Ohio, produced by the Geologic Resources Division in collaboration with its partners. It contains information relevant to resource management and scientific research. This report was prepared using available published and unpublished geologic information. The Geologic Resources Division did not conduct any new fieldwork in association with this report.

Hopewell Culture National Historical Park preserves part of a vast collection of mounds, walls, ditches, and other ceremonial earthworks created by ancient Hopewell people in south-central Ohio between about 1 CE and 400 CE. The park was first established as Mound City Group National Monument in 1923 to preserve prehistoric mounds of "great historic and scientific interest." It was greatly expanded and redesignated as a national historical park in 1992 to encompass five separate areas: the Mound City Group, Hopewell Mound Group, Hopeton Earthworks, Seip Earthworks, and High Bank Works. Legislation in 2009 expanded the park boundary to include the Spruce Hill Works. Together, the earthworks present various research and learning opportunities as well as a challenge to better understand the ancient culture that flourished there.

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 discusses geologic issues facing resource managers at the park, distinctive geologic features and processes within the park, and the geologic history leading to the park's present-day landscape. An overview graphic illustrates the geologic data; the Map Unit Properties Table summarizes the main features, characteristics, and potential management issues for all rocks and unconsolidated deposits on the digital geologic map for Hopewell Culture National Historical Park. This report also provides a glossary, which contains explanations of technical, geologic terms, including terms on the Map Unit Properties Table. Additionally, a geologic timescale (fig. 2) shows the chronologic arrangement of major geologic events, with the oldest events and time units at the bottom and the youngest at the top.

Ohio Division of Geological Survey (ODGS; 2003), Swinford et al. (2003), and Quinn and Goldthwait (1985) are the source maps for the Hopewell Culture National Historical Park digital geologic data. The rock units within and surrounding the park can be divided into three main types: (1) very old sedimentary rocks of mid-Paleozoic age (approximately 420 to 330 million years old); (2) ice age deposits from the Illinoian and Wisconsinan glacial periods (less than 2.6 million years old); and (3) modern fluvial deposits associated with stream channels dating to the past 17,000 years.

The Paleozoic sedimentary rocks—shales, siltstones, and sandstones—were deposited in basins associated with the construction of the Appalachian Mountains and the assembly of the supercontinent Pangaea. Hundreds of millions of years of the subsequent rock record are missing in south-central Ohio. The story picks up again during the ice ages, which began about 2 million years ago as glacial ice repeatedly advanced and retreated over the area, sculpting the landscape. Glacial deposits—outwash, moraines, tills, drift, and lacustrine sediments—from the most recent glacial period (called the "Wisconsinan") and at least one previous glacial period (the "Illinoian") are found within and surrounding the park. The park is located near the maximum extent of glaciation for the Wisconsinan and Illinoian periods. Significantly, Hopewell people constructed earthworks atop these glacial deposits. Following the most recent glacial retreat about 17,000 years ago, the geologic story has been one of river deposition and erosion, processes that continue to impact the park today along the banks of the Scioto River and Paint Creek.

Geologic issues of particular significance for resource management at Hopewell Culture National Historical Park were identified during a 2009 GRI scoping meeting and a 2012 follow-up conference call. They include the following:

- Flooding and Fluvial Processes. The Scioto River, Paint Creek, and North Fork Paint Creek are prominent features shaping the park's landscape today. Flooding along one or more of these waterways occurs on average every 2 to 3 years. Natural meandering of these channels potentially threatens park resources in at least four units: Mound City Group, Hopeton Earthworks, Hopewell Mound Group, and High Bank Works. Manmade ponds occur in several units of the park; no plans have been made to remove earthen dams at this time.
- Disturbed Lands and Mineral Resources. For hundreds of years, humans have utilized the rich natural mineral resources of the park area. Today, sand and gravel operations targeting glacial deposits continue throughout Ross County. Part of one large operation is located within Hopeton Earthworks unit. Remnants of a World War I training site, Camp Sherman, including the remains of an incinerator at Mound City, present issues for park resource managers.

- Slope Processes. Eroding riverbanks are subject to slumping and collapse. Slumping occurs within unconsolidated glacial deposits throughout the area, particularly when those units are undercut by fluvial processes, such as those along North Fork Paint Creek at Hopewell Mound Group, and along the Scioto River at Mound City. Rockfalls occur frequently on the steep slopes of Copperas Mountain, Spruce Hill, and other exposures throughout the park area. Concretions from the Ohio Shale weather out preferentially and fall into Paint Creek at Seip Earthworks.
- Seismic Activity. Earthquakes are not common in south-central Ohio. Geologists from the ODGS are concerned about potential impacts from the New Madrid Seismic Zone, which is centered in Missouri. Shaking from the massive 1811 and 1812 New Madrid earthquakes was felt in what is now the park.

Geologic features of particular significance for resource management at Hopewell Culture National Historical Park include the following:

- Glacial Features. The last two major glacial advances of the Pleistocene reached as far south as Ross County, and the park is located near the Illinoian and Wisconsinan terminal moraines. As such, myriad glacial features of erosion and deposition occur throughout the area. The glacial history is complex. Glacial features include outwash terraces, moraines, and glacial erratics (large pieces of rock transported by the glacial ice from elsewhere).
- Geologic Connections to Park Stories. Generations of Hopewell people took advantage of the local geologic setting by constructing precise earthworks and mounds atop glacial outwash terraces, perched above the reach of modern floods. Local Berea Sandstone (geologic map unit DMu) was used in the construction of the Chillicothe State House. During World War I, Camp Sherman was sited in the area because of the landscape's similarities to that of northeastern France.
- Paleontological Resources. The Paleozoic bedrock surrounding the park is fossiliferous, containing remains of marine invertebrates, fish, and plants. Pleistocene fossil remains such as mammoths may be present in the unconsolidated glacial deposits. The rocks in the park may contain Paleozoic fossils, but such fossils are found as cultural resources. Fossils occur as grave goods and in ceremonial deposits buried in Hopewell mounds, and may have been obtained through trade or direct procurement. Fossil shark teeth are among the most common and remarkable of these paleontological resources known to Hopewell collectors.
- Sedimentary Features. Sedimentary features within the Paleozoic bedrock of the park record the depositional environments in which they formed. Exposures of Ohio-Olentangy Shale (Do), visible on many hillsides throughout the area, contain classic wave ripples. The Ohio Shale is also famous for a variety of nodules and concretions, some of which include interesting minerals and can be as large as a small car.

The story of the park is intimately intertwined with the geologic features and processes visible from every unit. The ancient Hopewell people recognized many of these connections. The preservation of these features is a resource management priority and serves to educate generations to come about the interconnectivity of humans and the environment.

Acknowledgements

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

The Geologic Resources Division (GRD) relies heavily on partnerships with institutions such as Colorado State University, U.S. Geological Survey, state geological surveys, local museums, and universities in developing GRI products.

Special thanks to: Thomas Serenko, Frank Fugitt, and Mac Swinford (geologists, Ohio Division of Geological Survey) for providing information. Dafna Reiner (biologist), Kathleen Brady (curator) and Bret Ruby (archeologist/chief of resource management) at Hopewell Culture NHP provided additional information, photographs, and/or review comments.

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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 Hopewell Culture National Historical Park.

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 Geologic Resources Division (GRD) of the NPS 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 processes, 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 GRI 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).

Regional Information

> "It has been said that there is scarcely a point in either valley [Scioto River or Paint Creek] below Circleville or Bainbridge where one may not be within a few minutes ride of a mound, village site, or other evidence of aboriginal habitation."
>
> —Campbell (1918)

Preserving the mounds, earthworks, and ceremonial sites of the Hopewell culture, which flourished in this woodland area between about 1 CE and 400 CE (Common Era; preferred to "AD"), Hopewell Culture National Historical Park is located in Ross County in south-central Ohio. Redesignated and expanded as a national historical park in 1992, it was first established as Mound City Group National Monument in 1923 to preserve prehistoric mounds of "great historic and scientific interest." It was originally administered by the War Department but managed by the Ohio State Archaeological and Historical Society as a state memorial. The monument was transferred to the NPS in the 1930s and officially came under NPS management in 1946. In 1980, Congress added Hopeton Earthworks National Historic Landmark to the park. The 1992 redesignation incorporated additional sites of archeological interest throughout the area. Legislation in 2009 expanded park boundaries to include additional lands. Hopewell Culture National Historical Park is now spread over six units covering more than 473 ha (1,170 ac): Mound City, Hopeton Earthworks, High Bank Works, Hopewell Mound Group, Seip Earthworks, and the Spruce Hill Works.

The boundary between the Central Lowland and Appalachian Plateaus physiographic provinces, marked by the Allegheny Escarpment, transverses Ross County in the park area (fig. 1). Local sections within these provinces include the Allegheny Plateaus, Glaciated Allegheny Plateaus, and the Till Plains sections. The convergence of these numerous physiographic sections within a narrow area around the park is due to its location near the maximum extent of two major Pleistocene glacial advances in Ohio: the Illinoian and more recent Wisconsinan. Glaciers are tremendous reshapers of landscapes and their effects are highly visible today, more than 17,000 years later. Glacial outwash and other associated unconsolidated deposits cover much of the underlying bedrock.

The bedrock formations exposed in Ross County are primarily sedimentary rocks of Silurian to Devonian age (444 to 359 million years ago, figs. 2 and 3), as described by Swinford et al. (2003). Silurian shale, dolomite, and evaporite (salt) crop out in the most eroded, northern

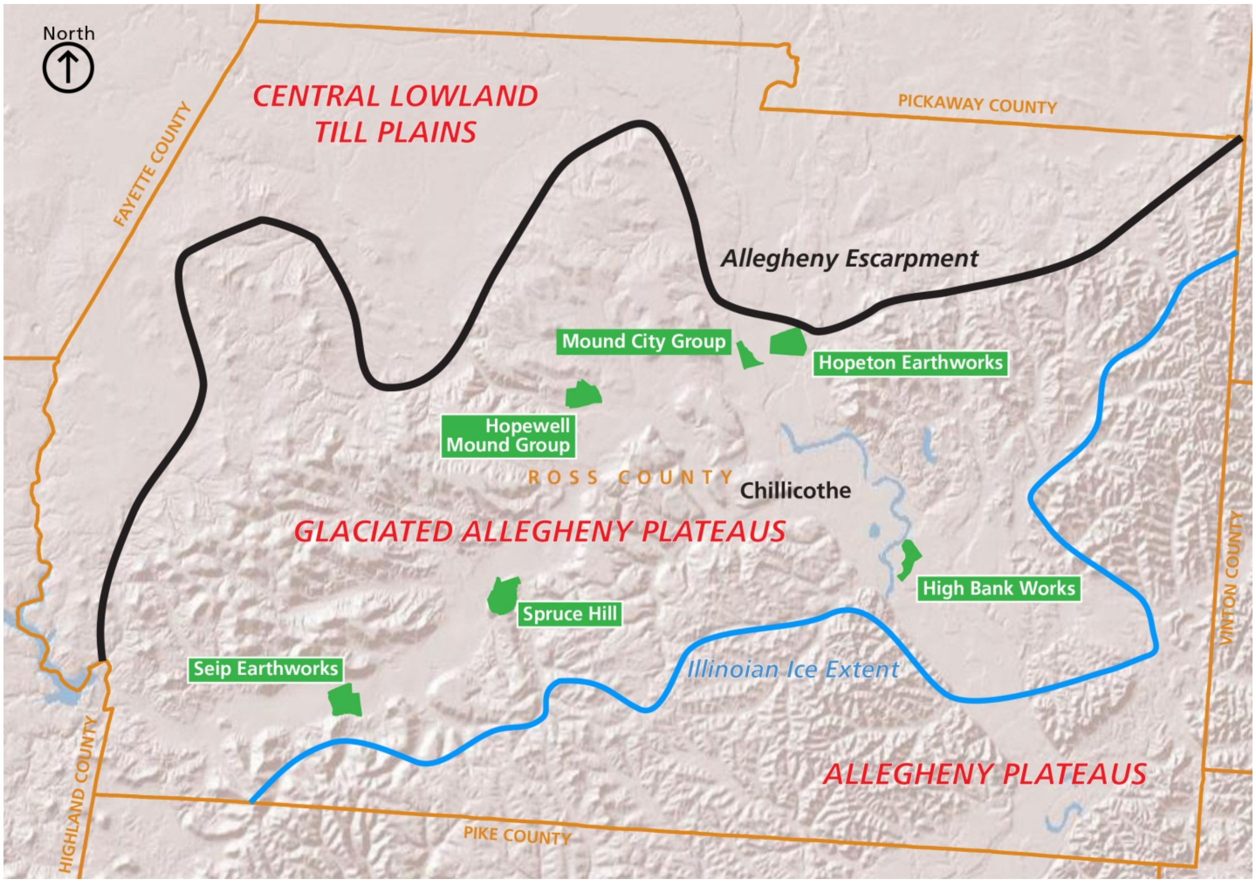

Figure 1. Generalized physiographic map of Ross County. Province names are in red capital letters. Hopewell Culture National Historical Park areas are labeled. The Allegheny escarpment separates the Central Lowland from the Appalachian Plateaus physiographic province. The Illinoian ice extent line marks the maximum extent of ice age glaciers in Ross County. Note the difference in topography between the glaciated (Till Plains and Glaciated Allegheny Plateaus) and unglaciated (Allegheny Plateaus) portions of the county. Graphic compiled and annotated by Jason Kenworthy (NPS Geologic Resources Division) using ESRI shaded relief basemap layer with information from Brockman (2002) and Quinn and Goldthwait (1985).

reaches of the county (geologic map units Ssu, St, and St-b). The only Silurian-aged rocks mapped within Hopewell Culture National Historical Park are from an undivided map unit (St-b) comprising the Tymochtee, Greenfield, and Peebles dolomites, and the Lilley and Bisher formations. Shale and sandstone dominate the Devonian units mapped in Ross County, including the Ohio-Olentangy Shale (Do), Sunbury Shale, Berea Sandstone, and Bedford Shale (all three mapped together as DMu). The Ohio Shale is rich in ironstone concretions, and is mapped beneath the Mound City Group, Hopeton Earthworks, Hopewell Mound Group, High Bank Works, and the lower flanks of Spruce Hill. The Sunbury Shale, Berea Sandstone, and Bedford Shale are mapped on the upper reaches of Spruce Hill and the top of Copperas Mountain, southeast of the Seip Earthworks. The erosion-resistant Devonian Berea Sandstone underlies topographically high, plateau-like areas. This famous building stone is featured in structures throughout Ohio, including the state's first statehouse in Chillicothe. The youngest local bedrock is Mississippian in age (359 to 318 million years ago) and includes sandstone, siltstone, and shale of the Logan and Cuyahoga Formations (Mlc). This unit caps higher hills and ridges in Ross County, including Spruce Hill.

The advance and retreat of ice age glaciers during the Pleistocene (2.6 million to 11,700 years ago) left an incredibly complex record of ice-contact and glacial-fluvial deposits (pl, Ig, Io, Ii, Il, We2–4, Wg1–4, Wit2, Wi3, Wi2, Wot, Wow, Woc, Wok, Wob, and Wl) on the landscape (Quinn and Goldthwait 1985). The ice age deposits cover much of the local bedrock and are responsible for the relatively muted local topographic expression. Notably, Hopewell Culture National Historical Park is located at the maximum extent of the Wisconsinan (most recent) glacial advance and at least one earlier advance, termed the Illinoian. The peoples of the Hopewell culture built mounds on a variety of named outwash terraces associated with the Wisconsinan advance. The Circleville Outwash (Woc) is mapped within Hopeton Earthworks, Mound City Group, Hopewell Mound Group, and High Bank Works. The Kingston Outwash (Wok) is mapped within the Seip Earthworks, near the base of Spruce Hill, and on the eastern margin of the Hopeton Earthworks unit. Wisconsinan glacial moraines are mapped in Hopewell Mound Group (We2) and the lowest reaches of Spruce Hill (Wg1). Spruce Hill is the only area of the park to preserve moraines (Ig) associated with the earlier Illinoian glaciation. Kames, small hills made up of deposits from rivers or lakes beneath or adjacent to a retreating glacier, are also mapped near Spruce Hill.

Holocene-aged (the past 11,700 years) river alluvium and alluvial terraces (Qal and Qalt) are the youngest units on the geologic map for the park and surrounding area. Alluvium associated with the Scioto River or Paint Creek is mapped within each area of the park (see Overview of Digital Geologic Data, Sheet 1 [in pocket]).

Bedrock units in the vicinity of Hopewell Culture National Historical Park are inclined gently (1° to 2°) eastward. Pre-glacial weathering of these units likely created a dissected plateau wherein resistant units capped hills and ridges and less-resistant units were worn away into valleys. This type of topography is reflected in the hillier, unglaciated southern portion of Ross County. The glaciers scoured the bedrock and left a thick mantle of unconsolidated deposits over the northern and central areas of the county. These events are responsible for the more subdued, gently rolling hills of northern Ross County. The park is located at the transition—the maximum extent of Pleistocene glaciation.

The Scioto River and its tributaries are now eroding through the thick glacial deposits, reworking the sediments, and meandering across their floodplains. The landscape within the park comprises gently sloped areas to relatively flat floodplains adjacent to the Scioto River and Paint Creek. Much of the park land was cleared for agricultural uses in the early 19th century.

American Indians constructed many of the archeological sites at Hopewell Culture National Historical Park on high glacial outwash terraces adjacent to rivers and streams. The Mound City, Hopeton Earthworks, and High Bank Works are located on terraces of the Scioto River. The latter two are not open to the public. The Hopewell Mound Group is near North Fork Paint Creek and includes Sulfur Lick Creek, whereas the Seip Earthworks and Spruce Hill units are on Paint Creek and a hilltop overlooking the stream, respectively. The park has legislated access to Spruce Hill, but does not own the land.

