National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

# Cuyahoga Valley National Park

## *Geologic Resources Inventory Report*

Natural Resource Report NPS/NRSS/GRD/NRR—2020/2154

**ON THE COVER**
**Photograph of blocks of Berea Sandstone in the channel of Chippewa Creek.**
**Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

**THIS PAGE**
**Photograph of a bedrock outcrop between Chippewa Falls and the confluence of Chippewa Creek and the Cuyahoga River. Bedrock includes Berea Sandstone (uppermost), Bedford Shale, and Ohio Shale (bottommost).**
**Photograph by Greg Tkachyk taken in October 2008.**

# Cuyahoga Valley National Park

## *Geologic Resources Inventory Report*

Natural Resource Report NPS/NRSS/GRD/NRR—2020/2154

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July 2020

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

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Please cite this publication as:

Thornberry-Ehrlich, T. L. 2020. Cuyahoga Valley National Park: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2020/2154. National Park Service, Fort Collins, Colorado.

NPS 644/171106, July 2020

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# Executive Summary

*The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI.*

*This report synthesizes discussions from a scoping meeting held in 2009 and a follow-up conference call in 2018 (see Appendix A). Chapters of this report discuss the geologic setting, distinctive geologic features and processes within Cuyahoga Valley National Park, highlight geologic issues facing resource managers, describe the geologic history leading to the present-day landscape, and provide information about the previously completed GRI map data. Posters (in pocket) illustrate these data.*

The Cuyahoga River slices through the plateau country of northeastern Ohio as an unexpected crevasse flanked by rolling uplands (see park map, fig. 1). Although there are other contenders, one could refer to it as the vegetated Grand Canyon of the east with its lush forests and meadows obscuring the rugged topography. Near vertical cliffs of sandstone and conglomerate frame an ancient valley that was filled with glacial deposits during the last major Ice Age. Now, a young river system is cutting through these deposits. The park's bedrock records a geologic history of more than 380 million years, beginning when much of Ohio was flooded by a shallow sea. The sea transgressed and regressed many times, depositing the mix of clays, silts, sands, and gravels that compose the park's stack of bedrock. Ancient rivers cut down through the rock layers for millennia prior to the glaciations of the Pleistocene more than 10,000 years ago. During these glaciations, vast continental glaciers advanced southward from Canada and covered the landscape with ice. These advances blocked and rerouted the old river systems. Resistant bedrock just south of the park area impeded glacial advance. This setting caused the glaciers to leave a complex record of deposits on the local landscape. The ancient river courses were filled with sediment and modern channels are still cutting through glacial deposits. Earth surface processes continue to modify the Cuyahoga Valley landscape. Geology and geologic processes affect nearly every facet of the natural environment of the park as well as its long and rich human history.

This report is supported by three GRI-compiled maps of the bedrock, surficial, and glacial geology of Cuyahoga Valley National Park. Fourteen maps were compiled to create a bedrock coverage (4-letter code: cuva) of portions of Summit and Cuyahoga counties, including the entirety of the park lands. This creates a picture of what the landscape would be if devoid of vegetation and overlying, unconsolidated surficial and glacial deposits. Some of this bedrock crops out on the surface, incised by local streams and rivers, or is perched as towering blocks above the valley floor. Surficial and glacial units are included in the GRI GIS data as two separate map products: a surficial geologic map (clvn) and a surficial and glacial geologic map (sucu). The surficial map provides a three-dimensional framework of the area's surficial geology with unit thicknesses, lateral extents, and vertical sequences of deposits (essentially a generalized cross section for each unit). The surficial and glacial map coverage differentiates the units deposited by the Pleistocene glaciers from those more recent units being reworked and accumulating on the modern landscape by Earth surface processes. The map data posters (in pocket) are primary figures of this GRI report, showing the GRI GIS data draped over shaded relief imagery of the park. Individual bedrock, surficial, and glacial units are included in the posters' legends.

The park's geologic features, processes, and management issues are outlined and described in this report. These include:

- fluvial features and processes
- flooding
- management of fluvial processes and flooding
- glacial features
- bedrock exposures
- ancient sedimentary features
- bedrock caves
- groundwater availability
- lacustrine features and wetlands
- geologic hazards
- abandoned mineral lands and disturbed lands

- paleontological resource inventory, monitoring, and protection

Table 3 of the report provides a detailed look at which features, processes, and/or issues pertain to each map unit included in the GRI GIS data. The table presents the units in relative stratigraphic order with the oldest bedrock on the bottom and the youngest surficial units on the top. The table is supplemented by a discussion of geologic features, processes, and resource management that includes relevant references and links to data and resources for park managers to provide guidance in making science-based decisions. Additional tables highlight the GRI GIS data layers for the three separate map products: cuva_geology.mxd; clvn_geology.mxd, and sucu_geology.mxd.

## GRI GIS Data Addendum (April 2020)

Following the submittal of this manuscript for publication, but prior to receiving its publication number, the GRI GIS data formats for Cuyahoga Valley National Park were updated.

This update does not change the content of the data, i.e., the map unit symbols used in the report remain the same. The data formats and map codes were changed and no longer correspond to references in the report nor the descriptive text in the "Geologic Map Data" section of this report. The following list summarizes the changes. In addition the GRI GIS data model was changed from 2.1 to 2.3.

- The bedrock geologic map, previously denoted by map code "cuva" (tables 3 and 5), is now "CUVA_bedrock."
- The surficial geologic map, previously denoted by map code "clvn" (tables 3 and 6), is now "CUVA_surficial."
- The glacial and surficial geologic map, previously denoted by map code "sucu"(tables 3 and 7), is now "CUVA_glacial_surficial."
- The following components are now available, in addition to those listed on pages 57 and 58:
    - ESRI file geodatabase with an Pro map (.mapx) file and individual layer (.lyrx) files.
    - Google Earth KML/KMZ file for all three maps (not just bedrock).
    - ESRI map service for all three maps.
    - GeoPackage (.qgz). Includes a QGIS project file for all three park maps.

# Products and Acknowledgments

*The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. The Ohio Division of Geological Survey developed the source maps and, along with University of Akron and NPS staff, reviewed GRI content. This chapter describes GRI products and acknowledges contributors to this report.*

## GRI Products

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

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. The GRI team conducts no new field work in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). The “Additional References” chapter and Appendix B provide links to these and other resource management documents and information.

Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri.


## Acknowledgments

Additional thanks to **Greg Tkachyk** (Cuyahoga Valley National Park) for providing many of the photographs used in this report.

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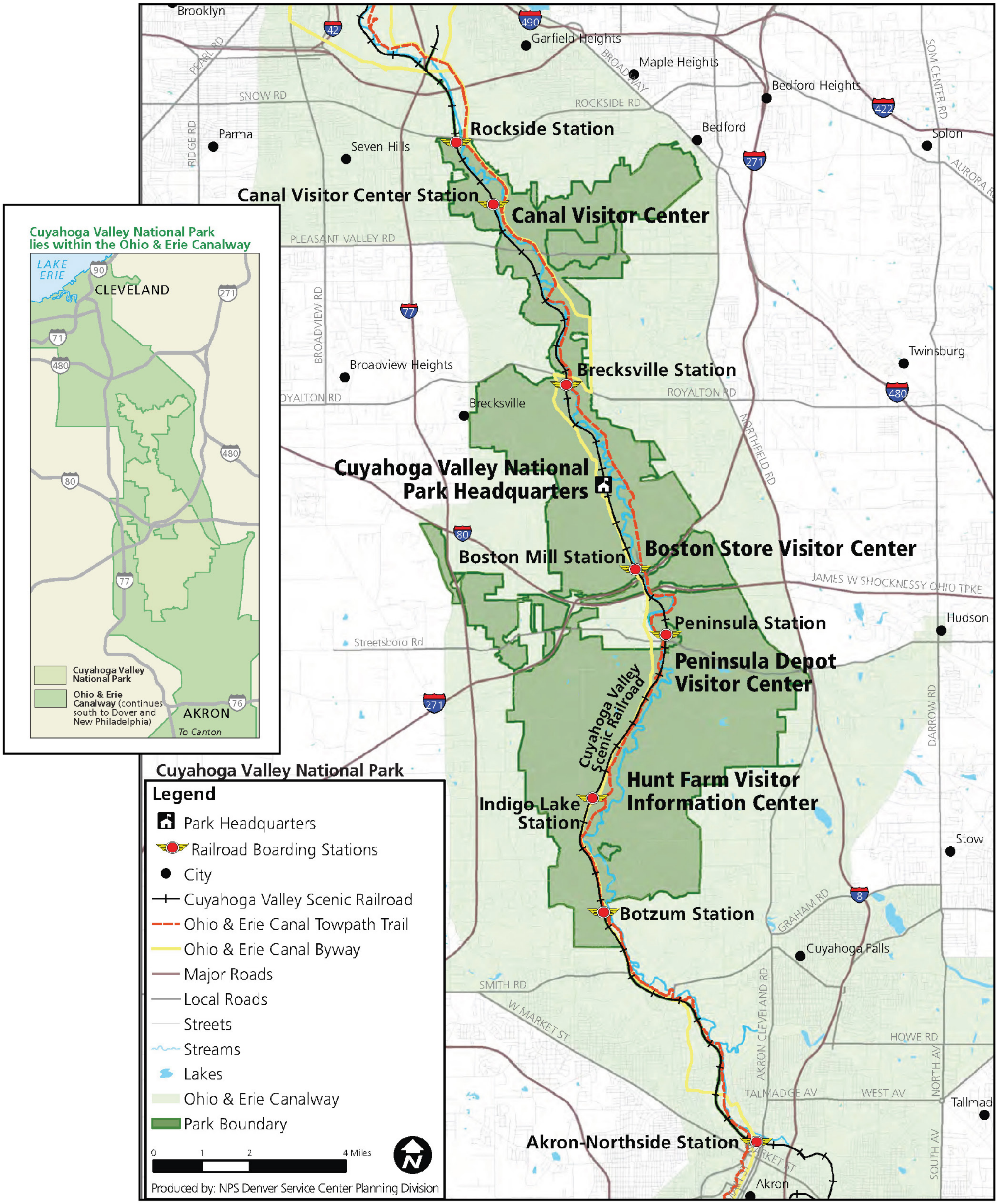



**Figure 1. Map of Cuyahoga Valley National Park.**
**NPS map, extracted from NPS (2013a). Refer to the NPS Harpers Ferry Center website for a more detailed park map (https://www.nps.gov/carto/app/#!/maps/alphacode/CUVA).**

# Geologic Setting and Significance

*This chapter describes the regional geologic setting of the park and summarizes connections among geologic resources, other park resources, and park stories.*

## Park Establishment

Lush river bottoms, leafy ravines, imposing cliffs, and cascading waterfalls make Cuyahoga Valley National Park a "green shrouded miracle" in the otherwise gently rolling landscape of north-central Ohio (Cockrell 1992). Some of the most remarkable distributions of landforms in the United States are concentrated in this relatively small portion of the world (Nash 2009). The rugged geology and lack of reliable groundwater sources prevented the area from being developed extensively—essentially preserving a natural "oasis". Originally established as a national recreation area on December 27, 1974 under Public Law 93-555, the park was redesignated as Cuyahoga Valley National Park on October 11, 2000. Wild and scenic river status is being sought for the Cuyahoga River including geologic outstanding resource values (John Peck, geologist, University of Akron, conference call 8 February 2018). The park stretches over 13,000 ha (33,000 ac) in Cuyahoga and Summit counties between the urban centers of Cleveland and Akron (fig. 1). Of this land, approximately 7,200 ha (18,000 ac) are federally owned, with the remainder owned by private parties, public agencies, and private land with easements. More than two million visitors come to the park every year to experience its peaceful setting and historical significance. Many more are simply passing through, enjoying a scenic respite from a normally congested commute.

As its name suggests, the park's centerpiece is the 35-km (22-mi) stretch of Cuyahoga River within the greater Ohio & Erie Canal National Heritage Corridor. The river begins in Geauga County, where The West Branch Cuyahoga and East Branch Cuyahoga meet near Burton, Ohio. From there it flows south until joining with the Little Cuyahoga River in Akron and makes an abrupt turn northward (Cockrell 1992) earning it the name "Ka-ih-ogh-ha" or "crooked river" by American Indians. As the crow flies, the Cuyahoga River empties into Lake Erie only 48 km (30 mi) west of where it begins (fig. 2). As the river flows, it crosses more than 134 km (84 mi), draining over 2,106 km$^2$ (813 mi$^2$; Nash 2009). The river and its tributaries, including Yellow Creek, Furnace Run, Tinkers Creek, West Creek (formerly Skinners Run), Brandywine Creek, and Chippewa Creek carve through unconsolidated Pleistocene glacial deposits atop mid to late Paleozoic sedimentary bedrock. The result is dramatic topography from the gently rolling farmland flanking the valley, to the near vertical sandstone and conglomerate cliffs, down to the relatively flat, open floodplain areas along the river channels and some of the larger tributaries. The valley has long been an animal migration route followed by an American Indian trade corridor. The Ohio & Erie Canal opened in 1827 supplied with water from the Cuyahoga River. The Valley Railway followed some 40 years later, taking advantage of this natural passage between the Ohio River and Lake Erie.