Eon	Era	Period	Epoch	Ma		Geologic Map Units	Ohio Events
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	Age of Mammals	Qal and Qalt deposited along streams and rivers; Wisconsinan (W) glacial units deposited; Illinoian (I) glacial units deposited; pl deposited	Fluvial processes, extensive glaciation during at least three major episodes; drainage changes
			Pleistocene	2.6			
		Tertiary – Neogene	Pliocene	5.3			
			Miocene	23.0			
		Tertiary – Paleogene	Oligocene	33.9			Ancient river systems established
			Eocene	55.8			
			Paleocene	65.5			
	Mesozoic	Cretaceous		145.5	Age of Dinosaurs	No Mesozoic unit is present on the park map	Ongoing erosion and weathering in Appalachian Mountains
		Jurassic		199.6			Rift basins form
		Triassic		251			Breakup of Pangaea begins; brittle faulting and volcanism
	Paleozoic	Permian		299	Age of Amphibians		Supercontinent Pangaea intact; Alleghany (Appalachian) Orogeny, more uplift and erosion
		Pennsylvanian		318.1			Uplift and erosion
		Mississippian		359.2		Deposition of Mlc	Fluvial and deltaic systems deposit sand, silt, and mud
		Devonian		416	Fishes	Deposition of DMu; Deposition of Do	Neoacadian Orogeny; Sea circulation is restricted, collects black mud
		Silurian		443.7		Deposition of St-b, St, and Ssu in shallow marine basin	Warm, shallow seas collect limy deposits and evaporites
		Ordovician		488.3	Marine Invertebrates		Taconic Orogeny, Cincinnati arch is uplifted, flanking basins subside
		Cambrian		542			Sandstone, shale, and carbonate deposited atop rifted basement; Extensive oceans cover most of proto-North America (Laurentia)
Proterozoic		Precambrian		1000; 2500			Supercontinent rifted apart; Grenville Orogeny formed supercontinent
Archean				≈4000		No Precambrian unit is present on the park map	
Hadean				4600		Formation of the Earth	Formation of Earth's crust

Figure 2. Geologic time scale. 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). Major tectonic events occurring in the greater Ohio area are included. The geologic map units for Hopewell Culture National Historical Park are also listed stratigraphically. Recent stratigraphic definitions by the Ohio Division of Geological Survey (ODGS) include updated stratigraphic nomenclature for unit "DMu" (Frank Fugitt, geologist, ODGS, email communication, 23 October 2012) after Shrake et al. (2011). Red lines indicate major boundaries between eras. Graphic design by Trista L. Thornberry-Ehrlich (Colorado State University), adapted from geologic time scales published by the U.S. Geological Survey (http://pubs.usgs.gov/fs/2010/3059/) and the International Commission on Stratigraphy (http://www.stratigraphy.org/ics%20chart/09_2010/StratChart2010.pdf).

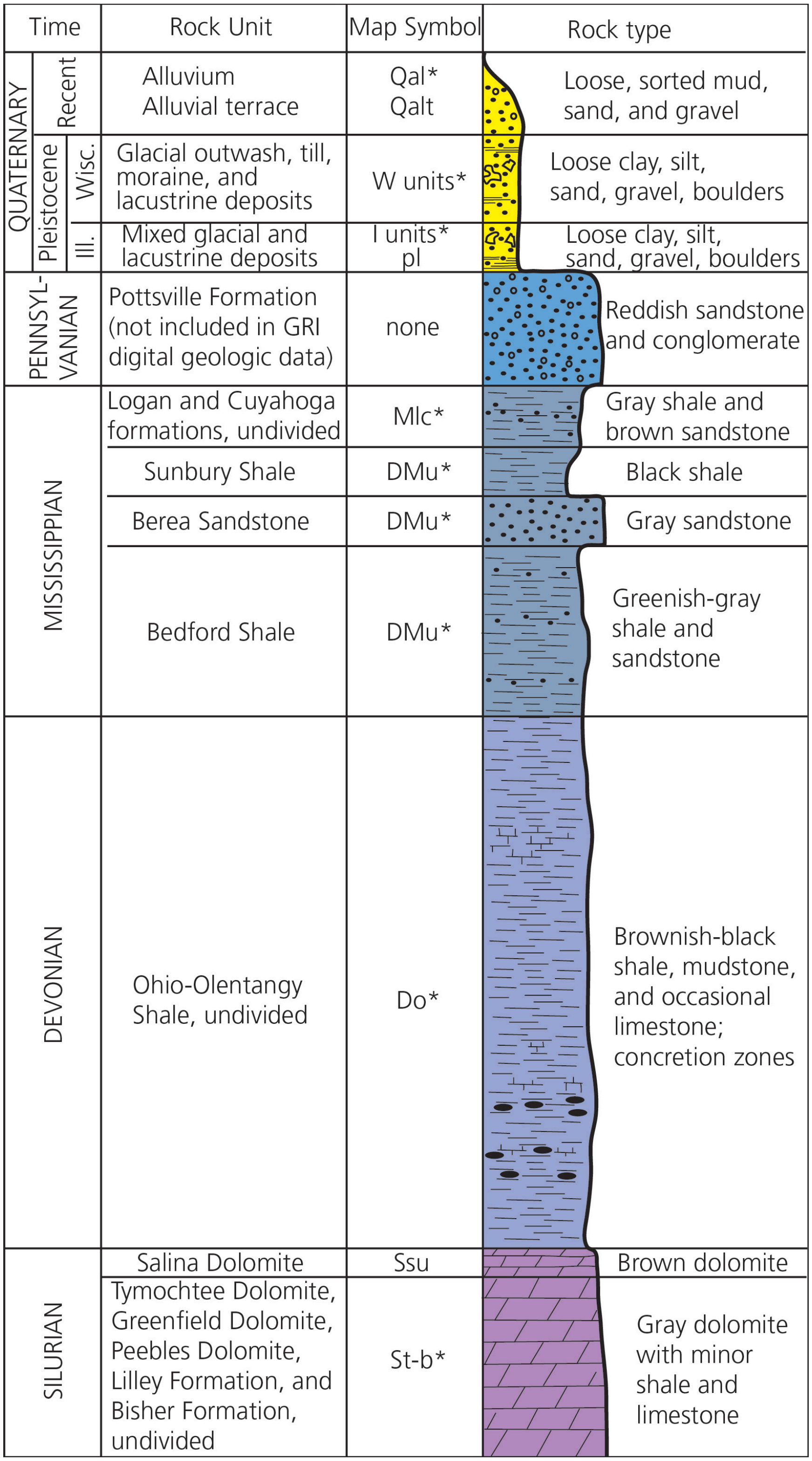

Figure 3. Generalized stratigraphic column for Ross County, Ohio. * = Geologic units mapped within Hopewell Culture National Historical Park. “Ill.” and “Wisc.” stand for Illinoian and Wisconsinan glacial stages, respectively. Recent stratigraphic definitions by the Ohio Division of Geological Survey (ODGS) have revised “DMu” nomenclature after Shrake et al. (2011) (F. Fugitt, email communication, 23 October 2012). See the Map Unit Properties Table for more detail. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Carlson (1991) and Hyde (1921).

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping meeting for Hopewell Culture National Historical Park on 8 October 2009 and a follow-up conference call on 26 March 2012 to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes those discussions and highlights particular issues that may require attention from resource managers. Contact the Geologic Resources Division for technical assistance.

During the 2009 scoping meeting and 2012 conference call, the following geologic resource management issues were identified for Hopewell Culture National Historical Park:

- Flooding and Fluvial Processes
- Disturbed Lands and Mineral Resources
- Slope Processes
- Seismic Activity

Resource managers may find *Geological Monitoring* (Young and Norby 2009) 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, including expertise, personnel, and equipment needed, approximate cost, and labor intensity.

Flooding and Fluvial Processes

The Scioto River, Paint Creek, North Fork Paint Creek, and Sulphur Lick Creek, as well as other small, intermittent streams, are prominent features on the park's landscape and contributed to the cultural story. Flooding along park waterways is relatively frequent, occurring every 2 to 3 years (Edelen et al. 1964; Thornberry-Ehrlich 2009). Major floods in 1898, 1913, 1937, 1945, 1948, and 1959 inundated vast portions of the town of Chillicothe and low-lying areas (below approximately 195 m [640 ft] above sea level) within the park units (Edelen et al. 1964). Near-record floods inundated the area in 1997 (National Oceanic and Atmospheric Administration 1998). Levees, dams, and other structures were installed along regional waterways for flood control and impound features such as Paint Creek Lake (in 1974) and Rocky Fork Reservoir (Mayo and Bartlett, Jr. 1981). Shoreline armoring has been installed at the Mound City Group, but not at any other park site.

American Indians of the Hopewell cultures constructed most of their earthworks on glacial outwash terraces (geologic map units Wob, Wok, Woc, Wow, Wot, and potentially Io [only Woc and Wok are mapped within park boundaries]) located approximately 24 m (80 ft) above the 500-year floodplain. Thus, the mounds and associated cultural resources are not considered to be under immediate threat of loss or damage from regular seasonal floods or even century-scale flood events.

Park staff is concerned about flooding impacts on other cultural resources, roads, trails, fences, and other visitor use facilities located at lower elevations. For example, flooding is a serious issue for trails in the Mound City Group (fig. 4) and impacts the primary access road to the Hopeton Earthworks. The Mound City trails flood on average three times per year. Flooding usually does not require repair work, but necessitates the removal of slippery river mud (Dafna Reiner, biologist, Hopewell Culture NHP, email communication, 1 August 2012). The Tri-County Trail running adjacent to the Hopewell Mound Group unit is subjected to seasonal flooding. The local park district (not the NPS) maintains the trail. Low spots at the High Bank Works unit are prone to flooding, although no infrastructure there is currently threatened (Hopewell Culture NHP staff, conference call, 26 March 2012). Portions of the square earthwork enclosure at the Seip Earthworks are located on the active floodplain of Paint Creek and are subject to overbank flooding. Streamside levees constructed in the 19th or 20th centuries provide some measure of protection (Bret Ruby, archeologist/chief of resource management, Hopewell Culture NHP, email communication, 1 February 2013).

Fluvial processes, particularly river cutbank erosion, are also issues for non-mound cultural resources. Such undercutting and stream erosion are accelerated by the lack of stabilizing vegetation. As Hyde (1921) noted more than 90 years ago, every stretch on the river where the bank was devoid of trees was being undercut. The park has an interest in assessing whether clearcutting by landowners across the river from the park could affect erosion along the park's riverbank. The park has no easement along the river and logging is not likely to cease on private land (Hopewell Culture NHP staff, conference call, 26 March 2012). The park could submit a technical assistance request to the GRD to assess potential impacts to park resources.

River erosion is of particular concern at the Hopewell Mound Group. Large, live trees fall over the cutbank edge due to slumping and erosion as the stream continues eroding the bank (figs. 5 and 6). The shoreline in this part of the park is not armored. According to park staff, this process seems to be accelerating with increased precipitation in the early 2000s and 2010s (Hopewell

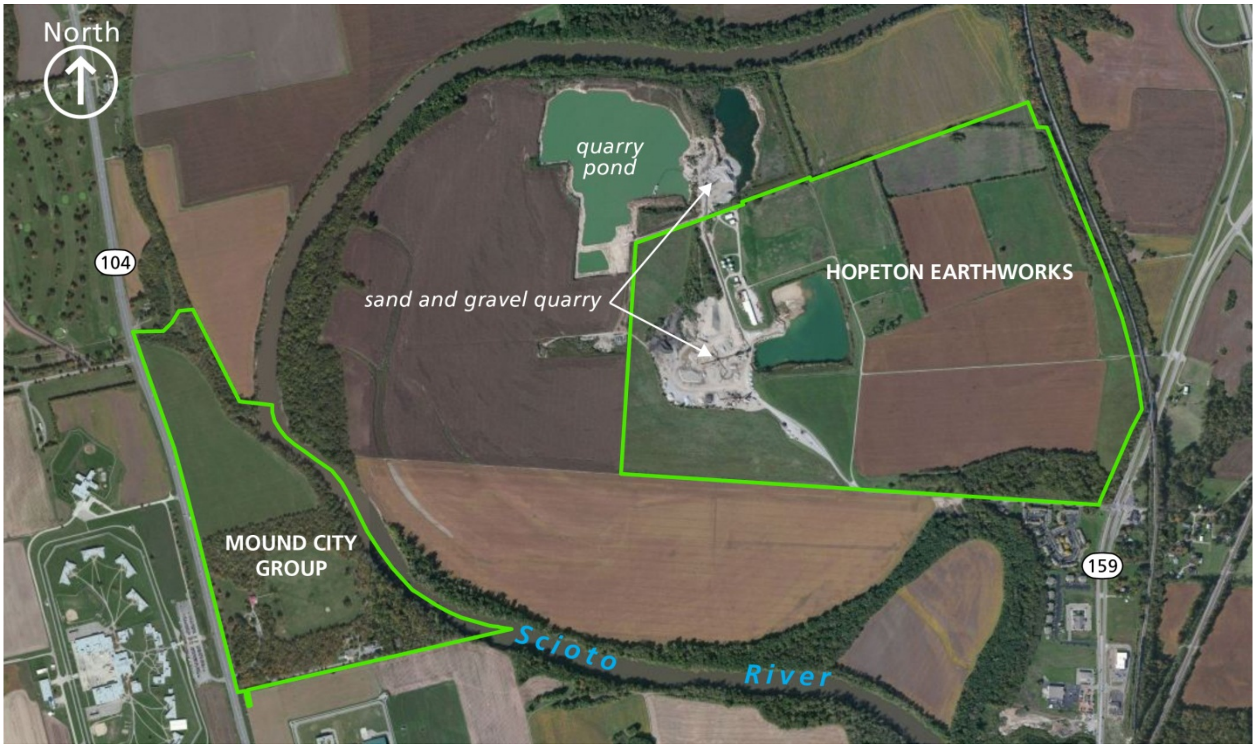

Figure 4. Aerial image of Mound City Group and Hopeton Earthworks. Trails in Mound City Group are subject to flooding, note the extensive Scioto River shoreline along the eastern boundary of the Mound City Group. On private land within the authorized boundary (green lines) of Hopeton Earthworks, the Shelly Company quarry is extracting sand and gravel from alluvium and glacial outwash (geologic map units Qal and Qoc; fig. 7). Such operations are common throughout the region and target expansive glacial deposits. Graphic compiled and annotated by Jason Kenworthy (NPS Geologic Resources Division) using Bing Maps imagery as an ESRI basemap layer.

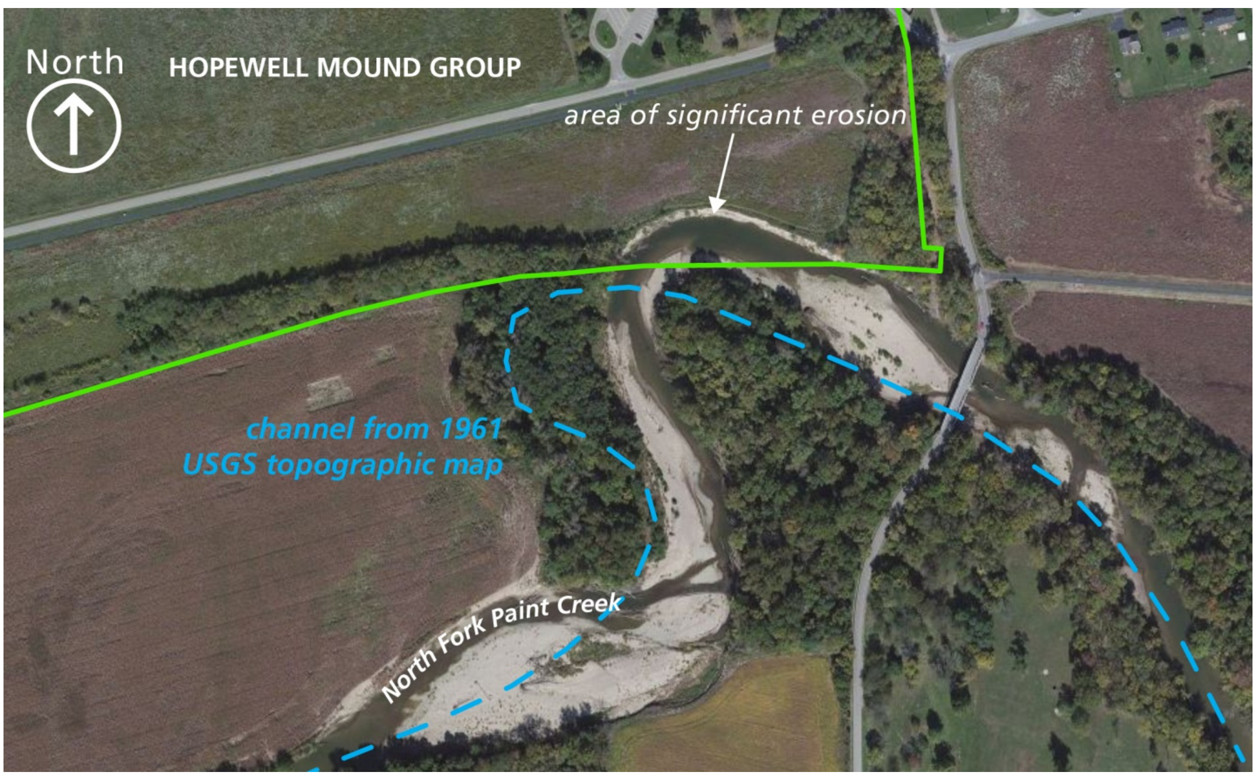

Figure 5. Aerial image of Hopewell Mound Group. Significant erosion (fig. 6) is taking place along North Fork Paint Creek near the southeast corner of the Hopewell Mound Group. Note change in position of the meander compared to the channel position indicated on the 1961 USGS topographic map for the Chillicothe West quadrangle. Park boundary in green. Graphic compiled and annotated by Jason Kenworthy (NPS Geologic Resources Division) using Bing Maps and USA Topo Maps (USGS topographic maps) basemap layers in ESRI ArcMap.

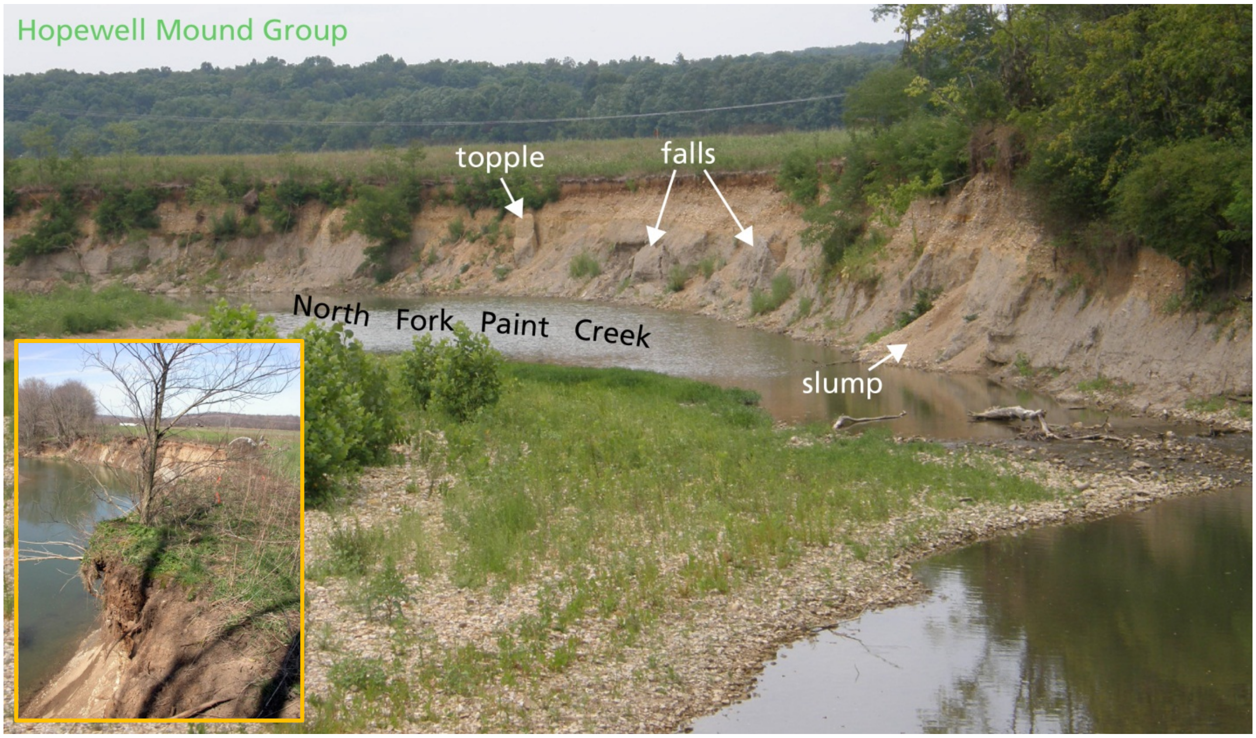

Figure 6. Photographs of North Fork Paint Creek cutbank within Hopewell Mound Group. Erosion along the cutbank has significantly changed the position of the meander with respect the park boundary (fig. 5). Trees also fall over the edge as the bank is undercut beneath them (inset). Slope processes along the cutbank include falls, topples, and slumps (fig. 9). Salvage operations within the park recovered cultural resources in the area threatened by continued erosion and slope processes. National Park Service photograph by Dafna Reiner (Hopewell Culture NHP) on 8 October 2009 with annotation by Trista L. Thornberry-Ehrlich (Colorado State University). Inset photograph from Bauermeister (2004, fig. 3).

Culture NHP staff, conference call, 26 March 2012). A 2005 site inspection (environmental assessment) by Woolpert, Inc. suggested that the North Fork Paint Creek would erode an additional 18 m (60 ft) of the hillslope adjacent to the stream. Erosion along this 300-m (1,000-ft) stretch occurs at a rate of 0.3 to 0.6 m (1 to 2 ft) per year (D. Reiner, email communication, 1 August 2012). Remediation efforts such as shoreline armoring would negatively affect a nearby bridge and other downstream areas; thus, park staff decided to monitor the site and allow natural erosional processes to continue in the area until resources were significantly threatened (Thornberry-Ehrlich 2009).

National Park Service archeologists from the Midwest Archeological Center and Hopewell Culture National Historical Park conducted data recovery (salvage) investigations at the erosion site in 2003, 2004 and 2006 (Bauermeister 2004, 2006, 2010; Landon 2010). Geophysical survey, surface collection, and limited excavations recovered artifacts and intact subsurface pit features relating to both Middle Woodland (Hopewell) and Late Prehistoric (Fort Ancient) occupations. The Middle Woodland period features include ceramics, stone tool debris, animal bone, fire-cracked rock and charcoal indicative of a range of cooking and processing activities. Small amounts of imported ceramics, copper, crystal quartz and mica point to participation in the inter-regional Hopewell Interaction Sphere and activities related to Hopewell ceremonialism conducted within the nearby earthwork precinct. It is believed these data recovery investigations successfully salvaged information from the archeological resources at risk. Erosion continues along the cut-bank exposure and the area is periodically monitored by park staff (B. Ruby, email communication, 7 January 2013).

At the Mound City unit, riprap was installed in the 1980s to curb Scioto River erosion and control flooding in order to protect cultural resources. This project achieved mixed results. The river course has since migrated away from the initially problematic area and the streambanks in this area appeared to be stable at the time of report writing (Hopewell Culture NHP staff, conference call, 26 March 2012). North of the visitor center at the Mound City unit, park maintenance crews planted rows of trees in an attempt to stabilize the steep river banks. Nevertheless, blocks of earth frequently slump into the Scioto River and the slope is considered to be very dangerous to visitors, with high erosion potential (Thornberry-Ehrlich 2009).

Dry Run is an intermittent stream within the Hopeton Earthworks unit. The stream is flanked by wooded areas and floods after heavy precipitation events (Thornberry-Ehrlich 2009). The nearby Scioto River also floods, impacting park fences and inundating Hopeton Road, which leads to the Hopeton quarry gravel pit within the park's legislated boundary. Hopeton Road is impassable when flooded, and the quarry is accessed via a gravel lane through the earthworks within the park. Large trucks traveling on the lane compact the subsurface, reducing pore space and permeability to groundwater flow, thereby increasing surface runoff. Park resource managers want to remove the gravel lane and negotiate with local entities to raise the elevation of Hopeton Road, which would avoid flooding and ensure access without the need for the gravel road.

Climate Change Impacts

A 2007 climate inventory for the park (Davey et al. 2007) reported detailed local climate information, some dating as far back as 1893, that had been gathered at 34 weather/climate stations in the park area (two within park boundaries at "Chillicothe Mound City" and "Chillicothe"). Between 1961 and 1990, mean annual precipitation in the park was between 1,001 and 1,500 mm (about 60 in) (Davey et al. 2007). Park staff and long-term Ohio residents have noted that several years around 2010 were very wet, particularly compared with the relatively dry years of the early 2000s (M. Swinford, geologist, Ohio Department of Natural Resources, Division of Geological Survey [ODGS] and Hopewell Culture NHP staff, conference call, 26 March 2012). Climate forecasts continue to predict relatively wet local conditions and the potential occurrence of high-precipitation storm events twice as often compared with drier years prior to 2009 (Karl et al. 2009). As climate continues to change, more severe weather events could alter runoff and erosion, thereby increasing flood recurrence and stream erosion. For more information regarding climate change science, adaptation, mitigation, and communication throughout the NPS, refer to the NPS Climate Change Response Strategy and the Climate Change Response Program (http://www.nature.nps.gov/climatechange/index.cfm, accessed 29 June 2012).

Monitoring

Lord et al. (2009) have provided an overview of river and stream dynamics, identified potential triggers of channel instability, and described methods for the monitoring of streams and rivers. Stream channel morphology is influenced by complex interrelationships among regional geology, climate, topographic gradient, drainage basin history, river history, and sediment load. Channel instability manifests as significant changes in channel bed elevation, cross-sectional morphology, and channel pattern changes. Vital signs, a subset of fluvial system characteristics that can be monitored to provide information about the condition and trends of a system, include: 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 (Lord et al. 2009).

Disturbed Lands and Mineral Resources

Sand and Gravel Operations

As is typical of regions near the termini of glaciers, sand and gravel resources occur throughout the park area in alluvial and glacial deposits. In 1921, Hyde described them as "inexhaustible." For the past 200 years, operations of various scales have extracted these resources from the Chillicothe region. Sand and gravel pits exist within and adjacent to park boundaries at Hopeton Earthworks (active) and Mound City (inactive since the establishment of Camp Sherman during World War I). Another sand and gravel operation is conducted by the Tow Path Gravel Company in close proximity to Hopewell Mound Group, north of Route 28 and south of North Fork Paint Creek. It affects the park's viewshed, as it is visible from a park trail and overlook located on a high glacial moraine at Hopewell Mound Group (D. Reiner, email communication, 1 August 2012). Regionally, most farms have small-scale (less than 0.4 ha [1 ac]) gravel pits for private use. A large-scale, active sand and gravel operation within Hopeton Earthworks unit is described below.

An abandoned sand and gravel pit is located within the Mound City Group unit and included in the GRD Abandoned Mineral Lands (AML) database (accessed 2 July 2012). Although not yet documented in the AML database, several abandoned sand and gravel pits, originally used by the railroad, are located along the CSX railroad corridor adjacent to High Bank Works. The land and quarries were incorporated into Hopewell Culture National Historical Park as part of the 1980 park expansion, although their location within park boundaries was not clear until the early 2000s (Hopewell Culture NHP staff, conference call, 26 March 2012). As of March 2012, no plan had been developed for the reclamation of these AML features.

Figure 7. Photograph of Shelly Sands Company sand and gravel operation at Hopeton Earthworks unit (also see fig. 4). Photograph by Dafna Reiner (Hopewell Culture NHP).

The Shelly Company is mining sand and gravel from alluvium and glacial outwash (Qal and Woc) in the Hopeton Earthworks unit (figs. 7 and 8). This operation began in the early 1980s and was in part responsible for inspiring the legislation to expand and establish Hopewell Culture National Historical Park with the goal of preserving additional earthworks from future quarrying operations. The Shelly quarry currently covers more than 40 ha (100 ac) within park boundaries and a roughly equivalent area adjacent to the Hopeton

Earthworks unit. No large earthwork has been impacted by quarry operations so far. The company plans to continue operations for decades, as they own vast holdings outside of the park along the Scioto River. When quarrying operations are complete, reclamation of the area would involve stabilizing the inclination of the quarry's sloping sides and revegetating the slopes to curb mass-wasting potential (Thornberry-Ehrlich 2009). As described in the "Flooding and Fluvial Processes" section, a gravel road that crosses park land is used to access the quarry when Hopeton Road is flooded.

Resource Damage from Adjacent Highway Expansion

In September 2009, a contractor working for the Ohio Department of Transportation (ODOT) inadvertently placed a silt fence within park boundaries at the Mound City Group unit, as part of a Highway 104 expansion project. A settlement with the ODOT signed in November 2010 allowed the park to survey, test, and assess archeological resources along the western boundary of the Mound City Group unit and determine the extent of damage. Surveys and subsequent excavations revealed the presence of Middle Woodland period (between about 1 CE and 400 CE) cultural features and verified the presence of buried site resources in the 3.30-ha (8.16-ac) project area. This project also resulted in the creation of an updated base map of Mound City with high-resolution aerial imagery, data from the statewide Ohio LiDAR project, accurate state site locations, park boundary, historical imagery, and project-related data layers (Perkins and Bauermeister 2012).

Wells

Only water wells are present within Hopewell Culture National Historical Park, but water, oil, and gas wells exist within the region. The ODGS website records the characteristics and locations of these types of well throughout Ohio. Water wells within the park at Mound City are used for the neighboring (across State Route 104) U.S. Department of Veterans Affairs golf course, and one is included in the GRD AML database (accessed 4 March 2013) as it is located in an abandoned sand and gravel quarry (Thornberry-Ehrlich 2009). Previously, the well on the northern edge of the Mound City unit was used as the main water source for the park and Veterans Affairs Hospital facility. The park now obtains potable water from a treatment facility run by the Ohio Department of Rehabilitation and Correction, and the well supplies water for groundskeeping. No plan for restoration currently exists (D. Reiner, email communication, 1 August 2012).

Stock Ponds and Quarry Ponds

An earthen dam impounds a pond situated 24 m (80 ft) above the North Fork Paint Creek at Hopewell Mound Group. Prior to inclusion in the park, the pond was used as a stock pond for cattle. At the time of report writing, the dam appeared to be stable and was not being managed by park staff in any way (Hopewell Culture NHP staff, conference call, 26 March 2012). The pond rapidly shrinking and filling with sediments; infilling mud is more than 1 m (3 ft) thick. The feature now functions as a wetland/marsh and provides amphibian (salamander) habitat (Thornberry-Ehrlich 2009). If the earthen dam were to fail, a boardwalk and intermittent stream would be flooded.

This low-lying area seasonally retains water, particularly in recent years (approximately 2009–2012) of markedly increased precipitation. This former cow pasture now contains successional vegetation (Hopewell Culture NHP staff, conference call, 26 March 2012).

Once abandoned, small-scale sand and gravel quarries fill with groundwater and function as ponds within the park and surrounding areas (fig. 8) (Thornberry-Ehrlich 2009). The large quarry ponds at Hopeton Earthworks are still part of an active gravel operation. Although they are not natural features, such disturbed lands function as important habitats. The park does not plan to restore or reclaim them.

Figure 8. Photograph of abandoned quarry. Abandoned quarries such as this one (part of the Shelly Company operation within and adjacent to Hopeton Earthworks) may function as important water habitats for local and migrating wildlife. National Park Service Photograph by Dafna Reiner (Hopewell Culture NHP) on 3 August 2012.

Veterans Administration Incinerator

The Veterans Administration incinerator was located on what is now park land within the Mound City unit, approximately 30 m (100 ft) north of the northeastern corner of the Mound City earthworks between the Scioto River and the railroad tracks. Two roads provided access to the incinerator, one of which was the former east–west Camp Sherman East Liverpool Road. The incinerator building was razed and the surrounding area reclaimed in July 1960 due to concern about fire hazards. A 90-m- (300-ft-) wide strip of land extending from State Route 104 to the river was transferred to the NPS. Issues associated with the site include incomplete restoration (Hopewell Culture NHP staff, conference call, 26 March 2012); debris from the incinerator operations, including broken dinnerware, cinder, slag, and construction remains, is noticeable on the ground surface and on the terrace slopes leading to the river (Kathleen Brady, curator, Hopewell Culture NHP, email communication, 28 March 2012). A preliminary site investigation was completed in 2012, resulting in recommendations for further site inspection and sampling to determine the need for additional Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) compliance or other appropriate action (PRIZM Inc. 2012).

Camp Sherman

The land that now comprises the Mound City unit was once part of Camp Sherman, a U.S. Army training camp during World War I. As detailed in the "Geologic Features and Processes" section, the U.S. Army chose this site in south-central Ohio because its climate, soil profiles, and landforms were similar to those of eastern France, where trench warfare was stagnating the war effort. Refer to http://www.chillicotheinfo.com/page.php?ID=6257 for a pictorial history of the camp.

In addition to previous settlement and agricultural impacts that obliterated many mounds in the area, Camp Sherman construction impacted all but the largest mound in what is now the Mound City Group. According to Peck (1967), one barracks building was reoriented around that largest mound. Following the closure and dismantling of Camp Sherman after the war, the federal government divided the land among various entities. Subsequent state penitentiary construction likely disturbed other Hopewell sites. The Veterans Affairs facility now occupies some of the training camp site.

Remnants of the land's military past remain a concern. In addition to the legacy of altering mounds, unexploded ordnance has been found locally (Thornberry-Ehrlich 2009). Mound City was part of the camp's barracks, not a weapons training area, so park staff does not expect to find unexploded ordnance in the park (Hopewell Culture NHP staff, conference call, 26 March 2012).

Destruction and Reconstruction of Regional Hopewell Sites

Central Ohio contains hundreds or thousands of Hopewell sites, including "regional" sites that were used by many native groups and contain mixed archeological resources, in contrast to discrete, local mounds used by a particular group for a specific period of time. Due to the lack of recognition and preservation, as well as ongoing urban development, these sites have been largely altered or destroyed. Many sites were destroyed during early European settlement as farming activities expanded to areas adjacent to local rivers. For example, at the Hopewell Mound Group unit, the topography of the earthen embankment and approximately 30 mounds is very "muted" after decades of plowing and other agricultural practices (O'Neal et al. 2005). Modern agricultural techniques of annual plowing and harrowing with tractors reduced the height of the earthworks at Hopeton Earthworks by approximately 3.0 cm (1.2 in.) per year and increased their width by 0.3 m (1 ft) per year (Blank 1985).

Another example of the impacts of modern land use on ancient Hopewell sites is the inclusion of a 10-km^2 (4-mi^2) Hopewell site within a golf course in Newark, Ohio, about 95 km (60 mi) northeast of Chillicothe.

In some cases, such as at Mound City, the ancient mounds have been reconstructed. The Mound City earthworks and mounds were reconstructed by the Ohio Historical Society in the early 1920s after Camp Sherman was decommissioned. Surprisingly, archeological investigations at Mound City beginning in 1920-1921 and continuing today demonstrate that significant subsurface deposits remain in virtually every area of the park unit, despite nearly two centuries of Euro-American impact (B. Ruby, email communication, 1 February 2013).

Monitoring Landform Change and Remote Sensing Techniques to Preserve Hopewell Sites

Despite many years of aggressive archeological, agricultural, and construction activities, some Hopewell earthworks remain relatively undisturbed. Such mounds provide excellent information regarding how to monitor the natural degradation of the features as well as test sites for non-invasive remote sensing techniques to describe buried resources.

Sections along the northern perimeter of the Hopewell Mound Group (located on a southwest-sloping moraine complex in geologic map units Woc and We2) retain original embankments and adjacent ditches contiguously for approximately 200 m (650 ft) (Quinn and Goldthwait 1985; O'Neal et al. 2005). This site was a subject area in a study seeking to model the natural degradation of earthworks. As with any landform composed of fine-grained materials (in this case clay loam), earthworks will naturally widen and flatten (if not accelerated by agricultural practices) over time due to slope processes such as creep and slope wash—a mass-wasting process by which material is transported by flowing water not confined to channels. This natural smoothing of the profile affects an archeologist's ability to: 1) determine how the appearance of the earthworks changed over time while assessing the function of the original earthwork form, 2) identify superposed and disturbed sediments and artifacts while evaluating the exposure age and preservation potential, and 3) estimate the time and labor investment required for original construction (O'Neal et al. 2005).

The Hopewell Mound Group was also the subject of a study aiming to establish protocols for the application of remote sensing techniques in archeological work. For example, surveys of deviations in Earth's magnetic field yielded regularly spaced magnetic anomalies interpreted to represent the remains of a 2,000-year-old wooden structure beneath Mound 1 (Burks and Pederson 2001). Magnetic and electrical resistance survey data can enable purposeful excavation of cultural resources to investigate prehistoric site use (Weinberger and Brady 2010). Magnetic anomalies have guided research beyond the earthworks in areas such as the North Forty north of Mound City, where fragments of pottery, charcoal, and chert have provided information about the function of this area within the Hopewell settlement system (Brady and Weinberger 2010).

One study at Hopeton Earthworks focused on using magnetic susceptibility to understand how earthworks were constructed. Data from soil cores taken from within and around the earthworks were compared with magnetic susceptibility testing results from trench profile walls (a known control) to determine potential soil matches between the earthworks cores and trench walls and, thus, their possible points of origination (Dempsey 2007, 2010). Another study used a cesium gradiometer and other geophysical instruments to accurately map the basal remnants of most earthen walls at Hopeton Earthworks. This map guided subsequent soil coring, which identified areas that were carefully quarried to supply material for the earthworks (Lynott and Mandel 2006a, 2006b; Dempsey 2010). The quarried material was precisely excavated and repositioned to create a discrete boundary between wall fill and in situ soils (Dempsey 2010).