According to the administrative history prepared by Cockrell (1992), the park's stated purpose is to preserve and protect "for public use and enjoyment, the historic, scenic, natural, and recreational values of the Cuyahoga River and adjacent lands of the Cuyahoga Valley". Geology features prominently in the park's six significance statements listed in the park's Foundation Document (National Park Service 2013a):

- Cuyahoga Valley National Park is an island of high ecological integrity within a densely populated urban region. Situated along a major river system at the southern edge of Lake Erie, and bordering the edge of Ice Age glaciation between the Appalachian Mountains and the Great Plains, the park's location supports a high biological diversity and provides a vital habitat corridor for migrating species.
- Rooted in national environmental and social movements of the 20th century, the establishment of the park was a community-driven response to urban sprawl and ecological abuses epitomized by fires on the Cuyahoga River. The park continues to lead in restoring degraded landscapes, perpetuating environmental awareness, and promoting the ethic of stewardship and sustainability.
- Resources in the Cuyahoga Valley illustrate a continuum of transportation corridors from early American Indian to modern times. Of national significance, the Ohio & Erie Canal was part of the first interstate transportation system in lands known as the U.S. interior to the East Coast. This opened up the entire region for industrialization and contributed to the growth of the economy at a critical time in U.S. history.
- Cuyahoga Valley National Park protects a large and diverse collection of cultural resources in the Midwestern United States, consisting of more than 600 examples of historic structures, cultural landscapes, and archeological sites. This exceptional assemblage conveys themes that include American

Indian and later settlement, transportation, agriculture, industry, and recreation.

- Cuyahoga Valley National Park came into being in 1974 as a unified patchwork of land ownership sewn together by an unprecedented grassroots effort of community partners. As an outgrowth of this partnership origin, the park has become an innovator and a national leader in shared stewardship models through its dynamic community engagement, nationally recognized partnerships, and one of the largest volunteer programs in the country.
- Located within a one-hour drive of over three million people, Cuyahoga Valley National Park offers in-depth, active, and innovative education and recreation opportunities that can provide a first national park experience to a large urban audience. These experiences are exemplified by a large community-connected trail system, a residential environmental education center, a scenic railroad, and a network of sustainable farms.

Surrounded by long-developed lands, Cuyahoga Valley National Park is an area of high ecological diversity and integrity situated along a major river system at the southern edge of Lake Erie. Here, the park borders the edge of the Pleistocene glaciation extent between the Appalachian Mountains and the Great Plains. Among the park's identified interpretive themes is the cultural and natural interplay wherein the mosaic of pastoral landscapes was created and continue to be influenced by the interplay of geologic, ecological, and cultural forces. The park's glacial history and varied topography support a unique species composition (see "Geologic Significance and Connections").

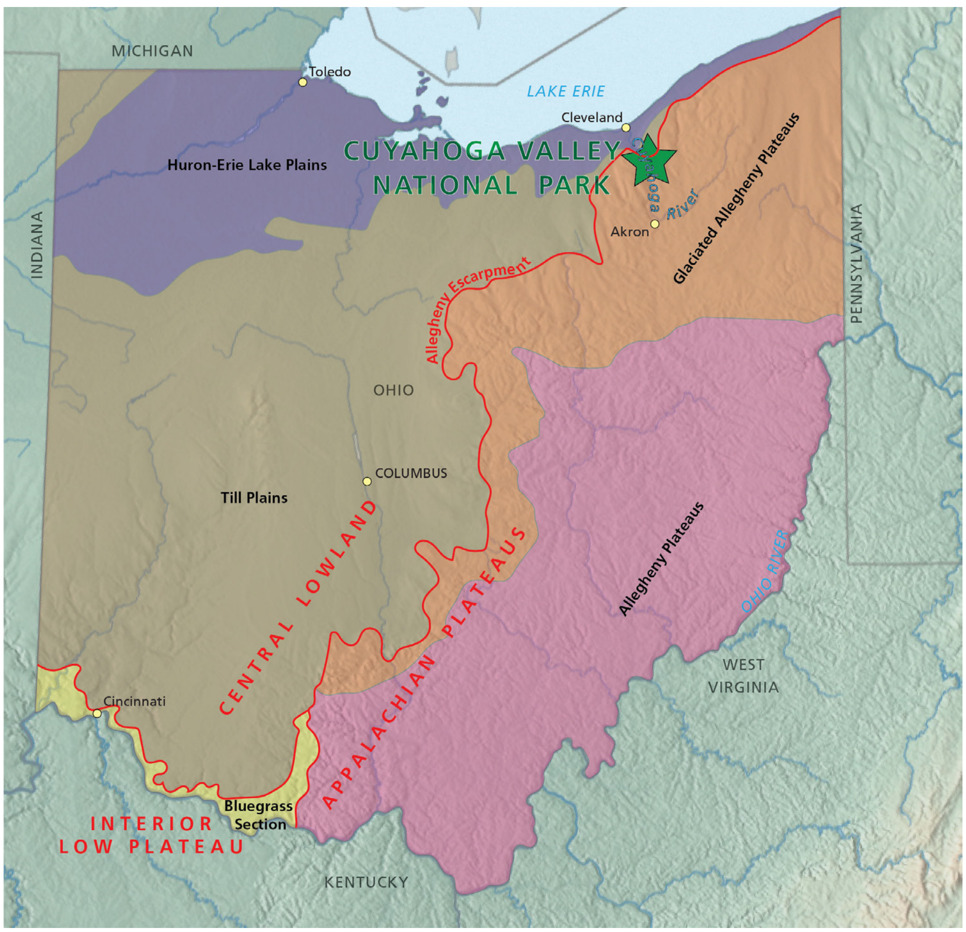



**Figure 2. Map of physiographic provinces of Ohio.**
**Cuyahoga Valley National Park (green star) is located on the sharp boundary between the Central Lowland and Appalachian Plateaus provinces—the Allegheny escarpment. Red lines represent boundaries between major provinces. Provinces comprise smaller physiographic sections. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Brockman (1998). Shaded relief base map courtesy of Tom Patterson (National Park Service).**

## Geologic Setting and History

The park marks an area where two major regions of North America meet, as the westernmost influences of Appalachian Mountain building give way to the vast midwestern plains. The boundary between these vastly different landscapes is represented by the Allegheny escarpment which runs through the park near Brecksville Station. East of the escarpment (southern portion of the park) is the Glaciated Allegheny Plateau section, part of the Appalachian Plateaus physiographic province. West of the escarpment (northern portion of the park) are the Huron-Erie Lake Plains and Till Plains sections of the greater Central Lowland (fig. 2; Brockman 1998). The escarpment corresponds to a slight increase in the dip or tilt of the underlying bedrock layers and is marked by a distinct change in topography from the flatter, lower terrain in the northwest (underlain by softer carbonate rocks) to the higher, steeper terrain in the southeast (underlain by sandstone and shale) (Ohio Division of Geological Survey 2002). The escarpment is locally a composite feature of Sharon Conglomerate and Berea Sandstone forming a resistant belt as much as 5 km (3 mi) wide (Nash 2009). In the park area, the Erie (Huron) Lake Plain forms the edge of a very low relief glacial lake basin separated from modern Lake Erie by shoreline cliffs. Major streams incise deep gorges. This changes abruptly across the Allegheny escarpment into ridges and flat uplands covered with glacial deposits and dissected by steep valleys. The valleys are either narrow, bedrock-walled gorges or broad, glacial-deposit filled meandering channels (Brockman 1998).

The park's landscape is a function of its foundational geology and the events that have occurred throughout geologic history (table 1) to create the present features. The park's geologic record spans back as far as 380 million years with deposition into or adjacent to a long-standing inland sea, part of the greater Appalachian basin (figs. 3–6). Changing depositional settings beginning in the Devonian through the Pennsylvanian left an incredibly complex geologic record that geologists continue to interpret.

**Table 1. Geologic time scale.**

The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division are in parentheses. Only geologic units mapped within the park are included. Age ranges are millions of years ago (MYA). National Park Service graphic using dates from the International Commission on Stratigraphy (http://www.stratigraphy.org/index.php/ics-chart-timescale).

| Era | Period/Epoch | MYA | Geologic Map Units | Local Geologic Events |
|---|---|---|---|---|
| Cenozoic (CZ) | Quaternary (Q)/ Holocene (H) | 0.01–today | **m**, r, Ho, Ha<br>**Qsg**, **Qsc**, **Qal** | Fluvial meandering, incision, and deposition. Ravines formed. |
| Cenozoic (CZ) | Quaternary (Q)/ Pleistocene (PE) | 2.6–0.01 | "**W**" units<br>**WPLcg** | Ice age glaciations; glacial outburst floods; glacial lakes impounded; river courses modified; early Cuyahoga River valley filled with sediment |
| Cenozoic (CZ) | Tertiary (T); Neogene (N) | 23.0–2.6 | None mapped | Fluctuating sea levels; meandering rivers |
| Cenozoic (CZ) | Tertiary (T); Paleogene (PG) | 66.0–23.0 | None mapped | Ongoing erosion and weathering<br>Valley incised by proto-Cuyahoga River |
| Mesozoic (MZ) | Cretaceous (K) | 145.0–66.0 | None mapped | Global mass extinction at end of Cretaceous (dinosaurs extinct) |
| Mesozoic (MZ) | Jurassic (J) | 201.3–145.0 | None mapped | Pangaea separated |
| Mesozoic (MZ) | Triassic (TR) | 251.9–201.3 | None mapped | Global mass extinction at end of Triassic<br>Breakup of Pangaea begins; Atlantic Ocean opened; sediments began building out the coastal plain |
| Paleozoic (PZ) | Permian (P) | 298.9–251.9 | None mapped | Global mass extinction at end of Permian. Supercontinent Pangaea intact. Increased sedimentation in the Appalachian Basin. Appalachians may have rivaled height of modern Himalayas. |

**Table 1, continued. Geologic time scale.**

| Era | Period/Epoch | MYA | Geologic Map Units | Local Geologic Events |
|---|---|---|---|---|
| Paleozoic (PZ) | Carboniferous; Pennsylvanian (PN) | 323.2–298.9 | **PNp**, **PNap, PNDsc** | Alleghany (Appalachian) Orogeny |
| Paleozoic (PZ) | Carboniferous; Mississippian (M) | 358.9–323.2 | **MDcbb**, **Mc** | Appalachian Basin collected sediment and subsided |
| Paleozoic (PZ) | Devonian (D) | 419.2–358.9 | **Dbb**, **Db**, **Ds, Doh** | Global mass extinction at end of Devonian; Appalachian Basin collected sediment and subsided |
| Paleozoic (PZ) | Silurian (S) | 443.8–419.2 | None mapped | Appalachian Basin collected sediment and subsided<br>Neoacadian Orogeny |
| Paleozoic (PZ) | Ordovician (O) | 485.4–443.8 | None mapped | Global mass extinction at end of Ordovician Uplift and erosion Taconic Orogeny |
| Paleozoic (PZ) | Cambrian (C) | 541.0–485.4 | None mapped | Extensive oceans covered most of proto-North America (Laurentia) |
| Proterozoic Eon; Neoproterozoic (Z) | Not defined | 1,000–541 | None mapped | Supercontinent Rodinia rifted apart |
| Proterozoic Eon; Mesoproterozoic (Y) | Not defined | 1,600–1,000 | None mapped | Formation of early supercontinent; Grenville Orogeny |
| Proterozoic Eon; Paleoproterozoic (X) | Not defined | 2,500–1,600 | None mapped | None reported |
| Archean Eon | Not defined | ~4,000–2,500 | None mapped | Oldest known Earth rocks |
| Hadean Eon | Not defined | 4,600–4,000 | None mapped | Formation of Earth approximately 4,600 million years ago |

### *Paleozoic Era (541 to 252 million years ago)—Bedrock Foundation Construction*

The oldest rocks in the park, visible in deep ravines in areas such as Tinkers Creek and Brecksville Reservation, are Paleozoic sedimentary rocks which originated in the Appalachian basin. The Appalachian basin was created when a volcanic arc collided with the eastern edge of North America during the first of three orogenies (the Taconic Orogeny) to construct the Appalachian Mountains (fig. 6A) 450 million years ago. As the mountains rose along the collision zone, Earth's crust bowed downwards farther inland (to the west) creating the deep Appalachian basin that would persist for hundreds of millions of years (fig. 6B). A warm, shallow sea filled the basin and collected vast amounts of sediment that eroded from the new mountains to the east. Ohio was host to a longstanding epicontinental sea, east of the Cincinnati basement arch, which was intermittently exposed and flooded. Because of its position between the highlands (lifted further by the second major mountain building event, the Acadian Orogeny at 340 million years ago) to the east, the ancient Canadian shield to the north, and the arch to the west, the Cuyahoga area was a sheltered bay-like setting with periodically restricted circulation (Thornberry-Ehrlich 2010). The oldest units in Cuyahoga Valley National Park record the return or incursion of the warm, shallow seas by the middle Devonian, 471 to 460 million years ago. Mixtures of limy sediments, mud, and volcanic ash collected in the basin.