Unlike trenching, coring, and other invasive archeological techniques, remote sensing may enable the preservation of remains in situ with minimal disturbance. Weymouth (1996) cautioned against relying solely on geophysical remote sensing, instead recommending that the results be used as a guide for further investigation. No single geophysical technique is applicable to all archeological pursuits because the physical property measured is dependent on the physical and/or cultural environment of the study (Weinberger and Brady 2010).

The NPS Midwest Archeological Center sponsors numerous projects within the park. Their website provides descriptions and other information that is beyond the scope of this report. For more information, please reference: http://www.nps.gov/mwac/featured_pro.htm. This website also includes regular newsletters featuring the latest information about Hopewell archeology. To further the recognition and foster the preservation of remaining mounds, and with a variety of partners, Hopewell Culture National Historical Park is in the process of pursuing World Heritage nomination for Hopewell mounds throughout Ohio(B. Ruby, email communication, 7 January 2013).

Slope Processes

Slope processes, such as slumping and creep, in the park are exacerbated by natural geologic features as well as by infrastructure development and other anthropogenic impacts (fig. 9). Eroding river banks throughout the park, particularly at Mound City, High Bank Works, and Hopewell Mound Group, are subject to slumping and collapse. Erosion-prone glacial deposits may also contribute to cutbank erosion along local streams (Thornberry-Ehrlich 2009). The unconsolidated and heterogeneous nature of the local glacial deposits makes them particularly susceptible to collapse and failure (fig. 6). Exposure and undercutting by rivers exacerbates the problem, as evidenced by advancing cutbanks and collapsing trees (see "Flooding and Fluvial Processes").

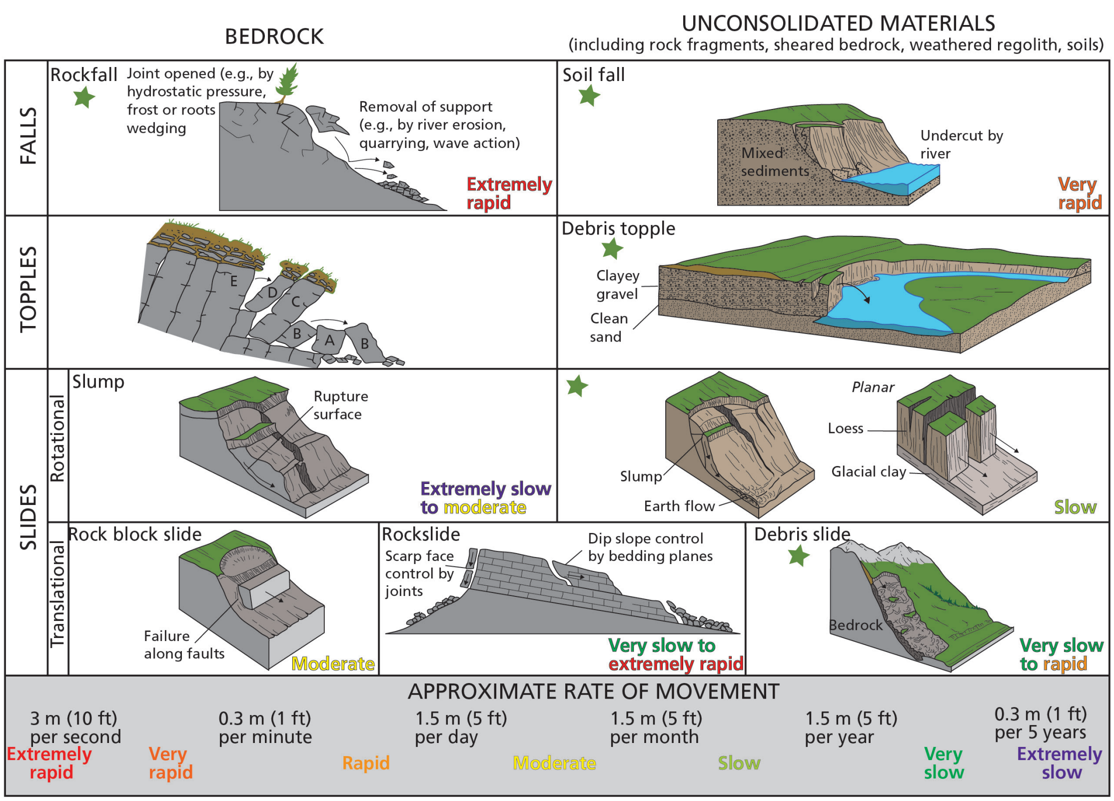

Figure 9. Schematic Illustrations of slope processes. Slope processes are categorized by material type, nature of the landslide, and rate of movement that are relevant to the park. Green stars denote mass-wasting processes that occur within Hopewell Culture National Historical Park. Rockfall is possible at the Spruce Hill and Seip Earthworks (across Paint Creek). Mass wasting in the unconsolidated materials category is occurring at High Bankworks, Hopewell Mound, and Mound City units. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

Certain bedrock geologic units are more prone than others to movement when exposed on slopes. Particularly in springtime and after heavy rains, rockfalls occur frequently in several areas within and near the park, including the slopes of (1) Copperas Mountain (outside of the park but part of the cultural viewshed), (2) Spruce Hill (fig. 10), (3) slopes across Paint Creek from Seip Earthworks, and (4) other similarly steep exposures throughout the park area (Carlson 1991). Concretions from the Ohio Shale (Do) frequently weather out of the shales and fall to the river below. This process occurs in exposures at the Seip Earthworks unit along Paint Creek.

Figure 10. Photograph of trail erosion at the Spruce Hill unit. Erosion exposes the underlying Ohio-Olentangy Shale (geologic map unit Do) on slopes at the Spruce Hill unit. National Park Service photograph by Dafna Reiner (Hopewell Culture NHP) on 3 August 2012.

The Pleistocene, pre-Illinoian lacustrine deposits, locally known as the Minford Silt (pl), are prone to slumping when exposed on slopes. Slumping within this geologic unit is a regional problem, but exposures of the Minford Silt do not likely pose direct threats to current park resources and infrastructure (Mac Swinford, geologist, Ohio Division of Geological Survey, conference call, 26 March 2012). Fine-grained, winnowed, aeolian, surficial loess (silt) deposits occur throughout the area, and were deposited just after glacial retreat when sediment-entraining vegetation had not yet colonized the area. The thickness of these deposits varies greatly throughout Ross County and loess is not a mapped unit within the GRI digital geologic map data. Nevertheless, loess deposits can be unstable on slopes and thus hazardous to build on (Thornberry-Ehrlich 2009).

The trails up the glacial moraine complex on the northern side of the Hopewell Mound Group are currently eroding due to trail design issues (fig. 11). Park staff completes repairs to these trails every year. Water bars installed during the summer of 2012 will be monitored to determine if these have successfully stemmed the persistent erosion here. Contact the NPS Geologic Resources Division for assistance in reviewing funding proposals or seeking additional funding sources. In addition to erosion issues, the trails are almost always slippery when wet and pose visitor safety hazards.

Figure 11. Photograph of trail erosion at Hopewell Mound Group. Erosion impacts the trail to the moraine complex overlooking the Hopewell Mound Group. Water bars were installed in 2012 to reduce the need for trail maintenance and increase trail safety. Photograph by Trista Thornberry-Ehrlich (Colorado State University) on 8 October 2009.

Wieczorek and Snyder (2009) described the various types of slope movement and mass-wasting trigger, and suggested five methods and vital signs useful for monitoring slope movements: types of landslide, landslide triggers and causes, geologic materials in landslides, measurement of landslide movement, and assessment of landslide hazards and risks. Their publication provides guidance for the use of vital signs and monitoring methodology.

Seismic Activity

Earthquakes are not common in Ross County, and the potential for seismic activity is low. Historically, Chillicothe experienced shaking associated with some of the largest earthquakes ever to strike North America. Damage to brick buildings occurred in Chillicothe, while significant damage befell Cincinnati following an 1812 earthquake on the New Madrid Seismic Zone (see below) (Williams 1981). In November 1889, a magnitude 2.1 earthquake occurred just south of Chillicothe. In April 2009, a magnitude 3.3 earthquake shook Gallipolis, Ohio (32 km [20 mi] southeast of Chillicothe), but no shaking was perceived by park staff. In accordance with the generally low potential for future earthquakes, seismic activity is not included in any resource management plan for Hopewell Culture National Historical Park (Hopewell Culture NHP staff, conference call, 26 March 2012).

The area that is now Hopewell Culture National Historical Park is close enough to the New Madrid Seismic Zone (in western Tennessee) that effects from the large 1811–1812 earthquakes were likely felt. Reactivation of the New Madrid fault zone is a significant concern for the ODGS, which is particularly interested in the potential for liquefaction along the Ohio River floodplain and other large river corridors. Given the destruction of Cincinnati during the 1812 earthquakes, the focus of this interest is closer to the city, 135 km (84 mi) southwest of Chillicothe (M. Swinford, conference call, 26 March 2012). The term liquefaction describes a phenomenon whereby a water-saturated, unconsolidated material substantially loses strength and stiffness in response to earthquake shaking, causing it to behave like a liquid. This process can have significant effects on the landscape and any infrastructure built upon the loose material. The U.S. Geological Survey maintains a website for the New Madrid earthquakes with links to current information and potential hazards (http://earthquake.usgs.gov/earthquakes/states/events/1811-1812.php), as well as produced public outreach materials (Williams et al. 2010).

The ODGS maintains a seismic detection network throughout the state, with 25 stations operated by universities and high schools; see: http://www.ohiodnr.com/OhioGeologicalSurvey/TheOhioSeismicNetworkHome/tabid/8144/Default.aspx. The closest stations to Hopewell Culture National Historical Park are at The Ohio State University in Columbus, Shawnee State University in Portsmouth, and Bloom Carroll Schools in Carroll (Thornberry-Ehrlich 2009). Seismic monitoring data can be used for many purposes, such as determining the frequency of earthquake activity, evaluating earthquake risk, interpreting the geologic and tectonic activity of an area, and providing an effective vehicle for public information and education (Braile 2009).

In the chapter about seismic monitoring in *Geological Monitoring*, Braile (2009) described methods for seismic monitoring such as monitoring earthquake activity, analysis and statistics of earthquake activity, analysis of historical and prehistoric earthquake activity, earthquake risk estimation, and geomorphic and geologic indications of active tectonics. In addition, Braile (2009) summarized seismic monitoring methods, including the expertise, special equipment, cost, personnel, and labor intensity required for the implementation of each method.

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 Hopewell Culture National Historical Park.

Discussions during the scoping meeting (8 October 2009, summarized in Thornberry-Ehrlich 2009), and a post-scoping follow-up conference call (26 March 2012) provided opportunities to develop a list of geologic features and processes operating in Hopewell Culture National Historical Park, including:

- Glacial Features
- Geologic Connections to Park Stories
- Paleontological Resources
- Sedimentary Bedrock Features
- Concretions and Nodules

Glacial Features

Repeated glaciations (ice ages) during the Pleistocene Epoch from about 2 million until approximately 20,000 years ago scoured and reshaped the topography in most of the northeastern United States and played a major role in the landscape and history of Hopewell Culture National Historical Park. Large continental ice sheets descended south from Canada several times during the Pleistocene, covering the Great Lakes area and extending into central Ohio. As differentiated in the GRI GIS data for the park, the most recent major advance is termed the "Wisconsinan," the previous (more expansive) advance is termed the "Illinoian," and earlier advances are considered "pre-Illinoian." The major events were not simply discrete advances and retreats, but comprised many smaller-scale advances, stagnations, and retreats over thousands of years. This process yielded a very complicated geologic record as subsequent glaciations overprinted and obscured deposits from earlier glaciations. Illinoian deposits are distinguishable from adjacent Wisconsinan deposits because of variations in loess thickness, leaching depth, and weathering profiles (Quinn and Goldthwait 1985). As noted in the "Geologic Connections to Park Stories" section, each unit of Hopewell Culture National Historical Park is located at or near an ice age glacier terminus (maximum extent) as shown in figure 12. The glaciated landscape north of the park and the unglaciated landscape to the south are separated by the Appalachian Plateau Escarpment—an exceptional setting that showcases the effects of glaciers on a landscape.

Glaciers are extraordinary and relentless movers of rocks, sediment, and other geologic materials. The park and surrounding area contain numerous features, large and small, that record the past presence or influence of glaciers, including outwash, outwash terraces, kames, kame terraces, eskers, drift, moraines, till, erratics, and lacustrine (lake) deposits (fig. 13). These features are mapped in the GRI GIS data for the park and were deposited directly by a glacier (till, moraines, erratics), by water flowing out of the glacier (outwash, kames, eskers), or by water in lakes dammed behind glaciers or glacial debris (lacustrine deposits). The term "drift" is applied to any rock material deposited directly by glacial ice or by water flowing from the glacier. These features are typically named after a location where they are particularly well exposed or were first described, and/or represent the geographic extent of a particular deposit (e.g., Kingston Outwash, Caesar Till, Yellowbud Moraine).

The effects of these vast amounts of glacial sediment and glacial erosion are widespread and pervasive. Today, the Scioto River flows southward within the wide valley of the buried (formerly northward-flowing) ancient Teays River system. The 60- to 90-m- (200- to 300-ft-) deep gorge at Alum Cliffs (across Paint Creek from of Hopewell Mound Group) was incised when ice blocked the river valley. Paint Creek now flows through this narrow slot. The original Paint Creek Valley to the north now has minor streams that are underfit to the much wider Paint Valley.

Till, Moraines, and Erratics

As expected for an area near the terminus of a glacier, tills and moraines are extensively mapped throughout Ross County (geologic map units Wi2, Wi3, Wit2, Wg1–4, We2–4, and Ig). Till is a typically unsorted and unlayered heterogeneous mix of clay, silt, sand, gravel, and boulders (fig. 14) deposited directly by or underneath a glacier that has not subsequently been reworked by water.

Moraines are ridges of material moved by or within glaciers that mark the edges and extent of the glacier. End moraines are produced at the margin of an active glacier. Ground moraines are areas of low-relief till deposited from within or beneath a glacier as it retreats. Terminal moraines mark the maximum extent of a glacier. Recessional moraines form during long "pauses" in the retreat of a glacier or as part of a minor readvance. Three major moraines—Lattaville, Reesville, and Yellowbud—are mapped in Ross County and represent extents of the Wisconsinan glacier as it retreated (fig. 12). End moraine deposits associated with the Lattaville Moraine (We2) are mapped in the Hopewell Mound Group and ground moraine deposits of the Boston Till (Wg1) are mapped on the lower reaches of Spruce Hill.

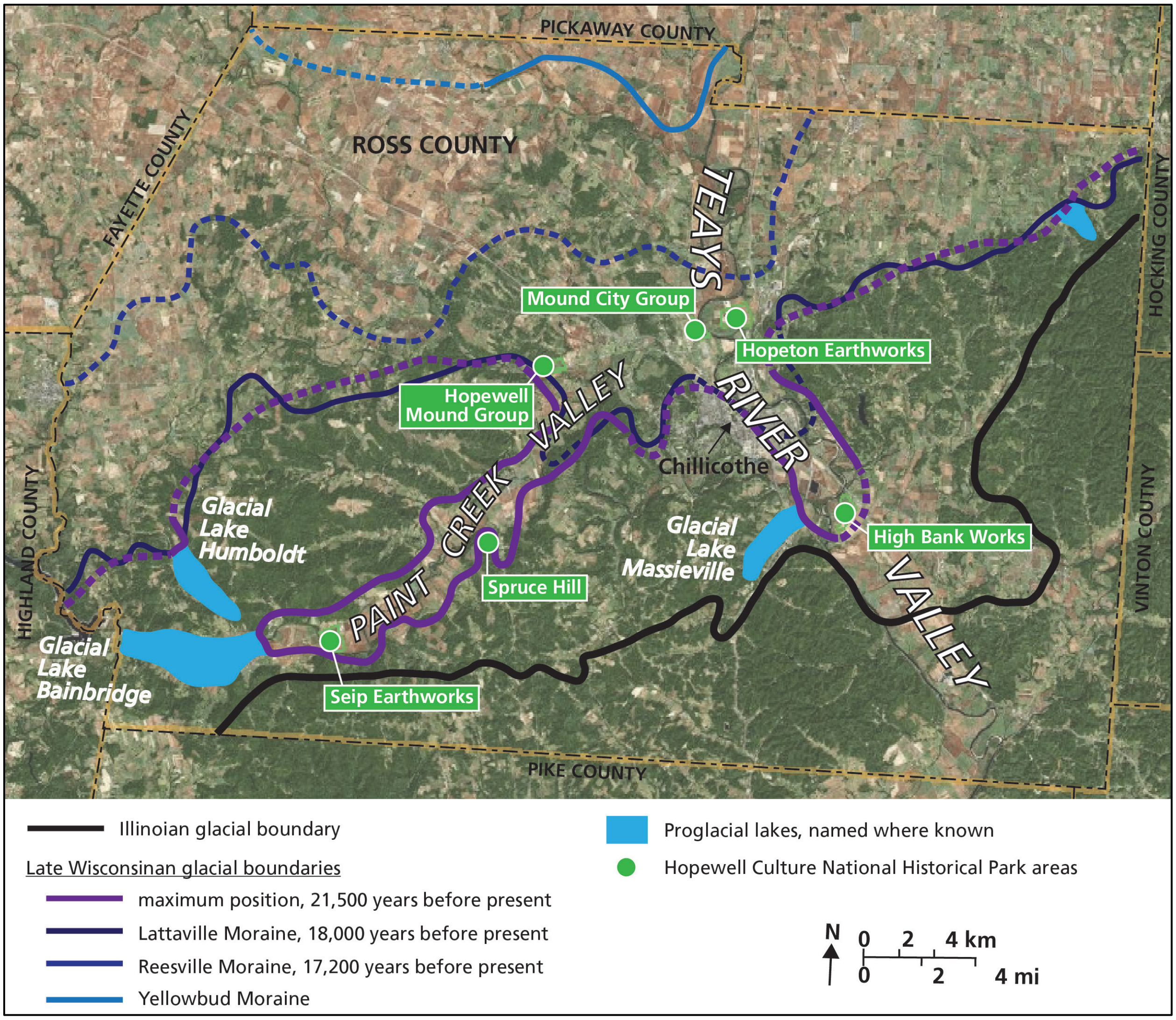

Figure 12. Aerial image of Ross County overlain with major Pleistocene glacial ice margins. Lines are dashed where approximated. Note the location of Chillicothe and Hopewell Culture National Historical Park units with respect to the buried bedrock channels of the Teays River and Paint Creek valleys. Also, note the distinct difference in vegetation and land-use patterns between glaciated and unglaciated areas. Graphic by Trista L. Thornberry-Ehrlich and Rebecca Port (Colorado State University) after figures in Quinn and Goldthwait (1985).

Glacial erratics are boulders or large stones that were moved from their original locations within or on top of a glacier. Glacial erratics may travel hundreds of kilometers from their source or be more locally derived. Hopewell Culture National Historical Park contains locally derived sandstone and limestone erratics as well as igneous and metamorphic rocks from the Canadian Shield. Some of these erratics contain minerals not found elsewhere in Ohio, including feldspar, gold, diamonds, and possibly copper (Taylor and Faure 1983; Thornberry-Ehrlich 2009). Locally, these “exotic” rocks make up about 10% of all glacial erratics (Thornberry-Ehrlich 2009). The park collection includes many Hopewell ceremonial- or status-related objects fashioned from native copper. These include cut-out bird effigies, headdresses, earspools, turtle effigy rattles, “breastplates,” and celts. The copper used to make these objects was likely quarried from primary bedrock sources in the Keweenaw Peninsula and Isle Royale regions of Lake Superior. Thousands of prehistoric mining pits are known from this region, and radiocarbon dates suggest some of these pits were being exploited more than 3,000 years ago. However, because several successive glaciations scoured these bedrock sources, it is possible that some Hopewell copper was collected from secondary glacial drift deposits: so-called “drift copper” or “float copper”(see Halsey 1996 and Martin 1999 for overviews; Bret Ruby, archeologist/chief of resource management, Hopewell Culture NHP, email communication, 1 February 2013).

Outwash

Outwash is stratified (layered) sand and gravel that was “washed out” from a glacier by meltwater streams and subsequently deposited beyond the edges of an advancing glacier or beyond the moraines of a retreating glacier. A variety of outwash deposits are mapped in the GRI GIS data for Hopewell Culture National Historical Park. The Bainbridge (Wob), Kingston (Wok), Circleville (Woc), Worthington (Wow), and Higby (Io) outwash

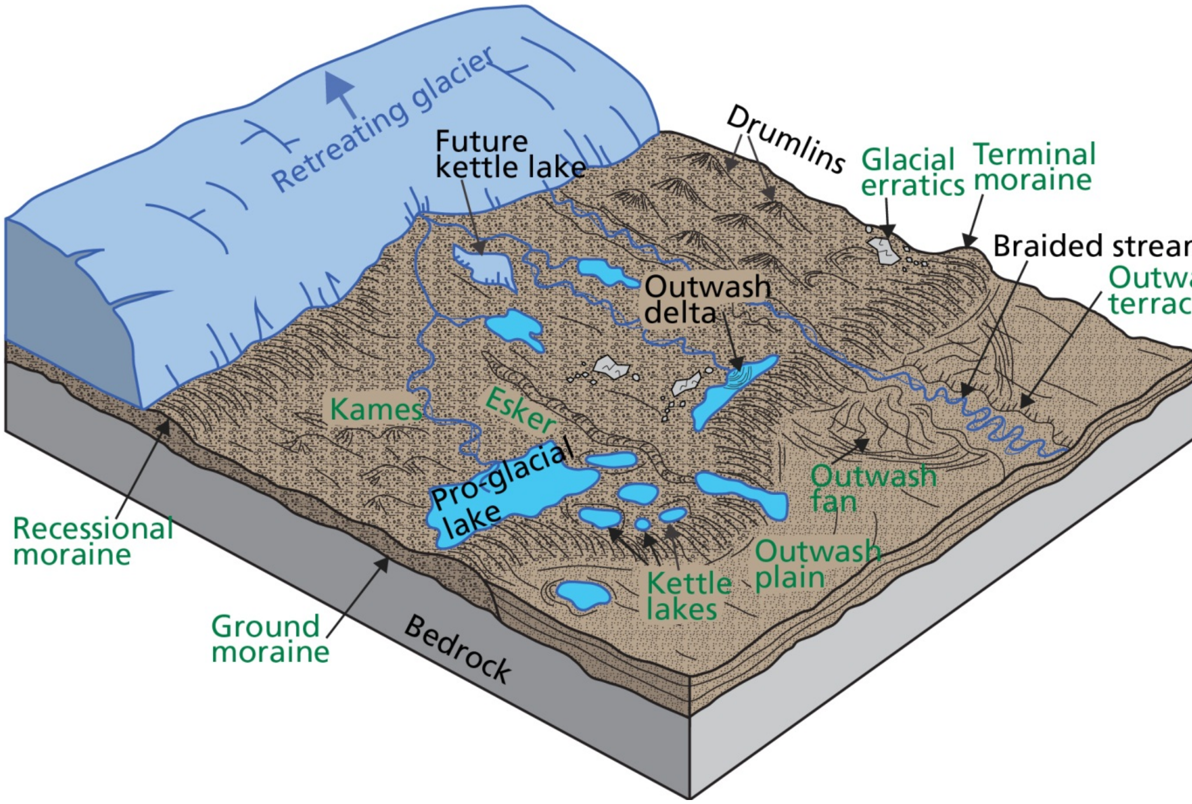

Figure 13. Schematic illustration of glacial features and deposits. Prominent glacial features on the landscape of Hopewell Culture National Historical Park include outwash deposits, recessional moraines, outwash terraces, glacial erratics, and kettles. Proglacial lakes formed within Ross County (fig. 12) but outside of what is now the park. Glacial features occurring in the park area are labeled in green. Not every glacial landscape preserves all of these features. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 14. Photograph of glacial till. An excavation trench reveals the unsorted (variety of sediment sizes), oxidized (reddish color) nature of the glacial till present on the landscape at Hopewell Culture National Historical Park. National Park Service photograph by Dafna Reiner (Hopewell Culture NHP) in 2009.

deposits are differentiated on the map. A generic "erosional terrace outwash" (Wot) unit is also included. The Circleville and Kingston outwashes are mapped within the park. Braided channels within the Circleville Outwash (Woc) are visible in fields near the Veterans Hospital, west of Ohio Route 104 (Quinn and Goldthwait 1985). High terraces indicate former, topographically higher, outwash drainages; they formed as the result of pulses of glacial ice melt (local retreat), which sent torrents of sediment-laden water southward (Thornberry-Ehrlich 2009). Terraces cut into outwash are particularly significant because the Hopewell chose them as sites for mounds and earthworks along the Scioto River and Paint Creek (see "Geologic Connections to Park Stories" section).

Kames and Eskers

Kames (Wi2, Wi3, and Ii) are mounds or small ridges of sand or gravel deposited by glacial streams or lakes. They are present regionally. Because of their size and morphology, kames are often mistaken for archeological mounds. Kames are mapped near Spruce Hill (Ii). An elongate gravel deposit paralleling Sulfur Lick Road in the Hopewell Mound Group is a suspected kame. McGraws Hill, just outside of park boundaries, is a local example of a kame. The boundary between ground moraines and kames is distinct due to 1) a topographic break to steeper, rougher gravel slopes of kames, 2) variation in loess thickness and carbonate leaching, and 3) differences in soil profiles reflecting the composition of parent materials (Quinn and Goldthwait 1985).

Eskers (Wi2 and Wi3) are long, sinuous, steep-sided ridges of material deposited beneath the glacier or between glacial ice that are left behind after the glacier retreats. The Circleville Esker (16 km [10 mi] north of Chillicothe at Circleville, Ohio) formed in a subglacial ice tunnel. Whether eskers occur within park boundaries is unknown; neither Wi2 nor Wi3 is mapped within the park.

Lacustrine Deposits and Kettles

During ice ages, southward-advancing continental ice sheets dammed northward-flowing rivers to form glacial lakes, the sources of fine-grained silt and other lacustrine deposits (Wl, Wob, Il, and pl). At least four such Wisconsinan-age lakes are differentiated within Ross County; although none is within Hopewell Culture National Historical Park boundaries (see fig. 12).

Kettles formed when a large block of glacial ice that was partially or totally buried by glacial sediment melts, leaving a depression. The depression naturally fills with groundwater where the water table intersects the sides of the kettle to form a lake or swamp. With the exception of some impounded farm ponds and former quarries, many small ponds and wetlands within the park (present in the digital geologic map data) are kettles.

Modern Hydrology and Soils

Glacial features are prominent in modern geomorphologic processes and the hydrogeologic system. A 1986 landfill study determined that the highly permeable nature of glacial deposits in the Chillicothe area was causing the rapid transmission and dilution of contaminants from the town's landfill into the local aquifer (Markley 1986). Springs and soils are associated with glacial deposits at Hopewell Culture National Historical Park. Seeps and springs emerge along exposures of fine-grained, clay-rich layers (aquitards) within some terrace edges and moraine deposits. At the Hopewell Mound Group, a spring is situated within an earthwork, emerging along the exposure of a clay-rich layer.

The difference between the glaciated and unglaciated features within the park and throughout Ross County extends to major soil types as well. Some are derived from glacial deposits and others derived from bedrock. Mapping these soil types helped define the maximum extent of the glaciated area in Ross County. The NPS Soil Resources Inventory program completed a soils inventory map of the park in 2007. These data are available from the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/App/Reference/Profile/1048897).

Geologic Connections to Park Stories

American Indian History and Mound Construction

The advance and retreat of Pleistocene (ice age) glaciers created vast deposits of till, lacustrine clays, moraines, and outwash across the landscape of central Ohio (see "Glacial Features" section). After the most recent glacial retreat occurred about 18,000 years ago, plants and animals recolonized the region. Humans eventually followed, and members of the Adena culture constructed the first mounds in what is now the park area at least 2,500 years ago. Adena mound construction tapered off around 2,000 years ago. Then, between about 1 CE and 400 CE, the Hopewell people built mounds and other cultural features that they used for burials, astronomical observations (solar and lunar alignments), and other ceremonial purposes, rather than for dwellings. Characteristic features such as the high walls and "gateway" mounds were likely used to create privacy rather than for warfare or defense (Shetrone 1926; Thornberry-Ehrlich 2009). A subject of current archeological debate, as discussed at the 2009 scoping meeting, is whether these societies were mobile or more sedentary, perhaps moving every decade (Thornberry-Ehrlich 2009).

Most mounds at Hopewell Culture National Historical Park were constructed on glacial outwash terraces from the most recent glacial advance, termed the "Wisconsinan" (Wok and Woc). These terrace-top areas are above even the 500-year floodplains and thus would have afforded reliably dry, near-river locations. The mounds remaining today are but a small fraction of those constructed by the Hopewell. Until they were largely destroyed by agricultural and other post–European-settlement land uses, extensive earthworks were present on every terrace on both sides of the Scioto River from the vicinity of the present-day fairgrounds in northern Ross County, southward for more than 20 km (12 mi).

Archeologists have hypothesized that the Hopewell and other indigenous peoples were deeply connected to the landscape. They attached significance to different geomorphological features and built their mounds upon and near them. They may have possessed knowledge about earth surface processes and landform development. For example, Serpent Mound, a prehistoric effigy mound located in Adams County about 52 km (32 mi) southwest of Hopewell Culture National Historical Park, was constructed on top of an ancient meteorite impact structure that formed 280 million years ago. Vertical and overturned bedrock with juxtaposed rock ages and a circular pattern of ring faults with more than 300 m (1,000 ft) displacement mark this structure in the subsurface. It is among the most unique geologic features in Ohio and two-thirds of it is traceable at the surface, although it lies under heavy vegetation and regolith. Cores were taken to determine the exact nature of the structure (Baranoski et al. 2003; Schumacher 2003). The placement of Serpent Mound atop this unique structure was possibly not coincidental. However, no evidence suggests that the native people knew of the special geology associated with the area and the theory remains under debate (Thornberry-Ehrlich 2009).

Within Hopewell Culture National Historical Park, mounds in the Seip Earthworks unit may have been placed to take advantage of a view of Copperas Mountain where the lower, east-dipping 15 m (50 ft) of the Ohio Shale (Do) is exposed along Paint Creek (Thornberry-Ehrlich 2009; Hopewell Culture NHP staff, conference call, 26 March 2012). Most of the Devonian sequence composed of the Ohio Shale, Bedford Formation, and Berea Sandstone is exposed in a sheer cliff more than 90 m (300 feet) tall (Do and DMu; see

Figure 15. Photographs of geologic materials in Hopewell archeological objects. (A) Spear point made with obsidian from Obsidian Cliff (now within Yellowstone NP). (B) Circular cutout of mica mined from the Appalachian Mountains. (C) Fossil shark teeth probably from the Florida coast. Holes suggest these items may have adorned necklaces. (D) A bear/dog headdress fashioned from copper mined in the Lake Superior region. National Park Service photographs courtesy Kathleen Brady (Hopewell Culture NHP).

inside cover) (Thornberry-Ehrlich 2009). Mineral occurrences, including fibrous masses of various iron sulfate minerals such as halotrichite-pickeringite (white, once called “alum”), melanterite (blue-green, "copperas", used in the past to dye cloth), and copiapite (yellow, "yellow copperas"), are present in cliffs exposed on the mountain (Carlson 1991; Mindat.org 2012). Colored, sediment-laden runoff of these minerals at various seeps along the bluffs may also be responsible for the name “Paint Creek” (Hopewell Culture NHP staff, conference call, 26 March 2012). Colored sediments may have attracted the prehistoric peoples, just as they did early settlers who named the location “Copperas” after the melanterite collected there to dye their clothes (Carlson 1991). Prehistoric peoples may have used these minerals for paints and dyes, and may have attributed medicinal or spiritual values to them (B. Ruby, email communication, 1 February 2013). The park currently lacks a Cultural Landscape Report, which could help document cultural resources and land use history. Park staff identified the need for such a report during the 2012 conference call.

Hopewell people quarried a variety of geologic materials, such as colored soils, gravels, and sands, to build mounds and other earthworks. Hopewell earthworks are extremely complex in construction and exhibit precise and intentional soil placement (Dempsey 2007). Trenching projects revealed that the Hopewell removed the A soil horizon and the top of the B horizon prior to construction of the earthen walls at Hopeton Earthworks. Wall construction then commenced on the exposed subsoil surface using two or three different soil types, which were carefully applied to form the wall core in distinct, unmixed layers. In situ soils then developed atop the outer surfaces (Lynott and Mandel 2006a, 2006b). Nearly 30,000 m^3 (39,000 yd^3, or more than 4,300 dump trucks–worth) of soil was quarried from inside the walls of the larger enclosures at Hopeton Earthworks (Lynott and Mandel 2006a, 2006b).

Different clay colors, such as reds and yellows, were apparently important to Hopewell cosmology, and religious beliefs and were key criteria determining soil placement in earthwork construction (Dempsey 2010). Clay-rich glacial tills (Wi2, Wi3, Wit2, Wg1–4, We2–4, and Ig), outwash (Wob, Wok, Woc, Wow) and lacustrine deposits (Wl, Il, and pl) were local sources for these materials. Color differences were due in part to provenance (original rock type) and chemical changes (e.g., oxidation or leaching) that occurred after deposition. An eroding cutbank along North Fork Paint Creek at Hopewell Mound Group exposes a 2- to 3-m- (6- to 8-ft-) thick clay layer at its base and might have been a source for the manufacture of pottery shards found in association with the earth mounds (Hopewell Culture NHP staff, conference call, 26 March 2012). At Hopeton Earthworks, recent coring projects revealed that some wall portions contain clay-rich deposits in three colors: yellow, red, and brown. Wall cores tend to be yellow and capped by a red layer, and gray-brown soils covered the entire wall (Dempsey 2010).

Large gravel layers are found around and on some mounds, and the enclosure wall at the Spruce Hill unit is composed almost entirely of sandstone slabs drawn from the Berea Sandstone [Dmu]. Fire-cracked rocks lined earthen ovens and roasting pits. Fire-cracked rocks have been found in all park units (Dafna Reiner, biologist, Hopewell Culture NHP, email communication, 1 August 2012). Local clays were mined for making pots and limestone (possibly from the Silurian Ssu, St, and St-b units) provided temper material.

Fragments of chert associated with Hopewell activities in the park area were likely not sourced from local bedrock (Brady and Weinberger; B. Ruby, email communication, 1 February 2013). The bedrock in Ohio most commonly associated with chert tool manufacturing are Pennsylvanian-age units of eastern Ohio (Stout and Shoenlaub 1945). Geologic map unit St-b has some chert present, however, only in small amounts and the park knows of no bedrock outcrops with suitable chert for stone tool manufacturing in Ross County (Swinford et al. 2003; B. Ruby, email communication, 1 February 2013). Local sources may have included secondary deposits in glacial drift and outwash (see “Glacial Features” section) (Stout and Shoenlaub 1945; B. Ruby, email communication, 1 February 2013)

Figure 16. Map of Hopewell interaction. The Hopewell peoples maintained an extensive interaction network that included many geologic materials (fig. 15). National Park Service map.

Archeologists have unearthed a wide variety of geologic materials in Hopewell sites, including native copper from the Keweenaw Peninsula in Michigan (fig. 15D; (Keweenaw National Historical Park), mica from the Appalachians (fig. 15B), silver from Ontario, iron meteorite beads from southern Kansas, obsidian from the Yellowstone area (fig. 15A), and a variety of fossils (see “Paleontological Resources” section) (Margolin 2001; McCoy et al. 2008). These items attest to a vast and diverse interaction network throughout the North American continent (fig. 16). These materials moved by means of a variety of mechanisms: some may have been passed from hand to hand in trade; some may have been brought back by collecting expeditions launched from Ohio; and some may have been carried to Ohio as gifts by pilgrims from distant lands (Case and Carr 2008).

Ohio State History

The Scioto Valley and Chillicothe played prominent roles in the early history of Ohio. A 1796 expedition, outfitted by Colonel Massie in Kentucky to establish a settlement at the mouth of Paint Creek, chose a site about 1.6 km (1 mi) upstream on a fertile floodplain prairie and named the town Chillicothe after the former Indian village in the vicinity (Campbell 1918). In 1797, Ebenezer Zane established "Zane's Trace," a shorter, more reliable overland route across the Ohio frontier from Wheeling, West Virginia to Maysville, Kentucky. Pioneers traveling this route took advantage of local geologic resources, including the Berea Sandstone (DMu), as building stone (Wolfe 2006). Chillicothe was the capital of the Northwest Territory from 1800 to 1803; it was the capital of the State of Ohio from 1803 to1810 and again from 1812 to 1816.