By the end of the Devonian, around 359 million years ago, the seas had become stagnant and anoxic, and had accumulated large amounts of black, organic-rich mud. These muds eventually lithifying to form black shales, such as the Ohio Shale (geologic map units **Doh** and **Ds**; Swinford et al. 2003). Coarser layers in

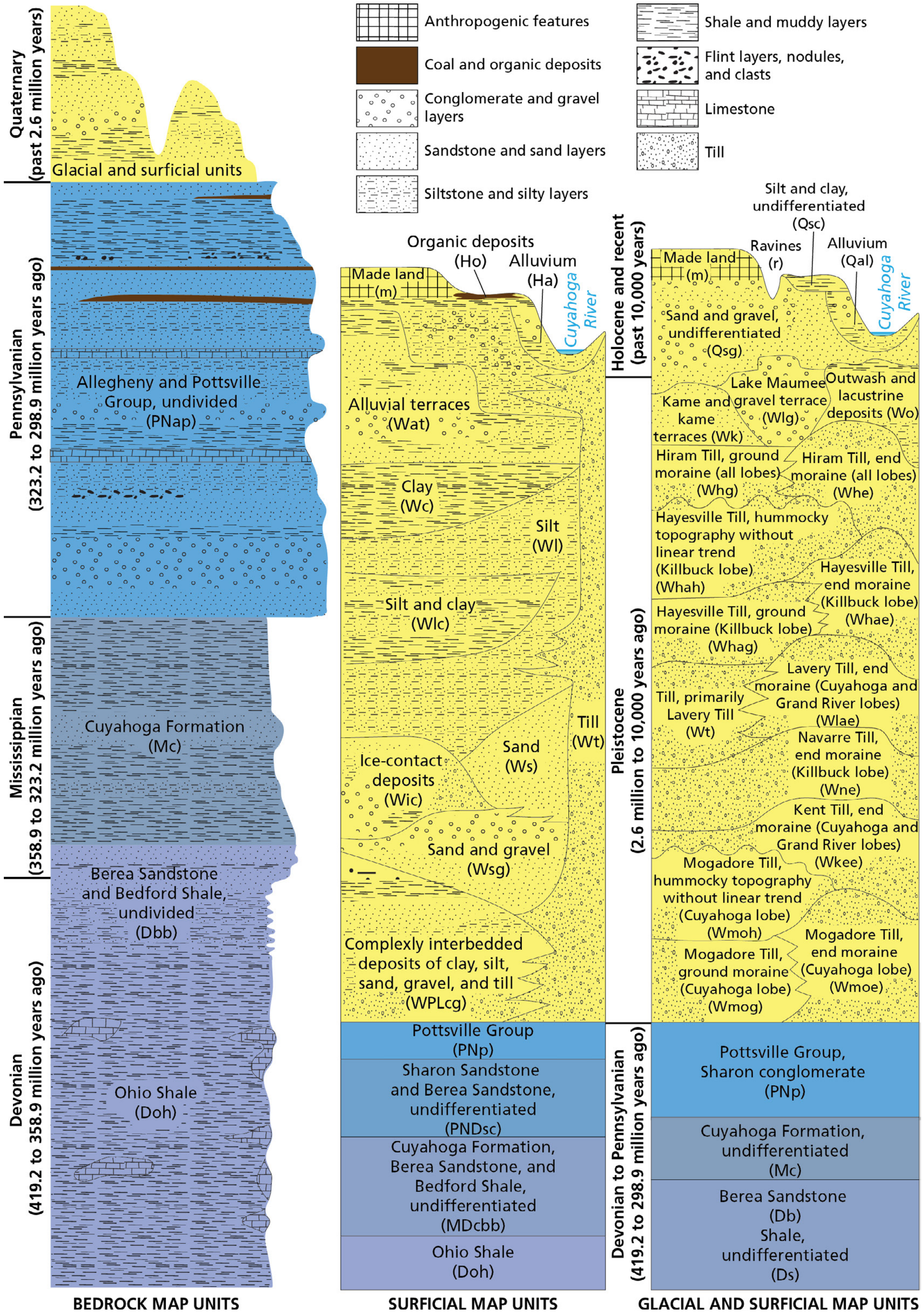



**Figure 3. Stratigraphic section.**
**Devonian, Mississippian, and Pennsylvanian sedimentary bedrock underlies much more recent Quaternary (Pleistocene and Holocene/recent) glacial and surficial deposits. Vertical placement is representative of age only and not necessarily spatial proximity. Units are from the GRI GIS data (see "Geologic Map Data") comprising three different maps. Unit colors are according to US Geological Survey standards for geologic time periods. Section is not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from the GRI GIS data.**


Allegheny and Pottsville Group, undivided (PNap)
Pottsville Group (PNp)
Pottsville Group, Sharon conglomerate (PNp)
Sharon Sandstone and Berea Sandstone, undifferentiated (PNDsc

Cuyahoga Formation (Mc)
Cuyahoga Formation, undifferentiated (Mc)
Cuyahoga Formation, Berea Sandstone, and Bedford Shale, undifferentiated (MDcbb)

Berea Sandstone (Db)
Berea Sandstone and Bedford Shale, undivided (Dbb)
Shale, undiffferentiated (Ds)
Ohio Shale (Doh)

**Figure 4. Photographs of bedrock exposures in approximate stratigraphic order.**
**The oldest bedrock in the park is Devonian shale, visible in places such as Chippewa Creek (4). Younger mixes of shale, sandstone, siltstone, and conglomerate overlie the shales. The youngest bedrock is coarse sandstone and shale from the Pennsylvanian, dramatically visible at Ledges overlook (1). Photographs 1, 3, and 4 by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009. Photograph 2 presented as an unnumbered figure in a presentation by M. Angle (Geologist, Ohio Division of Geological Survey) in autumn 2009.**

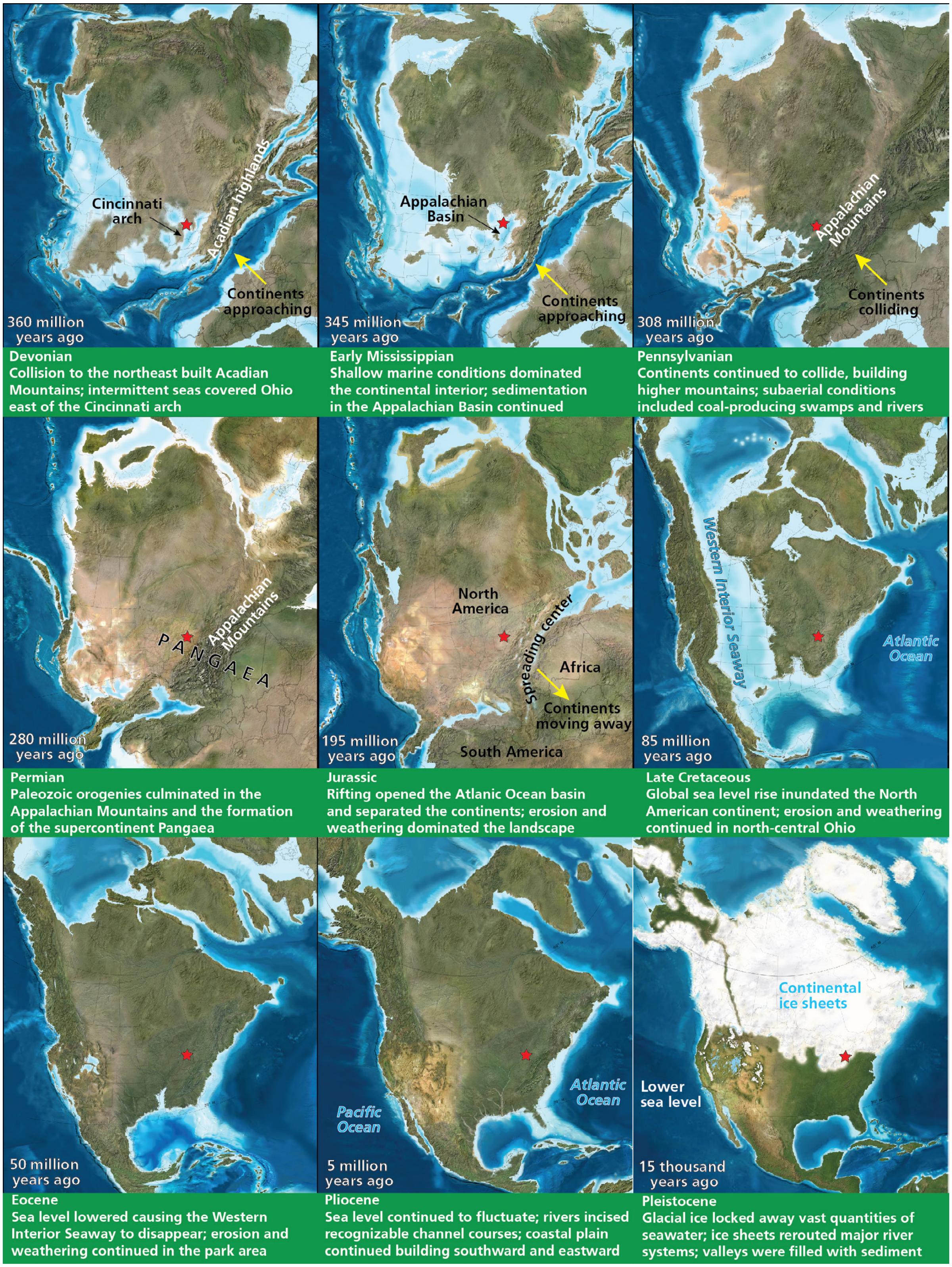
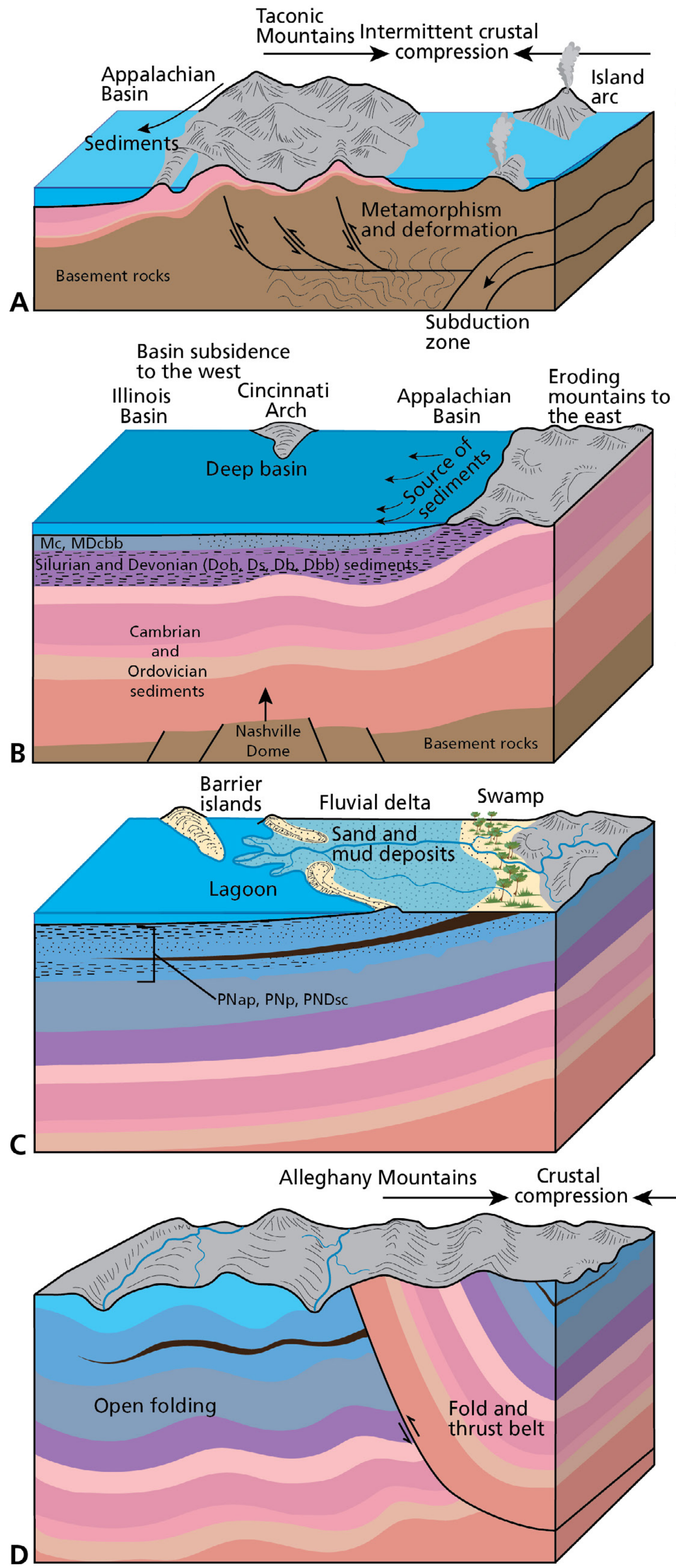



**Figure 5. Paleogeographic maps of North America.**
**A paleogeographic map represents geographic conditions of Earth's past, including the distribution of land and sea. The red star indicates the approximate location of Cuyahoga Valley National Park. Graphic complied by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic maps created by Ron Blakey (North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc.), additional information is available at http://deeptimemaps.com/map-room-non-profit/.**




450 to 420 million years ago–the Taconic Orogeny to the east provided source of sediment and caused metamorphism and deformation. The Appalachian Basin subsided in response to crustal loading during the orogeny and began accumulating sediments.