The Berea Sandstone (DMu) was selected as the building stone for the first statehouse in Chillicothe. Construction began in 1800 and was a very early use of Ohio stone for building purposes, perhaps the first public stone structure erected in the Northwest Territory (Wolfe 2008). Berea Sandstone was featured in the grand houses of prominent families in the early state capital. Flagstones of Berea Sandstone were also used locally for sidewalks and other construction. The Berea Sandstone was quarried at an exposure southwest of Chillicothe at Cemetery Hill (Wolfe 2008). The Mississippian Cuyahoga Formation (Mlc) forms much of the original statehouse in Columbus, but proved to be a relatively low quality building stone given its poorly cemented character (Wolfe 2008). The modern statehouse is constructed of Devonian Columbus Limestone (not included in the GRI digital geologic data) (Wolfe 2008).

Camp Sherman and World War I

Soon after the United States entered World War I in April 1917, Camp Sherman was established. This site was selected because of its similarity to the landscapes surrounding Paris, where U.S. troops would be fighting. In an effort to provide the troops with the best training possible, the Council for National Defense commissioned a geologic survey of the area to present detailed physical features of the camp at which they were training. This survey (Hyde 1921) was published too late for use in World War I combat (Armistice was in 1918), but is an invaluable resource for understanding the geologic setting of Camp Sherman and how geology affects military operations and strategy.

Camp Sherman has physiographic similarities to areas northeast of Paris, as far as the Vosges Mountains. In Ohio, a prominent westward-facing escarpment (the edge of the Appalachian Plateau) rises above glaciated plains and a long gentle slope of dissected hill country lies to the east. Between Paris and the Rhine River Valley, several such escarpments each face eastward over a plain, with west-facing back slopes to the plain at the foot of the next escarpment in the series. The escarpments in Ohio compare well in height and degree of dissection with those in France (Hyde 1921).

The underlying topographies in central Ohio and northeastern France were formed by very similar processes, including continental glaciation. As described in Hyde (1921), both areas have gently inclined (dipping) sedimentary bedrock layers. In Ohio, the rocks dip gently eastward so that belts of older rocks are exposed further westward and the youngest bedrock is exposed on the eastern edge of the state (fig. 17). In France, the rocks dip gently westward; thus, the orientation of the topography is reversed from that in Ohio. Topographic development was also affected by differences in erosional resistance of the bedrock formations. As weathering commenced, the belts of bedrock were lowered at different rates depending on their resistance to erosion. Softer shales and soluble limestones eroded more quickly and readily than more-resistant sandstones. Sandstones such as the Berea Sandstone (DMu) support local ridges and high ground.

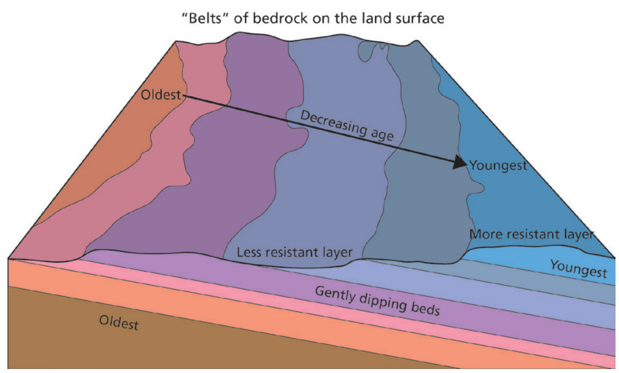

Figure 17. Schematic cross-sectional view of gently dipping bedrock and its surficial expression as belts of bedrock. Such a situation exists in south-central Ohio, where topographic differences are largely controlled by the erosional resistance of underlying bedrock. More-resistant rocks such as sandstones remain as ridges, whereas less-resistant shales or soluble limestones tend to underlie valleys. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

Escarpments such as those northeast of Paris, France, were significant obstacles to military movements and provided strategic high ground for defense. Natural gateways, formed where streams eventually breach the escarpments, are also strategic points of interest. Camp Sherman is located just inside one of these gateways through the Allegheny Escarpment, in a setting very similar to World War I battle sites such as Nancy, Toul, Epernay, Rheims, Laon, and La Fere (Hyde 1921).

Once the decision to build a camp north of Chillicothe was made, construction of Camp Sherman began in July 1917 and some 40,000 troops were eventually stationed there. The camp was constructed (fig. 18) atop Hopewell mounds, many of which were leveled to make room for the 1,370 buildings of the camp. Camp Sherman did not stand for long. After the war ended, it functioned temporarily as a veteran's education center and hospital. Ultimately, the camp was dismantled in the 1920s and none of the original buildings remain. The land now is divided among the Veterans Administration Medical Center, the Ross Correctional Institution, a wildlife refuge, the Chillicothe Correctional Institution, and Hopewell Culture National Historical Park (Ohio Historical Society 2012).

Figure 18. Photograph of Camp Sherman. Horse stables of the 322nd Field Artillery on 2 May 1918. Note the Allegheny Escarpment rising above the glaciated plains (foreground). Ohio Historical Society photograph: http://www.ohiohistorycentral.org/entry-images.php?rec=670 (accessed 4 May 2012).

Vegetation Diversity

Hopewell Culture National Historical Park lies near the significant boundary and ecological transition zone between unglaciated terrain to the southeast and the glaciated, muted landscape to the northwest. Because glaciers scoured some areas and deposited thick drift piles in others, soil types north of this boundary differ markedly from those in the unglaciated areas. Not surprisingly, the glacial boundary divides two phytogeographic regions in Ohio (Bennett and Course 1996). The plant community in the unglaciated area of the Allegheny Plateau is much longer established and undisturbed compared with that on the glaciated till plain, where vegetation was reestablished following the last glacial retreat from the area some 17,000 years before present. Because of this juxtaposition of plant communities, the flora of the park area is richer than would otherwise be expected (Bennett and Course 1996). Bennett and Course's (1996) survey of the park identified 438 plant species, of which 65 were newly recorded in Ross County. Two species, an orchid (*Spiranthes ovalis*) and a rush (*Eleocharis ovate*), are on Ohio's threatened and endangered species list (Bennett and Course 1996).

Hopewell Culture National Historical Park contains several marsh areas that merit notice as vital habitats for amphibian, bird, and other wetland species. A vernal (springtime) wetland area is present at Spruce Hill. Scientists use the term "vernal" to refer to seasonally flooded depressions found on substrates with particularly impermeable layers, such as clays. Several small, enigmatic swampy areas are also present on the end moraine deposits associated with the Lattaville Moraine (We2) at the Hopewell Mound Group. These may represent glacially derived kettles, but field study is required to conclusively determine the nature of the marsh areas within the Hopewell Mound Group unit (Thornberry-Ehrlich 2009; Hopewell Culture NHP staff, conference call, 26 March 2012).

Paleontological Resources

Cultural Resource Contexts

The NPS documents fossils in three contexts: within the rocks of a park, as part of a park's museum collections, and in various cultural resource contexts (building stones, archeological resources, historical documents). Fossils have not yet been documented within the rocks of Hopewell Culture National Historical Park, but are known from cultural resource contexts and curated in the park's museum collections (Hunt et al. 2008). These paleontological resources are primarily associated with trading between the Hopewell people and other American Indian groups within a vast network (fig. 16). Fossil remains associated with ceremonial sites include crinoid stems, shells, horn and branching corals, shark's teeth, barracuda jaw, and fragments of a mastodon or mammoth tusk (Hunt et al. 2008; Thornberry-Ehrlich 2009; Hopewell Culture NHP staff, conference call, 26 March 2012). The Hopewell used local crinoid stem segments from the Silurian Brassfield Formation (not mapped in the park's geologic data), exposed at the surface west of Chillicothe, as beads (Hunt et al. 2008; Thornberry-Ehrlich 2009). The shark's teeth are perforated and were found with shells, suggesting that they were part of a necklace (fig. 15C; Kenworthy and Santucci 2006; Hunt et al. 2008; Hopewell Culture NHP staff, conference call, 26 March 2012). The specimens from the Mound City Group were subjects of a recent study that concluded these are all fossil teeth from two shark species: *Carcharodon carcharias* (great white shark) and *C. megalodon* (a giant shark extinct for more than 1.5 million years); and likely collected from an ancient buried setting in southwest Florida (Colvin 2011).

Many of the park's cultural fossil resources, including the mammoth tusk fragments, were noted during 1920s archeological excavations. The excavated artifacts were originally housed with the Ohio Historical Society; however, park curators do not know what happened to the mammoth tusk fragments after their discovery (Hunt et al. 2008; Hopewell Culture NHP staff, conference call, 26 March 2012).The Hopewell Mound Group also contained abundant fossils, including some that were locally sourced. Caesar Creek, 60 km (36 mi) west of Chillicothe, is a famous fossil collecting site. Ordovician fossils collected from there were likely traded among Hopewell people (Hopewell Culture NHP staff, conference call, 26 March 2012).

Potential Resources

In addition to the fossils that are part of the park's museum collection, some potential for paleontological resources exists in the geologic units throughout the park and surrounding area. In general, fossils tend to be present in Silurian and Ordovician bedrock located lower in the stratigraphic column than the coarse, clastic-rich rocks in the immediate park area (Mac Swinford, geologist, Ohio Division of Geological Survey, conference call, 26 March 2012). Local Silurian units (Ssu, St, and St-b), of which only St-b is mapped within the park (Seip Earthworks), contain body fossils of marine invertebrates, including chitinozoans, brachiopods, gastropods, bivalves, nautiloids, eurypterids, crinoids, conodonts, and bioherms, which are mounds built by small organisms and comprised of their remains. Trace fossils include vertical tubes and rare, horizontal walking traces (Hunt et al. 2008). The Devonian Ohio-Olentangy Shale (Do) is mapped in other areas of the park and potentially contains fossil conodonts, brachiopods, bivalves, cephalopods, placoderm fish, shark spoor, radiolarians, arthropods, and occasional plant impressions. Carbonized plant remains include wood and ferns. Trace fossils include burrows of the annelid worm *Sphenothallus* (Hunt et al. 2008). The Devonian and Mississippian Bedford Formation, Berea Sandstone, and Sunbury Shale (DMu) also contain fossil resources outside of the park, including brachiopods, pelecypods, plants, spore casings, sponge and abundant conodont remains, and trace fossils such as burrows (Hunt et al. 2008). The Mississippian Cuyahoga and Logan formations (Mlc) contain concretions that may be fossiliferous, mollusks, ammonoids, crinoids and trilobites, fish, and trace fossils (Hunt et al. 2008).

Unconsolidated Pleistocene and more recent deposits could contain fossils and/or pollen records. Glacial erratics locally contain fossils, the majority of which are horn corals and crinoid stem segments derived from Devonian Columbus Limestone, a unit exposed in a north–south-oriented band through the central portion of Ohio (Thornberry-Ehrlich 2009; M. Swinford, conference call, 26 March 2012). Glaciolacustrine deposits (pl, Il, Wob, Wl, and possibly Wok) are known to contain fossil mollusks locally (Hunt et al. 2008). No formal (field-based) paleontological inventory of on-site resources has been completed for Hopewell Culture National Historical Park.

Fossil resources in NPS areas require science-based resource management, as outlined in the 2009 Paleontological Resources Preservation Act (Public Law 111-11). Santucci et al. (2009) outlined potential threats to in situ paleontological resources and recommended the monitoring of"vital signs to qualitatively and quantitatively assess the potential impacts of these threats. Paleontological vital signs include: 1) erosion (geologic factors), 2) erosion (climatic factors), 3) catastrophic geohazards, 4) hydrology/bathymetry, and 5) human access/public use. The authors also presented detailed methodologies for monitoring each vital sign.

Sedimentary Bedrock Features

Sedimentary features in rocks preserve a record of conditions during their deposition and the processes by which they were deposited. Sedimentary rocks of Silurian, Devonian, and Mississippian ages are mapped in the park area (although they are mostly buried) and display myriad features that provide information regarding their original depositional environments. These features are described in greater detail in Carman (1947, 1955). Carman's studies were undertaken during core drilling on the south slope of Paint Creek Valley, 5 km (3 mi) southwest of Chillicothe, to determine the petroleum content of the Ohio Shale (Do).

Fine-grained mud and clay settle in low-energy, typically deeper-water depositional environments, leading to characteristic features such as thin beds and laminations that break into sheet-like layers ("fissile partings") within the Ohio-Olentangy Shale (Do; fig. 19) .The Ohio Shale is exposed at Copperas Mountain as the basal three-fourths of a 100-m (350-ft) cliff, of which the lower 45 m (150 ft) rise nearly vertically above Paint Creek (Carlson 1991). Portions of the Ohio Shale (Do) contain approximately 10% total organic carbon and appear very black in fresh outcrops and brownish in weathered outcrops. Other Ohio Shale layers have less organic content and are grayer in color. Because of its carbonaceous nature, the Ohio Shale emits a characteristic petroliferous odor (Swinford et al. 2003). Because of its abundance of heavy minerals, the Ohio Shale is also a known source of radon gas in Ohio.

Figure 19. Photograph of bluffs along Paint Creek. Ohio-Olentangy Shale (geologic map unit Do) exposed in slumps and bluffs along Paint Creek, as visible from across the stream at the Seip Earthworks unit at Hopewell Culture National Historical Park. The Ohio Shale breaks into characteristic slabs and platy pieces. Note the presence of a weathered concretion (~1 m [3 ft] in diameter) lying in the stream. Photograph by Trista Thornberry-Ehrlich (Colorado State University) on 8 October 2009.

In contrast to the Ohio Shale, which records a very tranquil depositional environment, the overlying Sunbury Shale, Berea Sandstone, and Bedford Shale units (mapped together as DMu) and Logan and Cuyahoga formations (mapped together as Mlc) contain sedimentary structures that indicate higher-energy conditions and decreasing water depths (Swinford et al. 2003). The coarse grain size of the Berea Sandstone and some portions of the Cuyahoga Formation indicates a nearshore, higher-energy depositional environment. Unit DMu (particularly the Bedford Shale) contains well-preserved oscillation ripples (fig. 20) formed as water washed back and forth. In this environment, marine fauna burrowed and scavenged, thereby churning or "bioturbating" the sedimentary layers.

Figure 20. Photograph of oscillation ripples. These ripples are on a slab of sandstone (DMu) at the Spruce Hill unit. National Park Service photograph by Dafna Reiner (Hopewell Culture NHP) on 3 August 2012.

Concretions and Nodules

Concretions and nodules are often spherical or ovoid, dense, well-cemented masses of material. Concretions form by the precipitation of iron carbonate (Fe_2CO_3) in concentric layers around a nucleus of material, sometimes a fossil. They typically form within water-saturated, unlithified sediment. Although they look similar to concretions, nodules do not form around a nucleus, but instead replace the host rock or sediment. Concretions are common in the lower portion of the black, thin-bedded Devonian Ohio Shale (Do) (Hyde 1921; Swinford et al. 2003). The Copperas Mountain site has been famous for concretions since the early 1800s. Some larger concretions have softer septarian cores and resistant, crack-free rims. Septarian concretions contain angular cavities or cracks, which are called "septaria." The uncracked body of the septarium is finely crystalline dolomite, and the material filling the veins or cracks may include minerals such as barite, cauclite, dolomite, and quartz (Carlson 1991).

The park's collections include some nodules or concretions (Thornberry-Ehrlich 2009). Iron and/or sulfur minerals, such as abundant pyrite, hematite, and marcasite, are found in these features. Regionally, such mineralized concretions or nodules inspired the naming of Sulfur Lick Creek, Sulfur Lick Road, Sulfur Lick Flat (across the valley from Copperas Mountain) and Sulfur Lick School (Hyde 1921; Thornberry-Ehrlich 2009). A local health spa (operating circa late 19th and early 20th centuries) even utilized natural springs containing dissolved heavy minerals derived from the Ohio Shale (Do) (Thornberry-Ehrlich 2009).

Concretions can be enormous—the size of a sedan car. As a concretion grows, adjacent soft and unlithified surrounding sediments deform around it. This type of soft-sediment deformation is visible in shale outcrops, such as those across Paint Creek from the Seip Earthworks unit. Because large, rounded concretions are typically more resistant to weathering than adjacent clay-rich shales, they frequently weather out of the shale. If exposed and undercut on a slope, concretions tumble down. For example, large concretions are visible in Paint Creek adjacent to the Seip Earthworks unit (fig. 19).

Geologic History

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

The geologic history of Hopewell Culture National Historical Park is represented by three groups of rocks and deposits. The oldest are Paleozoic sedimentary rocks, hundreds of millions of years old, deposited in a long-standing marine basin. These rocks were later tilted during several major mountain-building events (orogenies) that led to the formation of the Appalachian Mountains and the assembly of the supercontinent Pangaea. Much more recently, during the ice ages (within the past 2 million years), glacial ice sculpted the landscape and left thick, overlapping deposits upon its retreat. The youngest deposits, no more than 20,000 years old, are associated with the modern Scioto River and Paint Creek. Rocks from all three of these groups are present in Hopewell Culture National Historical Park, spanning a time period from the Silurian (about 444 million years ago) to the present.

Paleozoic Era (542 to 251 Million Years Ago)—Longstanding Marine Deposition and the Rise of the Appalachians

At the dawn of the Paleozoic Era 542 million years ago, the area that would become southern Ohio was a broad coastal plain adjacent to a deeper marine basin, analogous to the modern Gulf Coast (figs. 21 and 22A) (Coogan 1996). At this time, southern Ohio was just north of the equator. During the early Cambrian, tectonic forces stretched the crust of what would become east-central North America apart, forming basins separated by uplifted arches and domes. One such structure, the Cincinnati Arch, is a prominent regional uplift that extends north from the Nashville area in central Tennessee to northwestern Ohio (fig. 21). The Cincinnati Arch separates the Illinois Basin to the north and west from the Appalachian Basin to the east. At its northern extent, the arch opens into the northwest–southeast-trending Kankakee Arch and the northeast–southwest-trending Findlay arch. The broad area formed by the arches is called the Indiana-Ohio Platform. The bedrock mapped within Ross County is part of the eastern limb of the Cincinnati Arch. The arch and adjacent basins were present throughout most of the Paleozoic.

In the Middle Ordovician Period, the first of three major Appalachian Mountain orogenies began to change the eastern edge of the continent. During the Taconic Orogeny, from about 470 to 440 million years ago, a volcanic arc collided with proto-North America (a landmass referred to as Laurentia). The resulting highlands were located east of southern Ohio, but structures such as the Cincinnati Arch may have buckled upward (Kentucky Geological Survey 2003). As southern Ohio was far inland at the time, deformation was not

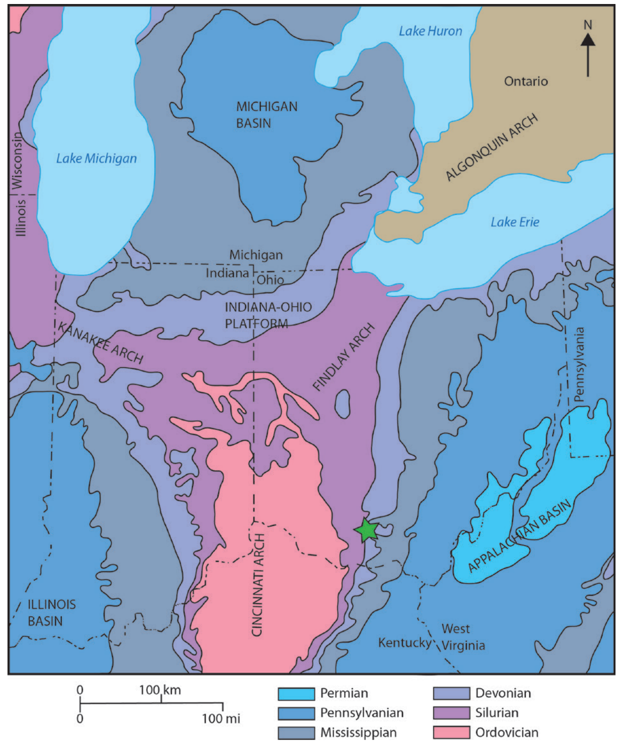

Figure 21. Map of regional geologic structures and ages of bedrock. Green star represents the location of Hopewell Culture National Historical Park. Refer to figure 17 for a schematic cross sectional view of southern Ohio (Cincinnati Arch to Appalachian Basin). Graphic adapted from figure 3-4 in Coogan (1996) by Trista L. Thornberry-Ehrlich (Colorado State University).

pervasive. While the mountains were rising, they immediately began to erode, shedding sediments to the east and west that filled adjacent basins. As seas retreated, the now-exposed sediments were deeply eroded (Coogan 1996).

From the Middle Ordovician through the Devonian, carbonate banks, reefs, lagoons, and bar deposits provided materials for vast deposits of now-buried limestones (Coogan 1996). Sediments shed from the Taconic highlands collected in an epicontinental (shallow) sea (Coogan 1996). A relative drop in sea level caused a break in deposition between the Ordovician (fig. 22B) and Silurian bedrock units. During the Middle to Late Silurian, sea level rose again and Ohio was inundated by warm, shallow seas that supported proliferous reef environments (fig. 22C). These subtropical, carbonate-bank deposits are mapped (geologic map units St and St-b) on the eastern and western flanks of the Cincinnati Arch (Coogan 1996; Swinford et al. 2003). Evaporite (salt) deposits were associated with the shallow, retreating Silurian sea (Ssu) (Coogan 1996; Swinford et al. 2003).

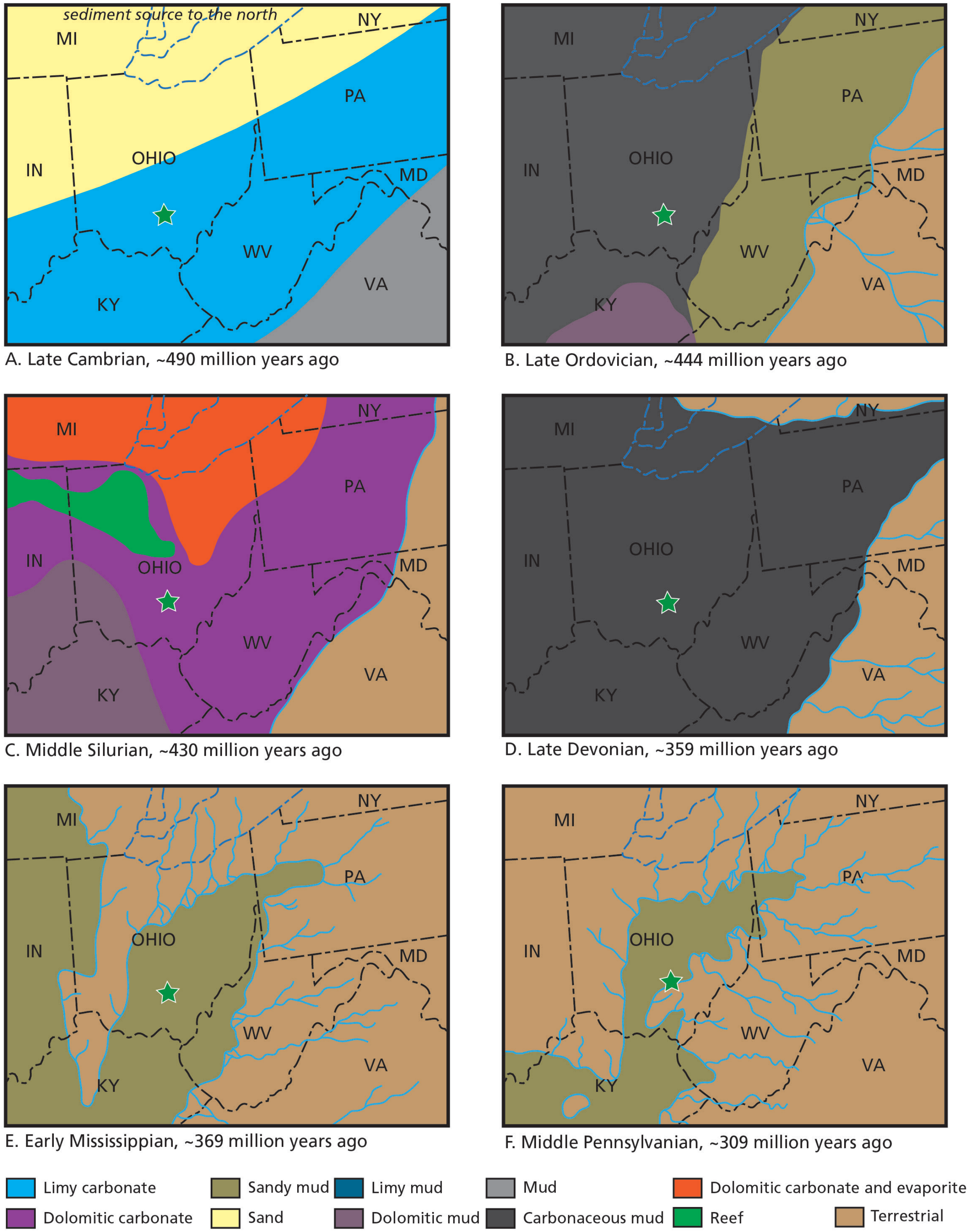

Figure 22. Generalized depositional environment maps of Ohio during the Paleozoic Era. As seas advanced and retreated and the Appalachian Mountains formed, depositional environments also changed. The varied depositional environments are reflected in the varied sedimentary rocks that underlie Hopewell Culture National Historical Park. Green stars represent the location of Hopewell Culture National Historical Park. Graphic adapted from figure 3-12 in Coogan (1996) by Trista L. Thornberry (Colorado State University).

Throughout the Devonian (about 416 to 359 million years ago), marine conditions prevailed and deposition was nearly continuous. These shallow seas collected deposits that would later become limestone, dolomite, shale, mudstone, and sandstone with occasional volcanic ash layers. The collision of additional landmasses with Laurentia during the Devonian Period signaled the onset of another mountain-building pulse—the Neoacadian Orogeny. This orogeny occurred as the African continent (part of a landmass known as Gondwana) approached Laurentia between 410 and 360 million years ago. As in the earlier orogeny, the Cincinnati Arch buckled upward. By the end of the Devonian (fig. 22D), continued subsidence of the shallow seas had formed stagnant bodies of water that collected vast deposits of organic-rich, black mud, which would become the Ohio Shale (Do) (Coogan 1996; Swinford et al. 2003). The shoreline of this stagnant basin was in central Pennsylvania (Coogan 1996).

By the end of the Devonian and beginning of the Mississippian (fig. 22E), the stagnant sea had been partly filled by fluvial and deltaic systems (Coogan 1996). Sandstones and siltstones were deposited in this environment (DMu and Mlc). Later in the Mississippian, limestone deposits again collected in shallow seas. The Sunbury Shale (DMu) records a brief return to stagnant conditions between the deposition of the Berea Sandstone and Cuyahoga Formation (Mlc) (Coogan 1996; Swinford et al. 2003). The Mississippian rocks were weathered deeply during another erosional event prior to the onset of Pennsylvanian deposition (fig. 22F) (Coogan 1996).

The Pennsylvanian-Permian Alleghany Orogeny (about 330 to 270 million years ago) involved a continental collision between Laurentia and Gondwana, completing the assembly of Pangaea and lifting the Appalachian Mountains to their maximum height. Their grandeur was analogous to the modern Himalayas. Horizontally deposited Paleozoic units may have been tilted during this event (Carman 1947).

Mesozoic Era, Paleogene Period, and Neogene Period (251 to 2.6 Million Years Ago)—Erosion of the Appalachians

Rocks from this time period are not represented within Hopewell Culture National Historical Park. Nevertheless, global and regional events altered the landscape and set the stage for ice age and more recent deposits.

When the Mesozoic Era began, Pangaea began to rift apart into roughly the continental landmasses that exist today. Rifting pulled what would become Africa and South America apart from North America, forming the Atlantic Ocean. The middle of North America, including Ohio, was slowly uplifting. As a result, rivers eroded the high peaks of the Appalachians, forming the deposits of the Coastal Plain to the east and filling the lowlands to the west of the mountains (Coogan 1996).For the few million years or so prior to the ice ages, the ancient Teays River system flowed across Ross County from southeast to northwest and was the primary drainage for the region. It entered southeastern Ross County from a now long-abandoned course through West Virginia (fig. 23). The Paint Creek Valley was a main tributary to the Teays, forming a junction with the ancient river near what is now Andersonville, about 11 km (7 mi) north of Chillicothe. At Chillicothe, this river valley system was once more than 1.6 km (1 mi) wide, larger than the modern Ohio River, and 150 m (500 ft) above sea level (Quinn and Goldthwait 1985).

The Teays River system eroded down into bedrock. Old, buried bedrock channels are visible on the bedrock map of Ohio. Bedrock structures likely influenced the location of the incised river course. In western Ohio, the paleochannels of the Teays River system formed relatively narrow notches in the carbonate surficial rocks, possibly aligning with preexisting joint patterns. Regional, deep-seated faults that formed during a billion-year-old Grenville-age failed rift system in western Ohio may have been a controlling factor in the orientation of the Teays Valley there (Thornberry-Ehrlich 2009). Another early, bedrock-incised river system—the Deep-Stage Newark River—lies nearly 30 m (100 ft) below the Scioto River floodplain, which is now filled with glacial sediments (Quinn and Goldthwait 1985).

Figure 23. Map of ancient Teays River. The ancient Teays River course flowed northwestward through Ohio. Pleistocene glaciers blocked this drainage, forming a series of glacial lakes, burying the valley, and ultimately rerouting drainages throughout the area toward the current Ohio River course (the northern boundary of Kentucky with Indiana and Ohio). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Hansen (1995) and Woods (2004).

Pleistocene Epoch (2.6 Million to 11,700 Years Ago)—Ice Age Glaciations

Repeated glaciations (ice ages) during the Pleistocene Epoch occurred between about 2 million and 10,000 years ago. The glaciers scoured and reshaped the topography of most of the northeastern United States. Thick sheets of ice repeatedly advanced and retreated from the Arctic into what is now the United States. The line of maximum advance crosses Ross County, Ohio (see fig. 12). Evidence of glaciation and ice movement is present as various types of glacial deposits, which mantle much of the landscape at Hopewell Culture National Historical Park. Glacial sediments and features include those formed directly by moving ice (moraines, till, kames, striations, grooves). Others are glaciofluvial (deposited by rivers flowing out of glaciers) or glaciolacustrine (deposited in lakes near glaciers). The "Surficial Units" GIS data layer for the park includes glacial deposits, which are further described in the "Geologic Features and Processes" section.

Glacial ice covered the northern three-quarters of Ross County during two major ice age events—the older Illinoian and the more recent Wisconsinan stages (Quinn and Goldthwait 1985). Hopewell Culture National Historical Park is located near the southern margin of both glacial events. During an early Pleistocene glacial advance, prior to the Illinoian advance, ice dammed local drainages including the Teays River Valley downstream (north) of Chillicothe to form 400-km- (250-mi-) long Teays Lake (Janssen 1960). The Minford Silt (pl) mapped in southeastern Ross County collected in this lake (Janssen 1960; Quinn and Goldthwait 1985). Teays Lake was the first (oldest) of many such ice-dammed lakes to form in what is now Ross County (see fig. 12).

Illinoian ice advanced into Ross County from the north-northwest. Thin Illinoian glacial drift deposits suggest that the ice stand was generally of short duration locally (Quinn and Goldthwait 1985). Throughout the myriad advances and retreats of the Illinoian glaciers, glacial moraine and till (Rainsboro Till [Ig]) were deposited, glacial outwash (Io) accumulated beyond the glacial margin, and permanent changes to drainages resulted. The southern bedrock margin of Paint Creek Valley was mantled by stratified drift (Ii). Two levels of outwash may be attributable to deposition during two substages of Illinoian glaciation. Patches of till over the higher terrace indicate an Illinoian ice readvance following its deposition. The presence of glacial erratics on the summits of Sugarloaf Mountain, Bunker Hill, Mount Logan, and Rattlesnake Knob demonstrates that the highest areas of the Appalachian Plateau margin were covered with ice during the Illinoian glaciation. During an interglacial event, erosion incised extensive valleys in the glacial outwash (Io). Some of these valleys (e.g., Dry Run, Walnut Creek, Little Walnut Creek, Salt Creek, and Sandy Bottom Run) again served as drainages during Late Wisconsinan events. This function is clearly indicated by the presence of younger Wisconsinan outwash terraces several meters below the outwash (Io) surface. Inliers of Illinoian drift occur within the area of later, Wisconsinan glaciation, occurring as nunataks (high "islands" of unglaciated land within glacial lobes).

Many local drainages were blocked by glacial ice, forming proglacial lakes (Il). Major drainages, such as the Teays River and the Deep-Stage Newark River, were diverted by downcutting at sediment-clogged outlets of proglacial ice-dammed lakes (including glacial lakes Bourneville, Massieville, Humboldt, and Bainbridge) (Quinn and Goldthwait 1985). Glacial Lake Bourneville formed as Illinoian ice blocked drainages in the Paint Creek and Owl Creek valleys west of Slate Mills. Downcutting at the lake outlet formed the Alum Cliffs gorge. Glacial Lake Massieville was formed in the Indian Creek Valley by Illinoian and Late Wisconsinan ice sheets (Quinn and Goldthwait 1985).

As the Illinoian ice retreated, the Teays and Deep-Stage Newark river valleys served as major spillways for meltwater discharge and accumulation areas for glacial outwash (Io), burying the original bedrock channels to great depths (Quinn and Goldthwait 1985). The distribution of Io indicates that the main Illinoian meltwater discharge primarily passed through the Teays-Stage Valley, rather than occupying the Deep-Stage Newark River Valley. This pathway likely resulted from the erosion of lacustrine valley fill (Minford Silt [pl]) in the Teays River Valley and thick deposition in the Newark River Valley, which created a lower outlet for meltwater through the Teays Valley. The Newark River Valley may have been a narrow bedrock gorge that was too restrictive for the huge volumes of Illinoian meltwater, forcing the bulk of discharge through the older Teays outlet.

An interglacial period (Sangamonian) followed the final retreat of the Illinoian glacier from about 120,000 to 75,000 years before present. Deep soils developed and glacial deposits were eroded (Quinn and Goldthwait 1985). Some Illinoian outwash occurs 60 to 75 m (200 to 250 ft) above the floodplain of the modern Scioto River, east of Chillicothe (Leverett 1942).

The Wisconsinan glacial advance ("stage") overprinted much evidence of the earlier Illinoian. The first advances of Wisconsinan ice did not extend into the Chillicothe area, but later advances encompassed the Paint Creek Valley, reaching a maximum extent around 21,500 years before present (Quinn and Goldthwait 1985). Because the Wisconsinan was the most recent ice advance, ample evidence of it remains. Wisconsinan ice sheets deposited at least three till units in Ross County: Boston, Caesar, and Darby tills. The Boston Till, deposited approximately 21,500 years before present, marked the maximum position of the Late Wisconsinan ice margin in Ross County. The Lattaville (Wi2, Wit2, Wg2, and We2) and Reesville (Wi3, Wg3, and We3) end moraines accumulated at the maximum advance or readvance ice positions associated with the Caesar and Darby tills, respectively.

As mentioned above, Glacial Lake Massieville was formed in the Indian Creek Valley by Late Wisconsinan ice sheets. Around the same time, Glacial Lake Bainbridge formed as early Late Wisconsinan ice advanced southwestward up the Paint Creek Valley and blocked the drainage near Bainbridge. Glacial Lake Humboldt formed simultaneously as the ice sheet blocked the Buckskin Creek Valley north of Humboldt (Quinn and Goldthwait 1985).

Approximately 18,000 years before present, the Scioto glacial sublobe readvanced to a position relatively coincident with the northern margin of the Appalachian Low Plateau, leaving the Lattaville End Moraine behind. Another less extensive readvance 17,200 years before present left behind the Reesville End Moraine (Quinn and Goldthwait 1985). An ice margin stagnation (very minor readvance) 17,000 years before present resulted in the deposition of the Yellowbud Moraine in north-central Ross County (Quinn and Goldthwait 1985).

The Wisconsinan glaciers retreated step-wise and intermittently from the Ross County area, depositing three levels of outwash, each associated with a moraine indicating the ice-margin position: the Worthington (Wow), Circleville (Woc), and Kingston (Wok) outwashes associated with the Powell, Marcy-Yellowbud, and Lattaville moraines, respectively. The Kingston Outwash was the highest level of Late Wisconsinan outwash. The Worthington Outwash is the youngest glacial deposit in Ross County; it was deposited down the Scioto River Valley as part of a final readvance approximately 15,000 years before present. The Circleville and Kingston outwashes are mapped within Hopewell Culture National Historical Park.

Holocene Epoch (11,700 Years Ago to Present)—Erosion and Establishment of the Modern Landscape

At the beginning of the Holocene Epoch, thick glacial deposits mantled the landscape of Ross County as far as the Appalachian Plateau escarpment. Overall, drainage divides in the county shifted northward as a result of glacial impoundment of lakes and the deposition of vast drift deposits along the escarpment. The topography was subdued by glaciers' scouring of the uplands, widening and filling valleys with till, glaciofluvial and glaciolacustrine silts, sands, and gravel (Szabo and Angle 1983). Modifications to the glacial drift deposits at this time included 1) gullying on higher outwash terraces and end moraines, 2) deposition of low-lying alluvial terraces atop gravel outwash terraces, and 3) erosion of outwash terraces and intermittent formation and abandonment of many stream channels on the valley-fill surface (Quinn and Goldthwait 1985).