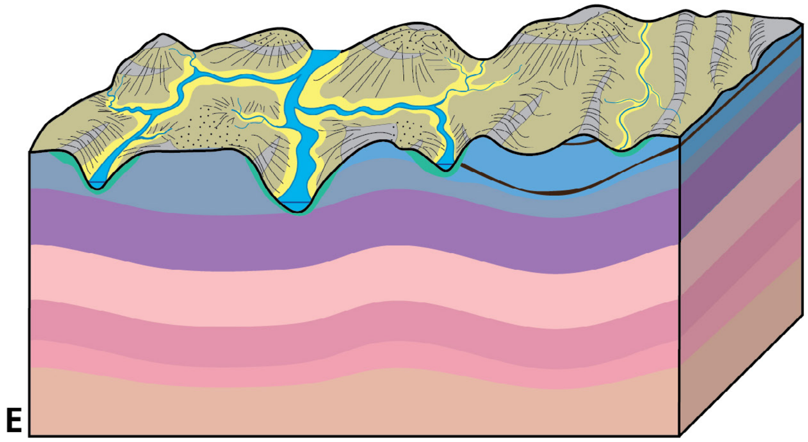
340 million years ago–the Acadian-Neoacadian Orogeny to the northeast provided source of sediment to the Appalachian and Illinois basins, which continued to subside and deepen. Quiet marine conditions dominated deposition of mixed sand, silt, mud, and carbonate Mississippian sediments in the park area.

*geologic map unit symbols included for units present in the park

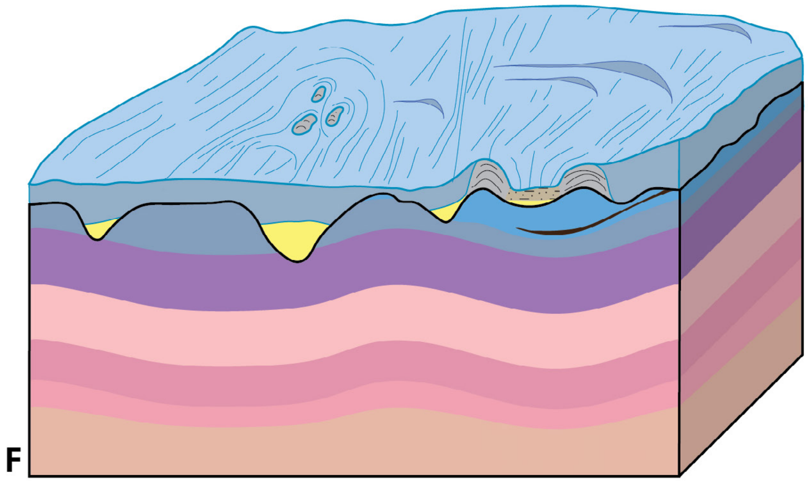
310 million years ago–the Alleghany Orogeny was beginning to uplift the Appalachian Mountains to the east causing folding and faulting in the Valley and Ridge province. Mixed fluvial and swamp depositional environments accumulated Pennsylvanian sands, silts, muds, and thick coal beds in the basin. Sea level was relatively low.

265 million years ago–the Alleghany Orogeny resulted in formation of **Pangaea and** extensive thrust faulting shoved older rocks atop younger rocks to the east. Faulting and folding formed long, linear ridges separated by narrow valleys to the east of the park. In the Appalachian and Illinois basins, deformation was limited to broad, open folds and very minor faulting. Rivers continued to cut through any Permian and Pennsylvanian sediments.

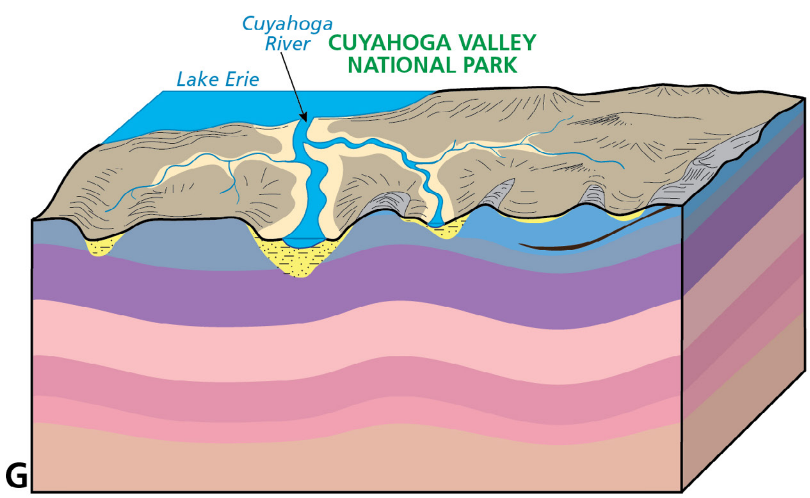
**Figure 6A–D. Schematic graphics illustrating the evolution of the Cuyahoga Valley National Park landscape. Graphics are not to scale. Graphics by Trista L. Thornberry-Ehrlich (Colorado State University), with information from White (1984), Ford (1987), Swinford et al. (2003), and a presentation by M. Angle (Geologist, Ohio Division of Geological Survey) in autumn 2009.**




150 million years ago–
**Pangaea** rifted apart and the *Atlantic Ocean* opened. Erosion and weathering continued to wear away the Appalachian highlands. Residuum formed via deep weathering and slope deposits accumulated. Rivers and streams incised bedrock, deposited terraces, and reworked alluvium mixed with colluvium.




2.5 million years ago–
Earth surface processes continued to wear away the highlands and removed vast amounts of material from the landscape. Continental ice sheets descended from the north and accelerated the erosion. The ice filled old bedrock river channels with sediments, obscuring the former landscape, and built moraines. Upon melting, glacial ice created numerous glacial lakes and outwash streams, which accumulated and reworked vast deposits of till and outwash ("W" units).




Past 15,000 years–glaciers retreated, the landsurface rebounded, and Earth surface processes began to form the wetlands and river valleys such as the Cuyahoga River and its tributaries that now collect alluvium and swamp deposits. Sediments are continually eroded from the uplands and reworked as alluvium along the river channels ("Q" and "H" units).

**Figure 6E–G. Schematic graphics illustrating the evolution of the Cuyahoga Valley National Park landscape. Graphics are not to scale. Graphics by Trista L. Thornberry-Ehrlich (Colorado State University), with information from White (1984), Ford (1987), Swinford et al. (2003), and a presentation by M. Angle (Geologist, Ohio Division of Geological Survey) in autumn 2009.**

these shales record periodic storm events that washed new sediments into the basin. Shallowing conditions in the inland sea during the latest Devonian and early Mississippian caused the deposition of dark, organic rich muds to give way to fluvial and deltaic systems, preserved as sandstone and siltstones of the Bedford Shale, Berea Sandstone, and Cuyahoga Formation (geologic map units **Ds**, **Dbb**, **MDcbb**, **Mc**, and **Mc**; Swinford et al. 2003). During the late Mississippian into the Pennsylvanian around 323 million years ago, Ohio was a relatively flat, open coastal plain with depositional environments shifting spatially and temporally from offshore marine, to coastal, to fluvial, and back to marine again (fig. 6C; Corbett and Manner 1988; Thornberry-Ehrlich 2010).

During the late Permian (265 million years ago) the Appalachian Mountains were rising again to the east during the Alleghany Orogeny (fig. 6D). This was the last of the major Paleozoic mountain building events that ultimately sutured together all of Earth's continental crust to form the supercontinent, Pangaea (fig. 5). The uplifted land provided a renewed source of sediment. Fluctuating sea levels produced rapidly alternating sequences of terrestrial, freshwater, and marine deposits to accumulate locally as the Allegheny and Pottsville Group, including the coarse-grained Sharon conglomerate (geologic map units **PNap**, **PNDsc**, and **PNp**), which was deposited in a high-energy, braided stream environment (Ohio Division of Geological Survey 2001, Swinford et al. 2003; Hunt et al. 2008; Thornberry-Ehrlich 2010).

### *Mesozoic Era (252 to 66 million years ago)—Weathering and Erosion*

The supercontinent Pangaea was relatively short lived and by the beginning of the Mesozoic Era, it began to rift, opening the Atlantic Ocean basin and many pull-apart basins along the eastern edge of North America. Whatever rocks may have been deposited atop the Pennsylvanian Pottsville Group were worn away by millennia of weathering and erosion across northern Ohio (fig. 6E). Throughout the early Mesozoic, the modern configuration of continents began to take shape and major drainages of eastern North America were established. The river drainage patterns of Ohio were vastly different than those seen today. At this time, an ancient river system, the Teays River, flowed west across the Appalachian Plateau into an immense inland sea that covered central North America during part of the Mesozoic Era (Grafton and Grafton 1980). Across a narrow drainage divide, the precursor to the Cuyahoga River was a tributary to the now extinct Erigan River, an east-west oriented system that paralleled the shore of modern Lake Erie and ultimately helped create the lake's east-west orientation (Domske 2008). This precursor excavated a rugged landscape, incising into the bedrock as deep as the Devonian Ohio Shale (**Doh**).

### *Cenozoic Era (the past 66 million years)—Modern Landscape Development and the Cuyahoga River*

Throughout the Mesozoic and into the Cenozoic eras, the primary geologic processes in the park area were river incision, slope movements, and weathering and erosion (fig. 6E). About two million years ago (Pleistocene Epoch), thick continental glaciers descended from the north in repeated advances (table 2). In northern Ohio, the preexisting river valleys were filled with ice and sediment, and features that had existed for millions of years were buried. Pleistocene glaciations (ice ages) forever changed the course of the Erigan, Teays, and Cuyahoga rivers (fig. 7).

**Table 2. Summarized Pleistocene stratigraphy of the Cuyahoga Valley National Park area.**

Table is adapted from table 9 in Angle et al. (2003). Ybp = years before present.

| Stage | Killbuck Lobe | Cuyahoga Lobe | Grand River Lobe |
|---|---|---|---|
| Wisconsinan<br>25,000 to 70,000 ybp | Hiram Till<br>Hayesville Till<br>Navarre Till | Hiram Till<br>Lavery Till<br>Kent Till | Hiram Till<br>Lavery Till<br>Kent Till |
| | unknown | Lacustrine? | unknown |
| Sangamonian<br>70,000 to 120,000 ybp | Lacustrine and alluvial deposits | Lacustrine and alluvial deposits | Lacustrine and alluvial deposits |
| Illinoian<br>120,000 to 730,000 ybp | Millbrook Till | Northhampton Till<br>Mogadore Till | Titusville Till |
| | Kame deposits | Kame deposits | Titusville Till |
| Pre-Illinoian<br>730,000 to 2,000,000 ybp | Mixed sediments in deep buried valleys | Mixed sediments in deep buried valleys | Mixed sediments in deep buried valleys |


**Figure 7. Map showing the Erigan and Teays river systems prior to glaciation.**
**The approximate location of the divide between the two river systems (west of Cleveland, and east of Indiana) is indicated by a red dashed line. The maximum glacial extent (white shaded area extending from southwestern New York to southern Illinois, and covering most of Ohio) covered the valleys of the Erigan and Teays river systems, blocking their drainages. Sediments eventually buried the rivers' courses, and altered the drainages of Ohio. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University) with information from the Ohio Department of Natural Resources. Shaded relief base map courtesy of Tom Patterson (National Park Service).**

Akin to massive bulldozers, the glaciers scoured and buried the underlying landforms in turns. Each glacial advance and retreat moved and deposited vast amounts of sand, silt, and clay sediments (fig. 6F). The Erigan river system provided the lowland that became Lake Erie and its tributary, the Dover River, drained northeast Ohio (Nash 2009; National Park Service 2017). The Teays's flow shifted to the modern Ohio River's southerly flow, whereas the Cuyahoga became the "Crooked River" curved channel flowing into Lake Erie at Cleveland (Grafton and Grafton 1980). Their watersheds are separated by a north-south water divide located south of the park in Akron, Ohio. Rivers north of this divide flow to Lake Erie and rivers to the south flow to the Ohio River and ultimately, the Gulf of Mexico (National Park Service 2017). During the most recent glacial maximum, the Wisconsinan, the upper Cuyahoga followed the ice margin and at 14,800 years ago, it flowed south. When the base level dropped, the Cuyahoga River began intense downcutting. It did not return to the old, buried channels, but cut a narrow, deep gorge. Several southward flowing streams including Furnace Run, Yellow Creek, and Mud Brook were captured into the Cuyahoga River watershed (Thornberry-Ehrlich 2010). The modern Cuyahoga River has not yet entirely excavated the mantle of glacial deposits overlying its original bedrock channel.

Each glacial advance overran and obscured evidence of the previous advance. For this reason, the most recent glacial maximum is locally best preserved ("**W**" geologic map units; White 1984; Ford 1987; Pavey et al. 2000). Complicating the situation further are the lobes of glacial ice (e.g., the Cuyahoga, Grand River, and Killbuck, lobes) that descended to different latitudes at different times. In northeast Ohio, geologic features such as the Allegheny (Portage) escarpment, served as buttresses to glacial advance, causing them to halt and deposit linear piles of sediment as end moraines (**Wmoe**, **Wkee**, **Wne**, **Wlae**, **Whae**, and **Whe**; Nash 2009). Northward of each end moraine is associated ground moraine smeared into place by the glacial ice (**Wmog**, **Whag**, **Whg**; White 1984; Ford 1987). Many of the glacial and surficial geologic units cannot be assigned to a glacial lobe or specific event and are mapped as till (**Wt**, **Wmoh**, **Whah**, **WPLcg**), sand and gravel (**Wsg**), sand (**Ws**), silt (**Wl**), silt and clay (**Wlc**), clay (**Wc**), and alluvial terraces (**Wat**). As the glacial ice melted, a whole suite of associated deposits accumulated including ice-contact deposits (**Wic**), kame and kame terraces (**Wk**), and outwash and lacustrine deposits (**Wo**; White 1984; Ford 1987; Pavey et al. 2000). In areas where drainage from the melting glacier was blocked by ice, debris, or a landform, a series of glacial lakes developed along the glacial front at subsequently lower elevations including Lake Maumee (I, II, and III), Lake Arkona (I, II, and III), Lake Warren (I, II, and III), Lake Wayne, Lake Grassmere, and Lake Elkton (Thornberry-Ehrlich 2010 from written communication M. Angle, Ohio Division of Geological Survey, geologist, 2009). These lakes had several outlets including the Wabash River, Grand River, Mohawk River, and the Niagara River. As the ice retreated to the east and north, new outlet channels opened and previous outlets passing through Indiana and Michigan were abandoned in favor of those draining toward New York (Thornberry-Ehrlich 2010 from written communication M. Angle, Ohio Division of Geological Survey, geologist, 2009). Glacial Lake Maumee, was a precursor to modern Lake Erie, occupying a larger basin and accumulating sediments (e.g., **Wlg**; White 1984; Ford 1987; Pavey et al. 2000). Since the end of the Pleistocene, the great weight of the glacial ice was lifted from Earth's crust and locally, the crust rebounded approximately 15 cm (6 in) (Thornberry-Ehrlich 2010). As the crust (base level) lifted, the local rivers cut down rapidly through the glacial deposits creating a new fluvial landscape (fig. 6G).

The Cuyahoga River and its tributaries are constantly lowering the base of the slopes, causing a recurring unstable situation wherein slopes are very steep and prone to failure in the narrow ravines (**r**). Some ravines drop nearly 180 m (600 ft) in a few miles (National Park Service 2017). Slope deposits such as talus and colluvium accumulate at the base of local slopes through a process called mass wasting. Rivers are powerful agents of landscape change and have their associated surficial units, including alluvium (**Ha** and **Qal**); floodplain deposits of silt and clay (**Qsc**); and sand and gravel (**Qsg**). In some areas, poor drainage, commonly caused by clay-rich deposits, supports the formation of marshes and swamps that collect organic deposits (**Ho**) (White 1984; Ford 1987; Pavey et al. 2000).

The Anthropocene Epoch was recommended to the International Commission on Stratigraphy (ICS) to denote the time of post-industrial revolution human alteration of the landscape. At Cuyahoga Valley National Park, the surficial geologic map unit "made land" (**m**) is testament to this human-driven landscape change (White 1984; Ford 1987; Pavey et al. 2000). Mapped disturbed lands in the parks include areas in which the topography has been altered by excavation, mining, filling, transportation infrastructure, or other anthropogenic processes. Units like "made land" record the map-scale human alteration of the landscapes to access and utilize the varied geologic resources of the Cuyahoga River valley.

## Geologic Significance and Connections

From its winding riparian corridor, narrow ravines, cascading waterfalls, and towering cliffs, geology is on stunning display in Cuyahoga Valley National Park. What is less obvious are the underlying features responsible for the preservation of the area of the national park today. Where Pleistocene glaciers deposited sand and gravel, artesian groundwater is abundant, but where thick, clay-rich till accumulated, groundwater is scarce (National Park Service 2017). This scarcity, as well as unstable soils and steep slopes, limited the human settlement within the valley compared to development on the upland areas on either side of the valley that boomed after World War II (Nash 2009). The park's natural, open setting was thus saved mostly intact.

### *Geologic Impacts on Human History*

Long a migration and transportation route, the Ohio & Erie Canal and subsequent Valley Railway took advantage of the valley's natural corridor between the Ohio River Valley and Great Lakes. The transportation network is among the park's fundamental resources (National Park Service 2013a). The first humans to enter the valley were Paleo-Indians as much as 12,000 years BCE as foragers and hunters of Pleistocene megafauna such as mastodon and mammoth, whose fossil remains are present (Cockrell 1992; Thornberry-Ehrlich 2010). Archaic-era American Indians settled seasonally in campsites in interfluvial (between drainages) rock shelters along bluff edges (possibly underlain by **Wt**) and the floodplain (underlain by **Qal**; White 1984; Ford 1987; Pavey et al. 2000). Earth surface processes have largely obscured or obliterated most of these sites (Cockrell 1992). The river was also used for transportation with portages at watershed divides. The modern Portage Trail, Portage Path, and Portage Lakes are some local examples of this legacy (Nash 2009). When group territoriality and long-distance trading traditions began more than 800 years BCE, stone-tool making and cold-hammered copper were more common. Copper may have come from areas such as the Keweenaw Peninsula in northern Michigan (Thornberry-Ehrlich 2013; copper history in the area is interpreted at Keweenaw National Historical Park, https://www.nps.gov/kewe/index.htm). The Cuyahoga Valley's fertile floodplain and upland terraces supported maize and squash agriculture that spawned seasonal villages and mound-building culture in Ohio (Cockrell 1992; Thornberry-Ehrlich 2013). Several phases of warfare and American Indian resettlement resulted in limited habitation in the Cuyahoga River valley when fur traders first established contact around 1640 CE. Eventually, members of the Ottawa from the western Great Lakes moved into northeast Ohio and their legacy endures in giving the Cuyahoga its name as "the crooked river" (Cockrell 1992).

In 1786, Moravian missionary John Heckewelder built the first European-American settlement, "Pilgerruh" (pilgrim's rest) along the Cuyahoga River, but it was quickly and mysteriously abandoned. Other trading posts were established at Portage Path and near the junction of Tinkers Creek and the Cuyahoga River. It was largely ignored for settlement until 1796 when official surveying began (Cockrell 1992). Even then, the heavily forested valley discouraged many farmers, the steep and rugged valley walls were commonly unstable, and the park area remained relatively isolated with only small subsistence farms (Cockrell 1992). Sustainable farms remain part of the park today and, together with the rural landscape, compose some of the park's fundamental resources (National Park Service 2013a). As a testament to the relationship between geology and early industry, in 1810, a mill was constructed at Brandywine Falls, where the stream drops 19.8 m (65.0 ft) over the Berea Sandstone and Bedford Formation. This supported sawmills, woolen mills, and a distillery (Corbett and Manner 1988).

Trails crisscrossed the valley: Cuyahoga, Chippewa, Mahoning, David Hudson, Columbia Road, and Lake Erie-Muskingum trails, as well as the Sagamore Path (Cockrell 1992). The Cuyahoga River valley would prove vital to American leaders such as George Washington who knew that the key to developing the continent's vast interior was establishing a viable transportation system. A series of canals was needed to link the Great Lakes with the large river systems (e.g., Ohio, Mississippi, and Potomac rivers). In 1788, Washington proposed canals linking the Cuyahoga, Big Beaver, and Muskingum rivers to connect the Ohio River and Great Lakes (Cockrell 1992). In 1825, the Ohio Legislature authorized construction of the Ohio & Erie Canal which coursed from Cleveland south along the Cuyahoga River, over the Portage summit at Akron to the Tuscarawas, west to the Licking, then to the Scioto at Columbus, before turning south to the Ohio River town of Portsmouth for a total of 496 km (308 mi). The entire canal was complete in 1832; however, the first link opened in 1827 in Cuyahoga Valley with 61 km (38 mi) of canal, 44 locks and three aqueducts. Construction utilized the valley's resources, including quarried sandstone (geologic map units **Dbb**, **Db**, **MDcbb**, **PNDsc**; Swinford et al. 2003). Of particular note, the Berea Sandstone is a significant source of building stone. It has been quarried for more than 200 years and is one of the most widely used sandstones in North America (Hannibal 2019). The quarries and exposures in Cuyahoga County are particularly significant (Hannibal 2019).

The canal dominated north-south transportation in the Cuyahoga Valley for a half-century. Today, the canal is identified as one of the park's fundamental resources as it served as a catalyst that spurred regional and national economic and industrial growth (National Park Service 2013a). Rugged topography temporarily prevented the construction of a railroad route between Cleveland and Akron. Railroads had elsewhere usurped canal use with faster, more efficient transport. The "Valley Railroad" would come eventually in 1880 and is another fundamental park resource (National Park Service 2013a). It paralleled the west bank of the Cuyahoga River and the Ohio & Erie Canal. In 1913, a major flood caused all canal operations in the valley to end. By this time, subsistence farming had all but ceased in the valley and the forests were stripped (Cockrell 1992). Cleveland and Akron became industrial centers and expanded toward the Cuyahoga River valley, which remained somewhat of a quiet backwater and popular recreation area, even as far back as the 1870s (Cockrell 1992).

Parts of Cuyahoga Valley National Park were among the earliest conservation efforts in the state employing such luminaries as W. A. Stinchcomb and Frederick Law Olmsted Jr. to create a series of park reservations around the perimeter of Cleveland connected by scenic parkways— "The Emerald Necklace" (Cockrell 1992). A 1925 Olmsted report focused on preserving the valley's scenery, discussing its "occasional gorges and picturesque ravines where the streams have worn through the sandstone strata, and some hills of a more or less rugged character commanding broad outlooks over the countryside". This report stressed the importance of controlling unsightly development of any noticeable part of the landscape, which could destroy the beauty of the entire scene (Cockrell 1992). Lack of funding caused a haphazard patchwork of included parklands that accumulated in piecemeal fashion to become the national park area today.

In the 1930s, oil and gas exploration began in the vicinity with most of the production coming from the Devonian shales (**Doh**, and **Ds**, and Berea Sandstone). Around this same time, the Civilian Conservation Corps (CCC) undertook many restoration and development projects in what would become Cuyahoga Valley National Park. They created dams impounding lakes at Virginia Kendall Park and Furnace Run Reservation. They used local sandstone (possibly **PNap** or **Dbb**, **Db**, **MDcbb**, **PNDsc)** to build the iconic visitor facilities at the Ledges and the Happy Days Camp (Cockrell 1992; Swinford et al. 2003). The Virginia Kendall State Park Historic District is among the fundamental resources of the park; it displays the concept of developing park landscapes for harmonious human use. Opportunities listed for Virginia Kendall include highlighting the geological crossroads of the area (National Park Service 2013a).

Continued urban sprawl and improved highway connections applied pressure to save the Cuyahoga Valley from residential development. The Cuyahoga Valley Association fought much of this development for reasons including the increased sedimentation into the Cuyahoga River and its tributaries, as well as increased runoff from impervious urban surfaces such as parking lots causing increased flood hazards. Scenic values were invoked to ward off planned utility lines that would have bisected some of the most beautiful parts of the valley (Cockrell 1992). In June 1969, the polluted mouth of the Cuyahoga River caught fire and burned for three days; the river became an impetus for Earth Day in 1970 and helped spawn the modern environmental movement in the US. In 1974, after years of lobbying and negotiating, Cuyahoga Valley National Recreation Area was established, bringing a much-needed parkland to the state that ranked the lowest per capita in recreational acreage in the country (Cockrell 1992). The community engagement necessary to establish and manage the park is fundamental to its successful existence in an urbanized landscape with varied landownership and land uses (National Park Service 2013a).

### *Geologic Ecosystem Connections*

In addition to the historical connections briefly presented here, geologic features and processes are fundamentally connected with vegetation patterns, many animal habitats, soils, and water resources. Corbett and Manner (1988) described the following park habitats: slump, hemlock ravine, upland dry woods, floodplain, slope, old field, and wetland—all directly tied to the local geologic terrain and geomorphic history. Slump habitat, characterized by slope movements with dryer conditions at the top of the exposure and wetter conditions below occurs at places like Pinery Narrows. The slow but constant movement of the slump prevents vegetation succession. Hemlock ravine habitats, such as that at the ravine across Tinkers Creek, occurs on valley fill in ravines or in the shadow of bedrock ledges on north- and east-facing slopes. Upland dry woods, characterized by plants tolerant of dry conditions or nearly no soil, forms on stony soils derived from Berea Sandstone or glacially derived sands and gravels in places such as the trail to the Ledges area. Floodplain habitats border many park rivers and creeks. These support plants that can withstand wet conditions and feature rich, flood-nourished soils. Slope habitats, one of the most common habitats in the park, have fertile, moist, well-drained, and loamy soils, and are focused on warm south- and west-facing slopes. Old field habitats, as the name suggests, occur where agricultural fields or disturbed areas have been left fallow. This habitat is visible near the town of Everett and supports the establishment of pioneer species on the disturbed earth. Some wetland habitats occur in low areas along the banks of streams and river margins and on newly formed sand bars, swamps, swales, sloughs, and drainage ditches (including abandoned portions of the Ohio & Erie Canal). Clay-rich substrates (e.g., till) or others that prevent groundwater percolation underlie many local wetlands. Many park wetlands occur along the slopes, at the base of a slope, or in the floodplain and are commonly connected to a groundwater source (Bingham et al. 2016; S. Bingham, wetland biologist, Cuyahoga Valley National Park, written communication, 14 May 2019). Only wet-tolerant species can thrive in wetland habitats (Corbett and Manner 1988).