The Scioto River began to flow at this time, capturing smaller drainages as it flowed southward from west-central Ohio through the Columbus area, where the Olentangy tributary drainage joins the system. The Scioto River flows through the Chillicothe area before reaching the Ohio River drainage near Portsmouth. Locally, the Scioto River occupies the ancient, buried Teays River Valley; however, today's flow is in the opposite direction. The Scioto River appears underfit for the wide valley carved by glacial ice and meltwater. Alluvium and alluvial terraces (Qal and Qalt) are accumulating in the river channel and flanking riparian zones, respectively. Just a few thousand years ago, the Hopewell peoples took advantage of the modern landscape features to construct earthworks.

Geologic Map Data

This section summarizes the geologic map data available for Hopewell Culture National Historical Park. The Geologic Map Overview Graphics (in pocket) display the geologic map data draped over a shaded relief image of the park 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. 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. For reference, a geologic time scale is included as figure 2. Bedrock and surficial (glacial) geologic map data are provided for Hopewell Culture National Historical Park.

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 Hopewell Culture National Historical Park. These source maps provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report.

Ohio Division of Geological Survey. 2003. Bedrock-geology data of the Andersonville, Bourneville, Chillicothe East, Chillicothe West, Frankfort, Kingston, Morgantown, Summithill, and Waverly North quadrangles, Ohio (scale 1:24,000). Open-file bedrock-geology series maps. Ohio Division of Geological Survey, Columbus, Ohio, USA.

Quinn, M. J., and R. P. Goldthwait. 1985. Glacial geology of Ross County, Ohio (scale 1:62,500). Report of investigations 127.Ohio Division of Geological Survey, Columbus, Ohio, USA.

Swinford, E. M., G. A. Schumacher, D. L. Shrake, G. E. Larsen, and E. R. Slucher. 2003. Descriptions of geologic map units: a compendium to accompany Division of Geological Survey open-file bedrock-geology maps. Open-file report 98-1.Ohio Division of Geological Survey, Columbus, Ohio, USA. [Nomenclature updated by Shrake et al. (2011)].

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 Hopewell Culture National Historical Park 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 Hopewell Culture National Historical Park 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 1)
- Federal Geographic Data Committee (FGDC)–compliant metadata
- An ancillary map information document (.pdf) document that contains all of the supplemental 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

Table 1. Geology data layers in the Hopewell Culture National Historical Park GIS data.

Data Layer	Data Layer Code	On Overview Graphic?
Surficial Units	SUR	Yes
Surficial Contacts	SURA	Yes
Structure Contour Lines	CN1	No
Glacial Feature Lines	GFL	Yes
Mine Point Features	MIN	No
Bedrock Contacts	GLGA	Yes
Bedrock Units	GLG	Yes

Geologic Map Overview Graphics

The Geologic Map Overview Graphics (in pocket) display the GRI digital geologic data draped over a shaded relief image of the park and surrounding area. For graphic clarity and legibility, not all GIS feature classes may be visible on the overviews, as indicated in the table 1. Cartographic elements and basic geographic information have been added to overviews. Digital elevation data and geographic information, which are part of the overview graphics, are not included with the GRI digital geologic GIS data for the park, 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 park 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 overview graphic. Based on the source map scales (1:24,000 and 1:62,500) and U.S. National Map Accuracy Standards, geologic features represented in the geologic map data are horizontally within 12 m (40 ft) and 32 m (105ft), respectively, 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 Geosciences Institute Glossary of Geology *(fifth edition; 2005). Additional definitions and terms are available at: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.*

ablation. All processes by which snow and ice are lost from a glacier, including melting, evaporation (sublimation), wind erosion, and calving.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows to a hydraulically unconfined area. Commonly out of a mountainous area into an area such as a valley or plain.

alluvium. Stream-deposited sediment.

anhydrite. A mineral consisting of anhydrous calcium sulfate, which is gypsum without the water in its crystal structure. Readily alters to gypsum.

anticline. A convex-upward ("A" shaped) fold. Older rocks are found in the center.

aquiclude. See "confining bed."

aquitard. See "confining bed."

aquifer. A rock or sedimentary unit that is sufficiently porous that it has a capacity to hold water, sufficiently permeable to allow water to move through it, and currently saturated to some level.

arc. See "volcanic arc.

argillaceous. Describes a sedimentary rock composed of a substantial amount of clay.

argillite. A compact rock, derived from mudstone or shale, more highly cemented than either of those rocks. It does not easily split like of shale or have the cleavage of slate. It is regarded as a product of low-temperature metamorphism.

ash (volcanic). Fine material ejected from a volcano (also see "tuff").

axis (fold).A straight line approximation of the trend of a fold which divides the two limbs of the fold. "Hinge line" is a preferred term.

base flow. Stream flow supported by groundwater; flow not attributed to direct runoff from precipitation or snow melt.

base level. The lowest level to which a stream can erode its channel. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie rocks exposed at the surface.

basin (structural).A doubly plunging syncline in which rocks dip inward from all sides.

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two 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.

bioherm. A mound-like, dome-like, lens-like, or reef-like mass of rock built up by sedentary organisms, composed almost exclusively of their calcareous remains, and enclosed or surrounded by rock of different lithology.

bioturbation. The reworking of sediment by organisms.

braided stream. A sediment-clogged stream that forms multiple channels which divide and rejoin.

brittle. Describes a rock that fractures (breaks) before sustaining deformation.

calcareous. Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$).

calcic. Describes minerals and igneous rocks containing a relatively high proportion of calcium.

calcite. A common rock-forming mineral: $CaCO_3$ (calcium carbonate).

carbonaceous. Describes a rock or sediment with considerable carbon content, especially organics, hydrocarbons, or coal.

carbonate. A mineral that has CO_3^{-2} as its essential component (e.g., calcite and aragonite).

carbonate rock. A rock consisting chiefly of carbonate minerals (e.g., limestone, dolomite, or carbonatite).

cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

chemical sediment. A sediment precipitated directly from solution (also called nonclastic).

chemical weathering. Chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances; commonly results in a change in chemical composition more stable in the current environment.

chert. A 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).

clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).

claystone. Lithified clay having the texture and composition of shale but lacking shale's fine layering and fissility (characteristic splitting into thin layers).

cleavage. The tendency of a rock to split along parallel, closely spaced planar surfaces. It is independent of bedding.

concretion. A hard, compact aggregate of mineral matter, subspherical to irregular in shape; formed by precipitation from water solution around a nucleus such as shell or bone in a sedimentary or pyroclastic rock. Concretions are generally different in composition from the rocks in which they occur.

confining bed. A body of relatively impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers. Replaced the term "aquiclude."

conglomerate. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented, rounded clasts larger than 2 mm (0.08 in).

conodont. One of a large number of small, disjunct fossil elements assigned to the order Conodontophorida, phosphatic in composition and commonly tooth-like in form but not necessarily in function.

continental crust. Crustal rocks rich in silica and alumina that underlie the continents; ranging in thickness from 35 km (22 mi) to 60 km (37 mi) under mountain ranges.

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 shield. A continental block of Earth's crust that has remained relatively stable over a long period of time and has undergone minor warping compared to the intense deformation of bordering crust.

convergent boundary. A plate boundary where two tectonic plates are colliding.

craton. The relatively old and geologically stable interior of a continent (also see "continental shield").

creep. The slow, imperceptible downslope movement of mineral, rock, and soil particles under gravity.

crinoid. A marine invertebrate (echinoderm) that uses a stalk to attach itself to a substrate. "Arms" are used to capture food. Rare today, they were very common in the Paleozoic. Crinoids are also called "sea lilies."

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as water flow direction and depth.

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in a vertically oriented plane.

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.

deformation. A general term for the processes of faulting, folding, and shearing of rocks as a result of various Earth forces such as compression (pushing together) and extension (pulling apart).

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.

differential erosion. Erosion that occurs at irregular or varying rates, caused by differences in the resistance and hardness of surface material.

dip. The angle between a bed or other geologic surface and horizontal.

divergent boundary. An active boundary where tectonic plates are moving apart (e.g., a spreading ridge or continental rift zone).

dolomite. A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite (calcium-magnesium carbonate).

dolomitic. Describes a dolomite-bearing rock, or a rock containing dolomite.

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 the cutting is directed in primarily downward, as opposed to lateral erosion.

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

drift. All rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier. Includes unstratified material (till) and stratified deposits (outwash plains and fluvial deposits).

electromagnetic survey (method). An electrical exploration method based on the measurement of alternating magnetic fields associated with currents artificially or naturally maintained in the subsurface.

entrainment. The process of picking up and transporting sediment, commonly by wind or water.

eolian. Describes materials formed, eroded, or deposited by or related to the action of the wind. Also spelled "Aeolian."

ephemeral stream. A stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

epicenter. The point on Earth's surface that is directly above the focus (location) of an earthquake.

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

esker. A long, narrow, sinuous, steep-sided ridge composed of irregularly stratified sand and gravel that was deposited by a subglacial or englacial stream flowing between ice walls or in an ice tunnel of a stagnant or retreating glacier.

evaporite. A sedimentary rock composed primarily of minerals produced from a saline solution as a result of extensive or total evaporation of the solvent (usually water).

extension. A type of strain resulting from forces "pulling apart." Opposite of compression.

fan delta. An alluvial fan that builds into a standing body of water. This landform differs from a delta in that a fan delta is next to a highland and typically forms at an active margin.

fault. A break in rock along which relative movement has occurred between the two sides.

feldspar. A group of abundant (more than 60% of Earth's crust), light-colored to translucent silicate minerals found in all types of rocks. Usually white and gray to pink. May contain potassium, sodium, calcium, barium, rubidium, and strontium along with aluminum, silica, and oxygen.

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.

fold. A curve or bend of an originally flat or planar structure such as rock strata, bedding planes, or foliation that is usually a product of deformation.

foliation. A preferred arrangement of crystal planes in minerals. In metamorphic rocks, the term commonly refers to a parallel orientation of planar minerals such as micas.

formation. Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts.

fracture. Irregular breakage of a mineral. Any break in a rock (e.g., crack, joint, fault).

frost wedging. The breakup of rock due to the expansion of water freezing in fractures.

glacial erratic. Boulders transported by glaciers some distance from their point of origin.

graben. A down-dropped structural block bounded by steeply dipping, normal faults (also see "horst").

gully. A small channel produced by running water in earth or unconsolidated material (e.g., soil or a bare slope).

gypsum. The most common sulfate mineral (calcium sulfate).Frequently associated with halite and anhydrite in evaporites.

horst. Areas of relative "up" between grabens, representing the geologic surface left behind as grabens drop. The best example is the Basin-and-Range province of Nevada. The basins are grabens and the ranges are weathered horsts. Grabens become a locus for sedimentary deposition (also see "graben").

hydrogeologic. Refers to the geologic influences on groundwater and surface water composition, movement and distribution.

island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.

joint. A break in rock without relative movement of rocks on either side of the fracture surface.

kame delta. A flat-topped, steep-sided hill of well-sorted sand and gravel deposited by a meltwater stream flowing into a proglacial or other ice-marginal lake. The proximal margin of the delta was built in contact with glacier ice.

karst topography. Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

lamination. Very thin, parallel layers.

landslide. Any process or landform resulting from rapid, gravity-driven mass movement.

levee. Raised ridge lining the banks of a stream. May be natural or artificial.

limb. Either side of a structural fold.

limestone. A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of the mineral calcite.

liquefaction. The transformation of loosely packed sediment into a more tightly packed fluid mass.

lithology. The physical description or classification of a rock or rock unit based on characters such as its color, mineral composition, and grain size.

loess. Windblown silt-sized sediment, generally of glacial origin.

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 igneous rocks or poorly sorted clastic sediments or rocks. Also refers to rock or sediment in which a fossil is embedded.

meander. Sinuous lateral curve or bend in a stream channel. An entrenched meander is incised, or carved downward into the surface of the valley in which a meander originally formed. The meander preserves its original pattern with little modification.

mechanical weathering. The physical breakup of rocks without change in composition. Synonymous with "physical weathering."

meteoric water. Pertaining to water of recent atmospheric origin.

mica. A prominent rock-forming mineral of igneous and metamorphic rocks. It has perfect basal cleavage meaning that it forms flat sheets.

mid-ocean ridge. The continuous, generally submarine and volcanically active mountain range that marks the divergent tectonic margin(s) in Earth's oceans.

mineral. A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

moraine. A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited by glacial ice movement.

mud cracks. Cracks formed in clay, silt, or mud by shrinkage during dehydration at Earth's surface.

neoglacial. Describes the period of glacial readvance during the late Holocene, the most recent being the Little Ice Age (from the 1500s until the mid 1800s).

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6 to 7 km (3 to 4 miles) thick and generally of basaltic composition.

orogeny. A mountain-building event.

ostracode. Any aquatic crustacean belonging to the subclass Ostracoda, characterized by a two-valved (shelled), generally calcified carapace with a hinge along the dorsal margin. Most ostracodes are of microscopic size.

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.

paleogeography. The study, description, and reconstruction of the physical landscape from past geologic periods.

paleontology. The study of the life and chronology of Earth's geologic past based on the fossil record.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic periods.

parent material. The unconsolidated organic and mineral material in which soil forms.

parent rock. Rock from which soil, sediments, or other rocks are derived.

pebble. Generally, small rounded rock particles from 4 to 64 mm (0.16 to 2.52 in) in diameter.

permeability. A measure of the relative ease with which fluids move through the pore spaces of rocks or sediments.

phosphatic. Pertaining to or containing phosphates; commonly refers to a sedimentary rock containing phosphate minerals.

plate tectonics. The concept that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid asthenosphere.

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

platform. Any level or nearly-level surface, ranging in size from a terrace or bench to a plateau or peneplain.

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 (e.g., pores or voids) in a volume of rock or sediment deposit.

prodelta. The part of a delta below the level of wave erosion.

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

provenance. A place of origin. The area from which the constituent materials of a sedimentary rock were derived.

recharge. Infiltration processes that replenish groundwater.

reflection survey. Record of the time it takes for seismic waves generated from a controlled source to return to the surface. Used to interpret the depth to the subsurface feature that generated the reflections.

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

relative dating. Determining the chronological placement of rocks, events, or fossils with respect to the geologic time scale and without reference to their numerical age.

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

rift valley. A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.

ripple marks. The undulating, approximately parallel and usually small-scale ridge pattern formed on sediment by the flow of wind or water.

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.

rock fall. Mass wasting process where rocks are dislodged and move downslope rapidly; it is the fastest mass wasting process.

sand. A clastic particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16 mm (0.0025 in) to 2 mm (0.08 in).

sandstone. Clastic sedimentary rock of predominantly sand-sized grains.

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

shale. A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.

shoreface. The zone between the seaward limit of the shore and the more nearly horizontal surface of the offshore zone; typically extends seaward to storm wave depth or about 10 m (32 ft).

silicate. A compound whose crystal structure contains the SiO_4tetrahedra.

silicic. Describes a silica-rich igneous rock or magma.

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]).

siltstone. A variably lithified sedimentary rock composed of silt-sized grains.

sinkhole. A circular depression in a karst area with subterranean drainage and is commonly funnel-shaped.

slate. A compact, fine-grained metamorphic rock that can be split into slabs and thin plates. Most slate was formed from shale.

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

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

soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent material from which it formed.

specific conductance. The measure of discharge of a water well per unit of drawdown.

spreading center. A divergent boundary where two lithospheric plates are spreading apart. It is a source of new crustal material.

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

strata. Tabular or sheet-like masses or distinct layers of rock.

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

striations. Parallel scratches or lines.

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

subaerial. Describes conditions and processes that exist or operate in the open air on or immediately adjacent to the land surface.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

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

syncline. A downward curving (concave-up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.

synorogenic. Describes a geologic process or event occurring during a period of orogenic activity; also describes a rock or feature formed by those processes or event.

tectonic. Relating 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. Relating to land, Earth, or its inhabitants.

till. Unstratified drift, deposited directly by a glacier without reworking by meltwater, and consisting of a mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

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

trace fossil. Tracks, trails, burrows, coprolites (dung), etc., that preserve evidence of organisms' life activities, rather than the organisms themselves.

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.

type locality. The geographic location where a stratigraphic unit (or fossil) is well displayed, formally defined, and derives its name. The place of original description.

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.

upwarp. Upward flexing of Earth's crust.

volcanic arc. A commonly curved, linear, zone of volcanoes above a subduction zone.

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 March 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/

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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#/Views/

NPS Resource Management Guidance and Documents

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

2006 Management Policies (Chapter 4; Natural Resource Management): http://www.nps.gov/policy/mp/policies.html#_Toc157232681

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

Ohio Division of Geological Survey: http://www.dnr.state.oh.us/geosurvey/default/tabid/7105/default.aspx

U.S. Geological Survey: http://www.usgs.gov/

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

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

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

U.S. Geological Survey Reference Tools

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

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

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

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

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

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

Regional Geologic Sources

Lowell, T. V., R. K. Hayward, and G. H. Denton. 1999. Role of climate oscillations in determining ice-margin position; hypothesis, examples, and implications. Pages 193–203 *in* D. M. Mickelson and J. W. Attig, editors. Glacial processes past and present. Special paper 337. Geological Society of America, Boulder, Colorado, USA.

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Appendix: Scoping Meeting Participants

The following people attended the GRI scoping meeting for Hopewell Culture National Historical Park, held on 8 October 2009, or the follow-up report writing conference call, held on 26 March 2012. 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).

2009 Scoping Meeting Participants

Name	Affiliation	Position
Tim Connors	NPS, Geologic Resources Division	Geologist
Constance Jones	NPS, Hopewell Culture NHP	Biological Science Technician
Lisa Norby	NPS, Geologic Resources Division	Geologist
Jennifer Pederson-Weinberger	NPS, Hopewell Culture NHP	Superintendent
Dafna Reiner	NPS, Hopewell Culture NHP	Biologist
Mac Swinford	Ohio Geological Survey	Geologist
Trista Thornberry-Ehrlich	Colorado State University	Geologist

2012 Conference Call Participants

Name	Affiliation	Position
Kathy Brady	NPS, Hopewell Culture NHP	Curator
Jason Kenworthy	NPS, Geologic Resources Division	Geologist, GRI Reports Coordinator
Jennifer Pederson-Weinberger	NPS, Hopewell Culture NHP	Superintendent
Rebecca Port	Colorado State University	Research Associate
Dafna Reiner	NPS, Hopewell Culture NHP	Biologist
Bret Ruby	NPS, Hopewell Culture NHP	Archeologist/Chief of Resources
Mac Swinford	Ohio Geological Survey	Geologist
Trista Thornberry-Ehrlich	Colorado State University	Geologist

NPS 653/120138, March 2013

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