The park fosters distinctive biodiversity within its boundaries. The Cuyahoga River ecosystem is a fundamental resource to the park as its river, streams, canal, floodplains, and wetlands provide a buffer against impacts of development as the river connects to the Great Lakes ecosystem (National Park Service 2013a). The forest ecosystem is another fundamental resource at the park (National Park Service 2013a). Because the park is near where the Appalachian Plateaus give way to the plains of the Central Lowland, species from both regions flourish here. Appalachian species are most common (National Park Service 2017). The rich, well-drained uplands, dry and rocky valley slopes, cool and moist ravines, and broad valley floor all support

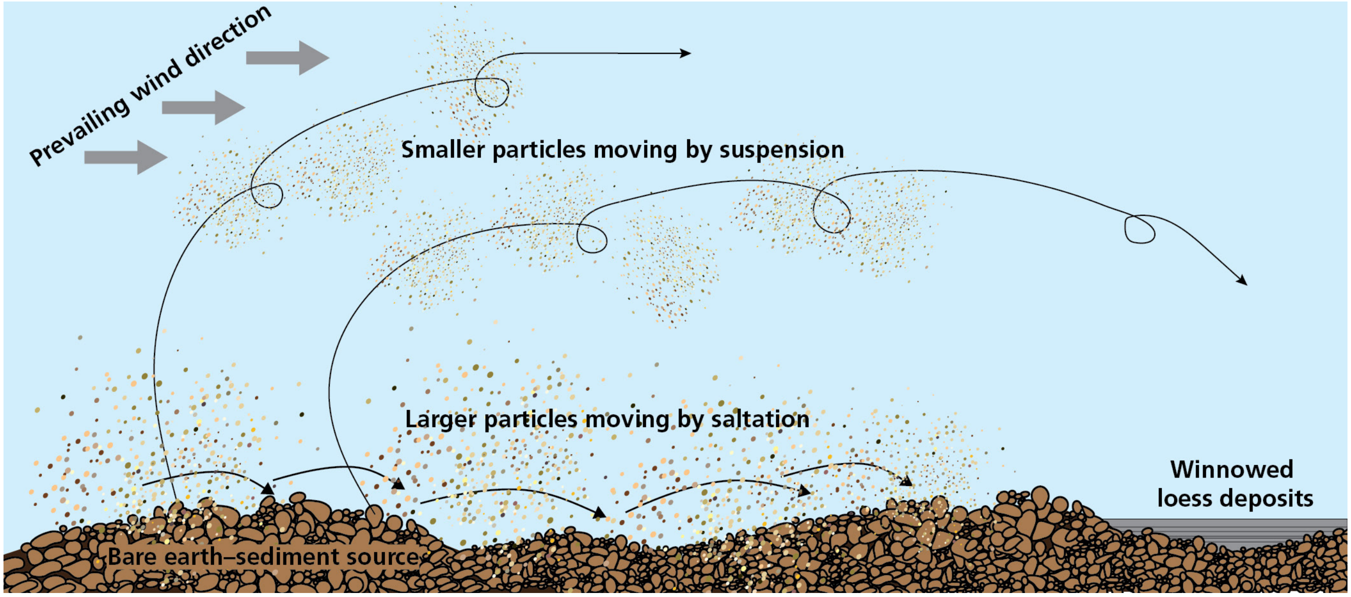



**Figure 8. Diagram showing loess formation.**
**Wind swept across barren areas, moving particles (smaller by suspension; larger by saltation) and dumping them in deposits that blanketed the landscape. Loess is part of the soil profile at Cuyahoga Valley National Park. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).**

different flora and fauna. More than 40% of Ohio's vascular flora occur in the Cuyahoga Valley. Areas such as the Ritchie Ledges or Columbia Run are cool and moist, offering places or refugia where ice age era plants (e.g., woodland ferns and eastern hemlocks) can still survive (Thornberry-Ehrlich 2010; National Park Service 2017). In areas where the unconsolidated glacial deposits slump downslope felling old trees, the resulting opening in the tree canopy allows successional vegetation to flourish as slump-block communities (Thornberry-Ehrlich 2010). Vegetation inventories for Cuyahoga Valley National Park are available at: https://irma.nps.gov/DataStore/Reference/Profile/2177152.

More than 65 individual soil types are mapped within the park, some of which contain distinctive horizons of glacial loess (fig. 8). Nearly 800 soil phases, soil-type subdivisions based on erosion, slope, stoniness, or soluble mineral content, attest to the geographic complexity of soils in Summit County alone (Thornberry-Ehrlich 2010). Soil resources are beyond the scope of this report and the subject of another natural resource inventory in the National Park Service. Soil resources inventory products for Cuyahoga Valley National Park were completed in 2013 and are available at: https://irma.nps.gov/DataStore/Reference/Profile/1048853. as well as on the Natural Resources Conservation Service Web Soil Survey portal: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

The Cuyahoga River was once a highly polluted and disturbed waterway with sources of past and present pollution to the river including wastewater facility discharges, inactive hazardous waste sites, combined sewer overflows, sanitary sewer overflows, and other point and non-point sources. In 1988, the Cuyahoga River Remedial Action Plan (RAP), now the Area of Concern (AOC), was established as part of a US-Canada effort to restore the Great Lakes. After more than 40 years of continuing restoration, the recovery of the lower Cuyahoga River is not only evident in the improvement in the aquatic species assemblages that inhabit the river water, but in the terrestrial wildlife associated with the riparian habitat of the river corridor. More than 70 species of native fish live in park waters (National Park Service 2013a). Cooperative efforts to improve water quality and preserve wetlands have transformed a once polluted river into an attractive place for wildlife. Much of the main stem of the Cuyahoga River and its larger tributaries throughout the park are in compliance with the State of Ohio's water quality standards for warm water habitat (Thornberry-Ehrlich 2010).

Because of the park's urban setting, land-use practices within the watershed and upstream of the park can strongly impact the ecosystem within the park. Forty-four communities impact tributary streams, and more impact the river itself. Developments typically involve an increase in impervious surfaces such as buildings, parking lots, streets, and sidewalks. Impervious surfaces cause runoff to flow quickly into the system rather than infiltrating the soil and slowly becoming part of the groundwater system. Increased impervious surfaces cause increased stormwater runoff, local erosion, sedimentation, stream channelization, and degradation of stream habitat and biodiversity (Thornberry-Ehrlich 2010). Examples of privately owned areas with significant disturbances include the catchment basin and stream stabilization at Furnace Run and near the O'Neill Woods at Yellow Creek where water quality is being degraded by adjacent landowners (Thornberry-Ehrlich 2010).

Predicted climate change trends will impact the ecosystem at Cuyahoga Valley National Park. Climate models indicate that both temperature and precipitation are projected to increase by 2.4–3.8°C (4.3–6.8°F) and 2%–4%, respectively, by 2100 (National Park Service 2013a). The National Oceanic and Atmospheric Administration (NOAA) has been tracking climate fluctuations since the 1950s. The Great Lakes region has experienced above average temperature increases during that period of time. Today, Lake Erie typically freezes for one month instead of three months on average each winter with 13 cm (5 in) less snowfall. Park staff have noticed vegetation emerging earlier in the spring than in past years. Understanding the triggers and outcomes of these changes is crucial to protecting the natural and cultural resources at the park (Thornberry-Ehrlich 2010). Climate change scenario planning is among the planning and data needs (medium priority) identified in the parks foundation document (National Park Service 2013a).

Additional information about other natural resources is available in the following references.

- Weather and climate inventory https://irma.nps.gov/DataStore/Reference/Profile/2170157
- Climate change trends for planning https://irma.nps.gov/DataStore/Reference/Profile/2217674
- Climate change exposures https://irma.nps.gov/DataStore/Reference/Profile/2214006
- Future warming and visitation https://irma.nps.gov/DataStore/Reference/Profile/2222819
- Biotic stressors at the park https://irma.nps.gov/DataStore/Reference/Profile/2219461
- Information regarding the park's water resources is available from the NPS Water Resources Division (http://go.nps.gov/waterresources)
- Wetland monitoring https://irma.nps.gov/DataStore/Reference/Profile/2236892
- The NPS Heartland Network currently inventories and monitors natural resources such as climate, land cover, fire ecology, aquatic invertebrates, fish communities, spring communities, plant communities, and invasive exotic plants (https://www.nps.gov/im/htln/index.htm).
- Ohio Division of Water publications for information about water resource management issues (http://www.dnr.state.oh.us/tabid/4079/Default.aspx)
- Manner and Corbett (1990) presented an environmental atlas of the Cuyahoga Valley National Recreation Area, before it became a national park.

# Geologic Features, Processes, and Resource Management Issues

*These geologic features and processes are significant to the park's landscape and history. Some geologic features, processes, or human activities may require management for human safety, protection of infrastructure, and preservation of natural and cultural resources. The NPS Geologic Resources Division provides technical and policy assistance for these issues.*

During the 2009 scoping meeting (see Thornberry-Ehrlich 2010) and 2018 conference call, participants (see Appendix A) identified the following geologic features, processes, and resource management issues. Table 3 correlates these items with GRI GIS geologic map units.

- Fluvial features and processes
- Flooding
- Management of fluvial processes and flooding
- Glacial features
- Bedrock exposures
- Ancient sedimentary features
- Bedrock caves
- Groundwater availability
- Lacustrine features and wetlands
- Geologic hazards
- Abandoned mineral lands and disturbed lands
- Paleontological resource inventory, monitoring, and protection

## Geologic Resource Management Guidance

The park's Foundation Document (National Park Service 2013a) and Resources Management Plan (National Park Service 1999) are primary sources of information for resource management within the park. Cultural landscape restoration and management are also addressed in a number of publications such as National Park Service (1993); however, cultural landscape inventories were identified as a data need in the park's the foundation document.

The Geologic Resources Division provides technical and policy support for geologic resource management issues in three emphasis areas:

- geologic heritage,
- active processes and hazards, and
- energy and minerals management.

Contact the division (http://go.nps.gov/grd) for assistance with resource inventories, assessments and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; law, policy, and guidance; resource management planning; data and information management; and outreach and youth programs (Geoscientists-in-the-Parks and Mosaics in Science). Park staff can formally request assistance via https://irma.nps.gov/Star/.

Resource managers may find *Geological Monitoring* (Young and Norby 2009; http://go.nps.gov/geomonitoring) useful for addressing 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, suggested methods of monitoring, and case studies.

The Geoscientists-in-the-Park (GIP) and Mosaics in Science (MIS) programs are internship programs to place scientists (typically undergraduate students) in parks to complete geoscience-related projects that may address resource management issues. Multiple GIP and MIS interns have worked on projects at the park, including the following since 2014:

- 2014, Yeyzy Vargas (MIS): Recreational water quality
- 2014, Laura Scaggs (GIP): Refining bedrock geologic mapping
- 2015, Brantley Montague (MIS): Water quality research
- 2015, Julia Skrovan (GIP): Interpretive app development
- 2016, Andrea Rocchio (GIP): Cuyahoga River toolkit web development
- 2017, Christian Heggie (MIS): River use and water quality
- 2017, Christina Tenison (GIP): Wild and Scenic River designation projects, water trail project, and rivers use "SOPs"
- 2018, Jaylin Solberg (MIS): Citizen science and bat emergence
- 2018, Catherine Ruhm (GIP): Abandoned mineral lands reclamation and tree planting
- 2019, Crystal Zhao (MIS): Citizen science and social trails

Products created by the program participants are available to NPS staff by contacting the Geologic Resources Division. Refer to the programs' websites at http://go.nps.gov/gip and https://go.nps.gov/mosaics for more information.

The 2009 GRI scoping meeting produced the following suggestions for resource managers at Cuyahoga Valley National Park:

- Consult with the Geologic Resources Division regarding trails management plan preparation
- Cooperate with local academic institutions to support student projects to develop geologic cross sections for the park
- Compile accurate and up-to-date geologic information for the park (this report is one part of this effort)
- Pursue outreach programs with surrounding communities for land and water stewardship
- Develop geology-specific interpretive programs for unique areas such as Pinery Narrows
- Study how increased visitation is impacting park resources, especially regarding trail erosion and parking lot development and use

The Ohio Division of Geological Survey website (http://geosurvey.ohiodnr.gov) has a wealth of geologic information for the park area along with digital maps available including geomorphic, materials, and stack maps, which convey the surficial topographic expression with depth of unconsolidated material

Other information available from the survey includes

- Abandoned Underground Mines Address Locator
- Map of Ohio Earthquake Epicenters
- Mineral Industries Map of Ohio
- Oil and Gas Map of Ohio with Address Locator
- Emergency Oil and Gas Well Locator
- Lake Erie Geology and Shore Erosion Map of Ohio with Address Locator
- Midwest Regional $CO_2$ Sequestration Partnership (MRCSP)

Additional Geologic information specific to the park area is available from the following sources

- Pringle (1982) discussed specific geologic sites in the park
- Hannibal (1998) detailed the geology along the Towpath Trail within the park
- Szabo et al. (2011) updated the understanding of the Pleistocene glaciations in northern Ohio
- Corbett and Manner (1988) describes the geology and habitats of the park in a field trip format
- Szabo (1987) discussed in detail the Pleistocene glacial stratigraphy of the Cuyahoga Valley
- Szabo and Angle (1983) described the complex quaternary (glacial) stratigraphy on both sides of the Cuyahoga Valley
- Angle et al. (2003) provided a concise glacial geology and bedrock summary

**Table 3. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

Only map units occurring within the boundaries of Cuyahoga Valley National Park are included. Units are presented in approximate order of their age with youngest at the top of the table. The map codes "clvn", "sucu", and "cuva" refer to the surficial GRI GIS map data, surficial and glacial GRI GIS map data, and bedrock only GRI GIS map data, respectively. Map unit colors correspond to GRI GIS data.

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Made land (**m**; clvn)<br>Made land (**m**; sucu) | None identified during mapping | **Flooding:** Areas of **m** provide infrastructure protection and flood control (e.g., dams and shoreline riprap)<br>**Geologic Hazards:** Areas of **m** mitigate geologic hazards (e.g., slope stabilizing gabions, riprap, and retaining walls)<br>**Abandoned Mineral Lands and Disturbed Lands:** One gravel pit is within **m** (sucu) inside park boundaries. Mapped as large areas where the original surface has been completely modified. May include reclaimed land, cut and fill, dumps, and continuous urban cover with asphalt, building complexes, structures, or other manmade surfaces. **m** (clvn) includes large cut and fill areas, including quarries and pits. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Ravine (**r**; sucu) | The unit **r** is only mapped in the portion of the park within Summit County.<br>**Fluvial Features and Processes:** Local creeks and streams incise steep valleys that make up the **r** units in the park.<br>**Glacial Features:** Glacial deposits line many ravines in the park.<br>**Bedrock Exposures:** Bedrock is exposed along many mapped areas of **r** in the park.<br>**Ancient Sedimentary Features:** Bedrock, exposed along some stretches of **r** may display ancient sedimentary features. | **Flooding:** Rapid draining along steep portions of r may contribute to flash flooding.<br>**Groundwater Availability:** Groundwater seeps may appear along ravine walls where flowing groundwater intersects Earth's surface.<br>**Geologic Hazards:** Steep and undercut slopes mapped as **r** are susceptible to slope processes.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** Fossil remains may be washed into ravines or exposed along their walls. |
| Alluvium (**Ha**; clvn)<br>Alluvium (**Qal**; sucu) | **Fluvial Features and Processes: Ha** (clvn) and **Qal** (sucu) are being deposited, eroded, and reworked by modern rivers and streams. Alluvium lines the Cuyahoga River channel and is mapped along larger tributaries, including Tinkers Creek and Furnace Run. Local alluvium includes grainsizes from silt and clay to boulders. Organic content commonly relatively high.<br>**Lacustrine Features and Wetlands:** Bog and marsh deposits (e.g., Beaver Marsh and Stumpy Basin) are included in **Qal**. | **Fluvial Processes:** River meandering threatens natural and cultural features such as the Ohio & Erie Canal, Towpath Trail, and Cuyahoga Valley Scenic Railroad.<br>**Flooding:** Alluvium is found on all floodplains in the park.<br>**Groundwater Availability:** Loose alluvium would readily transmit percolating groundwater.<br>**Geologic Hazards:** Seismic shaking in unconsolidated units like **Qal** and Ha would cause considerable instability.<br>**Abandoned Mineral Lands and Disturbed Lands:** Alluvium provides sand and gravel to local developers. |
| Silt and clay, undifferentiated (**Qsc**; sucu) | **Qsc** is mapped only in Cuyahoga County, northern reaches of the park. **Qsc** is a prominent unit in the valley, adjacent to modern alluvium, **Qal**. Its equivalent in Summit County map coverage is primarily **Wo**.<br>**Glacial Features: Qsc** includes thin outwash deposits.<br>**Lacustrine Features and Wetlands: Qsc** is an ancient lacustrine deposit in thick terraces along the Cuyahoga River valley. | **Fluvial Processes:** River meandering threatens natural and cultural features such as the Ohio & Erie Canal, Towpath Trail, and Cuyahoga Valley Scenic Railroad.<br>**Flooding: Qsc** is easily transported and reworked by flooding.<br>**Groundwater Availability:** Clay-rich **Qsc** would not readily transmit percolating groundwater.<br>**Geologic Hazards:** Seismic shaking in unconsolidated units like **Qsc** would cause considerable instability.<br>**Abandoned Mineral Lands and Disturbed Lands:** One gravel pit is within **Qsc** inside park boundaries. |
| Alluvial terraces (**Wat**; clvn) | Within park boundaries, **Wat** only occurs in a small area near Brushwood Lake.<br>**Glacial Features: Wat** deposits are old floodplain remnants of streams that flowed into high, proglacial lakes; today, they are perched above modern floodplains. | **Groundwater Availability:** Loose terrace deposits would readily transmit percolating groundwater.<br>**Geologic Hazards:** Seismic shaking in unconsolidated units like **Wat** would cause considerable instability. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Sand and gravel, undifferentiated (**Qsg**; sucu) | **Qsg** is only present in limited areas in the northernmost reach of the park.<br>**Glacial Features: Qsg** accumulated as beach-ridge, terrace, and valley-fill deposits some of which date back to glacial lakes and some of which are more recent.<br>**Lacustrine Features and Wetlands: Qsg** may be associated with former lake shorelines as beach ridges. | **Groundwater Availability: Qsg** likely yields a fair amount of groundwater because of its coarseness and permeability. Overall yield depends on location and unit thickness. |
| Lake Maumee gravel terrace (**Wlg**; sucu) | **Wlg** is mapped within park boundaries near Chaffee Road and Frazee House in Summit County where it is dissected by ravines, **r**.<br>**Glacial Features: Wlg** represents a small southward extension of glacial Lake Maumee as a terrace grading southward into glacial outwash at higher levels. | **Groundwater Availability: Wlg** likely yields a fair amount of groundwater because of its coarseness and permeability. Overall yield depends on location and unit thickness. |
| Kame and kame terraces (**Wk**; sucu) | **Wk** is mapped as isolated deposits in Summit County near park localities such as Brushwood Lake, Wettmore Road, Hale Farm and Village, and Hampton Hills.<br>**Glacial Features: Wk** was deposited as gravel and sand in knolls and irregular to level high terraces as sediments poured from the glacial ice in streams into proglacial lakes. **Wk** may also contain masses of till. Kame terraces may also be interpreted as dissected outwash terraces. | **Groundwater Availability: Wk** likely yields a fair amount of groundwater because of its coarseness and permeability. Overall yield depends on location and unit thickness.<br>**Abandoned Mineral Lands and Disturbed Lands:** Three gravel pits are within **Wk** inside park boundaries. Indigo Pond occupies a former quarry into a kame delta. |
| Outwash and lacustrine deposits (**Wo**; sucu) | **Wo** is mapped only in Summit County, southern area of the park. **Wo** a prominent unit in the valley, adjacent to modern alluvium, **Qal**. Its equivalent in Cuyahoga County map coverage is primarily **Qsc**.<br>**Glacial Features: Wo** includes the mixture of sediments (sand, silt, and clay) that are carried away from glacial ice in meltwater-streams, across outwash and lacustrine plains. Some deposits of **Wo** are remnants of stream terraces.<br>**Lacustrine Features and Wetlands:** Bog and marsh deposits (e.g., Stumpy Basin) are mapped on **Wo**. | **Fluvial Processes:** River meandering threatens natural and cultural features such as the Ohio & Erie Canal, Towpath Trail, and Cuyahoga Valley Scenic Railroad.<br>**Flooding**: **Wo** is common on the modern floodplains of the Cuyahoga Valley adjacent to alluvium.<br>**Groundwater Availability:** Lacustrine deposits may have low permeability and yield little groundwater.<br>**Geologic Hazards:** Glacial lake deposits are particularly unstable and susceptible to slope movements. Units such as **Wo** may support slump habitats.<br>**Abandoned Mineral Lands and Disturbed Lands:** Three gravel pits are within **Wo** inside park boundaries.<br>**Paleontological Resource Inventory, Monitoring, and Protection: Wo** may contain fossil pollen and spore records. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Silt (**Wl**; clvn) | **Wl** is not a prevalent surficial unit inside park boundaries, occurring only in the extreme southern end.<br>**Glacial Features:** Some deposits of **Wl** accumulated as thick, deltaic deposits of high glacial lakes (predecessors of Lake Erie). Other depositional settings include lowland surfaces and terraces. | **Geologic Hazards:** Glacial lake deposits are particularly unstable particularly unstable and susceptible to slope movements. Units such as **Wl** may support slump habitats. |
| Silt and clay (**Wlc**; clvn) | Within the park **Wlc** is only mapped near Brandywine Falls.<br>**Glacial Features: Wlc** accumulated as thick, valley-fill deposits of high, glacial lakes prior to the formation of Lake Erie. As such, it muted topographic features of preexisting landforms.<br>**Lacustrine Features and Wetlands:** Relatively poor drainage in **Wlc** leads to the formation of small bogs and swamps in undrained depressions. | **Groundwater Availability:** Low porosity and permeability in silt and clay yield little groundwater.<br>**Geologic Hazards:** Glacial lake deposits are particularly unstable and susceptible to slope movements. Units such as **Wlc** may support slump habitats. |
| Sand (**Ws**; clvn) | **Ws** deposits are mapped near Lake Erie, and only in a small area in the northern reaches of the park boundary.<br>**Glacial Features: Ws** occurs in terraces and buried valleys (where it may be older than the most recent glaciation), as well as beach-ridge deposits from glacial lakes prior to the formation of Lake Erie. | **Groundwater Availability: Ws** likely yields a fair amount of groundwater because of its coarseness and permeability. Overall yield depends on location and unit thickness. |
| Ice-contact deposits (**Wic**; clvn) | **Wic** is mapped within the park nearly Alexander Road (northeast) and Botzum (southwest).<br>**Glacial Features: Wic** formed directly from stagnant ice as kame or esker landforms (see **Wk**). **Wic** is highly heterogenous, including sorted gravel and sand, silt, clay, and lenses of till. | **Groundwater Availability:** Groundwater yields vary broadly for heterogenous units such as **Wic**. |
| Sand and gravel (**Wsg**; clvn) | **Wsg** is among the more commonly mapped units inside the park boundary, flanking the alluvium that lines the river valley.<br>**Glacial Features:** Similar to **Ws**, **Wsg** occurs in terraces and buried valleys (where it may be older than the most recent glaciation), as well as beach-ridge deposits from glacial lakes prior to the formation of Lake Erie. Locally, **Wsg** includes cross beds, organics, and layers of silt and clay. | **Fluvial Processes:** River meandering threatens natural and cultural features such as the Ohio & Erie Canal, Towpath Trail, and Cuyahoga Valley Scenic Railroad.<br>**Groundwater Availability: Wsg** likely yields a fair amount of groundwater because of its coarseness and permeability. Overall yield depends on location and unit thickness.<br>**Abandoned Mineral Lands and Disturbed Lands:** Units such as **Wsg** were tapped for sand and gravel pits. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
| --- | --- | --- |
| Hiram Till, end moraine (all lobes) (**Whe**; sucu) | **Whe** and **Whg** are common units located in the upland areas of the park, typically above mapped ravines, **r**, in Summit County.<br>**Glacial Features: Whe** is an unsorted mix of clay, silt, sand, gravel, and boulders deposited directly from glacial ice. The end moraine records a particular extent of a glacial advance and retreat. **Whe** is relatively clay rich. The Hiram is an important regional marker bed for the late Wisconsinan glaciation. | **Groundwater Availability:** Clay-rich, heterogenous till has relatively low permeability. |
| Hiram Till, ground moraine (all lobes) (**Whg**; sucu) | **Whe** and **Whg** are common units located in the upland areas of the park, typically above mapped ravines, **r**, in Summit County.<br>**Glacial Features: Whg** is an unsorted mix of clay, silt, sand, gravel, and boulders deposited directly from glacial ice. The ground moraine forms behind (ice-ward) of the end moraine for a given glacial advance. The Hiram is an important regional marker bed for the late Wisconsinan glaciation. | **Groundwater Availability:** Clay-rich, heterogenous till has relatively low permeability. |
| Hayesville Till, end moraine (Killbuck lobe) (**Whae**; sucu) | Whae occurs in one area of the park, along Sand Run Road in the southernmost reach.<br>**Glacial Features: Whae** is an unsorted mix of clay, silt, sand, gravel, and boulders deposited directly from glacial ice. The end moraine records a particular extent of a glacial advance and retreat. **Whae** is relatively silt rich. | **Groundwater Availability:** Clay-rich, heterogenous till has relatively low permeability. |
| Till (**Wt**; clvn)<br>Till, primarily Lavery Till (**Wt**; sucu) | **Wt** (clvn) encompasses the largest mapped area within park boundaries.<br>**Glacial Features:** End moraines (Defiance moraine) occur in **Wt** (sucu) within park boundaries. Till in northern Ohio is an unsorted mix of clay, silt, sand, gravel, and boulders deposited directly from glacial ice. In buried valleys, till may predate the last glaciation (Wisconsinan). The Lavery is an important regional marker bed for the late Wisconsinan glaciation. | **Groundwater Availability:** Clay-rich, heterogenous till has relatively low permeability.<br>**Abandoned Mineral Lands and Disturbed Lands:** One gravel pit is within **Wt** (sucu) inside park boundaries. |
| Mogadore Till, ground moraine (Cuyahoga lobe) (**Wmog**; sucu) | The southern tip of the park boundary intersects mapped areas of **Wmog**.<br>**Glacial Features: Wmog** is an unsorted mix of clay, silt, sand, gravel, and boulders deposited directly from glacial ice. The ground moraine forms behind (ice-ward) of the end moraine for a given glacial advance. **Wmog** is relatively coarse grained and rich in sand. The Mogadore is an important regional marker bed for the Illinoian or early Wisconsinan glaciation. | **Groundwater Availability:** Clay-rich, heterogenous till has relatively low permeability. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Allegheny and Pottsville Group, undivided (**PNap**; cuva) | **PNap** is mapped in the uppermost reaches of the park, near Happy Days Lodge.<br>**Fluvial Features and Processes:** Many waterfalls form where the resistant beds of **PNap** are undercut by streams eroding underlying, less resistant layers.<br>**Bedrock Exposures:** Exposures of **PNap** are prevalent in the higher reaches of the park, characterized by rapid horizontal and vertical rock-type changes. The unit is named from exposures in valley of Allegheny River, western Pennsylvania, and near Pottsville along a railroad cut on east side of water gap through Sharp Mountain, Schuylkill County, Pennsylvania, respectively.<br>**Ancient Sedimentary Features:** Mixed beds of shale, siltstone, sandstone, conglomerate, and some limestone, clay, flint, and coal indicate a wide variety of depositional settings.<br>**Bedrock Caves:** Ice-box cave occurs in an exposure of **PNap**. Petroglyphs were created on rocks near Ice-box cave (fig. 17). | **Groundwater Availability:** Springs and seeps are commonly associated with joints in the Sharon conglomerate. **PNap** likely yields a fair amount of groundwater (as much as 100 gpm) because of its coarseness and permeability. Overall yield depends on location, composition, and fracture density.<br>**Geologic Hazards:** As resistant caprock throughout the area, **PNap** is susceptible to blockfall when undercut by erosion of softer underlying units.<br>**Abandoned Mineral Lands and Disturbed Lands:** **PNap** has economic beds of coal and clay. No mapped quarries or mines exist in the park boundaries.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** Though not yet noted within park boundaries, fossil resources from **PNap** are documented elsewhere and could be present within the park upon further investigation. Potential fossils include marine fossils, plants, foraminifera, corals, ostracods, fusulinids, nautiloids, trilobites, gastropods, bivalves, brachiopods, crinoids, crustaceans, fish, and conodonts. Jumbled plant remains were noted at the GRI field trip in the Sharon conglomerate near Mary Campbell's Cave. |
| Sharon Sandstone and Berea Sandstone, undifferentiated (**PNDsc**; clvn) | **PNDsc** is mapped in one small location within park boundaries—near Happy Days Lodge. The Sharon Conglomerate (sandstone) crops out at Ritchie and Boston ledges.<br>**Bedrock Exposures:** The Sharon Sandstone was named from exposures near the town of Sharon, Mercer County, western Pennsylvania. Berea Sandstone is named for Berea, Cuyahoga County, Ohio, just west of the park.<br>**Ancient Sedimentary Features:** Extensive conglomerate beds indicate a high energy, high rate of sedimentation depositional environment. Quartz pebbles indicate a specific source rock (probably Canada). Lenses of clay shale indicate sweeping changes in depositional environment to lower energy, deeper water settings. Prior to the deposition of **PNDsc**, the underlying surface of Mississippian blue-gray shale and siltstone was eroded up to 60 m (200 ft).<br>**Bedrock Caves: PNDsc** may form bedrock caves in some exposures. | **Groundwater Availability:** Springs and seeps are commonly associated with joints in the Sharon conglomerate and along its contact with underlying units. **PNDsc** likely yields a fair amount of groundwater because of its coarseness and permeability. Overall yield depends on location, composition, and fracture density.<br>**Geologic Hazards:** Layers in **PNDsc** are form hills and cliffs, which may be susceptible to slope movement such as rockfalls. As resistant caprock throughout the area, **PNDsc** is susceptible to blockfall when undercut by erosion of softer underlying units.<br>**Abandoned Mineral Lands and Disturbed Lands:** See **PNap** and **Dbb**. The Berea Sandstone is a source of oil and gas, historically.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** See **PNap** and **Dbb**. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Cuyahoga Formation (**Mc**; sucu)<br>Cuyahoga Formation (**Mc**; cuva) | **Mc** (sucu) is mapped is the upper reaches of drainages in the Brecksville Reservation area of the park.<br>**Glacial Features:** Areas of **Ds**, **Db**, and **Mc** are locally mantled by end moraines (Defiance moraine).<br>**Bedrock Exposures: Mc** consists of basal Orangeville member upwards into the Sharpsville, Strongsville and uppermost Meadville members. **Mc** was named from exposures along the Cuyahoga River between Akron and Cleveland, basically, the length of the park.<br>**Ancient Sedimentary Features:** Shale dominates **Mc** suggesting deposition in deep-water, quiet, open marine conditions. | **Groundwater Availability:** Thin bedding and fine-grain size associated with the shales of **Mc** are not conducive to abundant groundwater (5 to 25 gpm) or high permeability.<br>**Geologic Hazards:** A mapped fault (outside of park boundaries) cuts **Doh**, **Dbb**, and **Mc** in an unknown offset/displacement.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** Fossils in **Mc** include brachiopods. The Meadville member is the most fossiliferous unit in northeastern Ohio with 125 species of sponge, coral, bryozoans, gastropods, mollusks, ammonoids, brachiopods, crinoids, and trilobites. GRI scoping participants noted zoophycos burrows and conularids within **Mc** at the Gorge Metropark. The Brandywine Creek and Falls area are noted fossil localities for **Mc**. |
| Cuyahoga Formation, Berea Sandstone, and Bedford Shale, undifferentiated (**MDcbb**; clvn) | See descriptions of **Mc**, **PNDsc**, and **Dbb**.<br>**Ancient Sedimentary Features: MDcbb** displays rapid changes in sedimentary rock type and features both horizontally and vertically, indicating a variable depositional environment over the time of its deposition. Sandstone layers may contain concentric, colored rings or iron stains called Liesegang banding.<br>**Bedrock Exposures:** The Cuyahoga Formation was named from exposures along the Cuyahoga River between Akron and Cleveland, basically, the length of the park. Berea Sandstone is named for Berea, Cuyahoga County, Ohio, just west of the park. Bedford Shale is named from exposures near the town of Bedford, along Tinkers Creek, so likely within park boundaries. | **Groundwater Availability:** See **Mc**, **Db**, and **PNDsc**<br>**Geologic Hazards**: Local layers in **MDcbb** form hills and cliffs, which may be susceptible to slope movements such as rockfalls.<br>**Abandoned Mineral Lands and Disturbed Lands:** The Berea Sandstone is a source of oil and gas, historically.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** See **Dbb**. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Berea Sandstone (**Db**; sucu) | **Db** is mapped in the middle reaches of local drainages in the Brecksville Reservation and Bedford Reservation areas of the park. Berea Sandstone is visible at Deep Lock Quarry, Brandywine Falls, Blue Hen Falls, and Sagamore Hills.<br>**Fluvial Features and Processes:** Sandstone ledges in formed in **Db** support waterfalls in Cuyahoga tributaries.<br>**Glacial Features:** Areas of **Ds**, **Db**, and **Mc** are locally mantled by end moraines (Defiance moraine).<br>**Bedrock Exposures:** Berea Sandstone is named for Berea, Cuyahoga County, Ohio, just west of the park.<br>**Ancient Sedimentary Features:** Sandstone layers may contain concentric, colored rings or iron stains called Liesegang banding.<br>**Bedrock Caves:** In areas where **Db** is undercut, ledges or overhangs may form cave-like features. | **Groundwater Availability:** Thin bedding and fine-grain size associated with the mix of sandstones and shales of **Db** are not conducive to abundant groundwater (5 to 25 gpm) or high permeability.<br>**Geologic Hazards:** Layers in **Db** form hills and cliffs, which may be susceptible to slope movement such as rockfalls. Areas of **Db** which are undercut by erosion of the underlying Bedford Formation (**Dbb**, **Ds**) are particularly vulnerable to slope processes.<br>**Abandoned Mineral Lands and Disturbed Lands:** The Berea Sandstone is a source of oil and gas, historically. It was used locally in mills, knife sharpening operations, canal locks, cemeteries, and for flagstones and building materials. Many prominent buildings in northern Ohio are made from this stone. Petroglyphs on the face of a quarried slab of Berea Sandstone, appear inside a Lutheran Church at Independence, Ohio. The Berea Sandstone is also used as a permeability standard in hydrogeologic studies.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** See **Dbb**. |
| Berea Sandstone and Bedford Shale, undivided (**Dbb**; cuva) | **Dbb** occurs as narrow bands adjacent to **Doh** flanking the valleys and beneath **Mc** units.<br>**Fluvial Features and Processes:** Ledges formed in Berea Sandstone support waterfalls in Cuyahoga tributaries.<br>**Bedrock Exposures:** The thickness of the Berea Sandstone is correlative to the presence or absence of the Bedford Shale. In areas where the shale was not deposited or eroded away, the sandstone is thickest. Siltstone layers in the Bedford Shale have ripple marks recording intermittent higher-energy depositional environments. Berea Sandstone is named for Berea, Cuyahoga County, Ohio, just west of the park. Bedford Shale is named from exposures near the town of Bedford, along Tinkers Creek, so likely within park boundaries.<br>**Ancient Sedimentary Features:** Ripple marks are common in sandstone beds. Sandstone layers may contain concentric, colored rings or iron stains called Liesegang banding. | **Groundwater Availability:** Thin bedding and fine-grain size associated with the mix of sandstones and shales of **Dbb** are not conducive to abundant groundwater (5 to 25 gpm) or high permeability.<br>**Geologic Hazards:** A mapped fault (outside of park boundaries) cuts **Doh**, **Dbb**, and **Mc** in an unknown offset/displacement.<br>**Abandoned Mineral Lands and Disturbed Lands:** One gravel pit and three quarries are within **Dbb** inside park boundaries. The Berea Sandstone is a source of oil and gas, historically.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** Fossils and trace fossils in **Dbb** include brachiopods, pelecypods, plants (e.g., wood), and spore casings. Tinkers Creek and Brandywine Falls are notable paleontological localities for **Dbb**. |

**Table 3, continued. Geologic features, processes, and associated resource management issues in Cuyahoga Valley National Park.**

| Map Unit (symbol; map code) | Features and Processes | Potential Resource Management Issues |
|---|---|---|
| Shale, undifferentiated (**Ds**; sucu) | **Ds** is mapped in the lower reaches of local drainages in the Brecksville Reservation and Bedford Reservation areas of the park. **Ds** is also covered by alluvium, **Qal**, along the northern Cuyahoga River valley.<br>**Glacial Features:** Areas of **Ds**, **Db**, and **Mc** are locally mantled by end moraines (Defiance moraine).<br>**Ancient Sedimentary Features:** See **Doh** and **Dbb**. | **Groundwater Availability**<br>Thin bedding and fine-grain size associated with the shales of **Ds** are not conducive to abundant groundwater (5 to 25 gpm) or high permeability.<br>**Geologic Hazards**<br>Radioactive layers in **Ds** may pose a radon hazard to humans in building basements and natural cavities.<br>**Abandoned Mineral Lands and Disturbed Lands**<br>Two gravel pits are within **Ds** inside park boundaries. The Devonian shale is a source of oil and gas, historically.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** See **Doh** and **Dbb**. |
| Ohio Shale (**Doh**; cuva) | **Doh** is mapped in the lowermost elevations of the park. It makes up the largest percentage of mapped area within park boundaries. The Chagrin Shale crops out in the walls of the valley in the norther sections of the park.<br>**Fluvial Features and Processes:** For stretches of the Cuyahoga River that are incised channels, **Doh** crops out.<br>**Bedrock Exposures: Doh** consists of the Huron, Chagrin, and Cleveland members in ascending order. **Doh** is named for exposures in Ohio River hills, in the neighborhood of Rockville, Adams County, Ohio far south of the park.<br>**Ancient Sedimentary Features:** Shale beds accumulated in deep water, sometimes anoxic conditions evidenced by the dark black color, petroliferous odor and carbonate/siderite concretions. | **Groundwater Availability:** Thin bedding and fine-grain size associated with the shales of **Doh** are not conducive to much groundwater yield (<5 gpm) or high permeability.<br>**Geologic Hazards:** A mapped fault (outside of park boundaries) cuts **Doh**, **Dbb**, and **Mc** in an unknown offset/displacement. Slumping within Doh occurs at Pinery Narrows. Radioactive layers in **Doh** may pose a radon hazard to buildings and natural cavities.<br>**Abandoned Mineral Lands and Disturbed Lands:** The Devonian shale is a source of oil and gas, historically. The Chagrin Shale is mined to make lightweight expanded aggregate (haydite) for use in concrete block and precast concrete shapes.<br>**Paleontological Resource Inventory, Monitoring, and Protection:** Fossils and trace fossils in **Doh** include conodonts, fish, shark, spores, plant impressions, brachiopods, bivalvess, cephalopods, burrows, annelid worm(?), arthropods, foraminifera, ammonites, crinoids, and ferns. Brandywine Falls in the park is a notable paleontological locality for **Doh** and **Dbb**; fossils from which are curated in the Cleveland Museum of Natural History. |

## Fluvial Features and Processes

Fluvial features are those which are formed by flowing water. Fluvial processes both construct (deposit alluvium **Ha** and **Qal**) and erode landforms (e.g., valleys or ravines, **r**; White 1984; Ford 1987; Pavey et al. 2000). The Cuyahoga River and its tributaries form the fluvial features at Cuyahoga Valley National Park. Fluvial features occur on many scales in the park ranging from the large river valleys to the smallest streams. Examples of park's fluvial features include meandering river channels, point bars, floodplains, and terraces (see fig. 9). River channels are the perennial course of the flowing water. As a river flows around curves the flow velocity (and thus erosive energy) is greatest on the outside of the bend. The river erodes into its bank on the outside of a curve and leaves point bar deposits on the inside of the bend. Point bars are crescent-shaped ridges of sand, silt, and clay deposited on the inside of meander loops where the water's velocity is slowest. As the process continues, the outside bend retreats farther, while the inside bend migrates laterally, creating migrating meanders. Meandering reaches its extreme

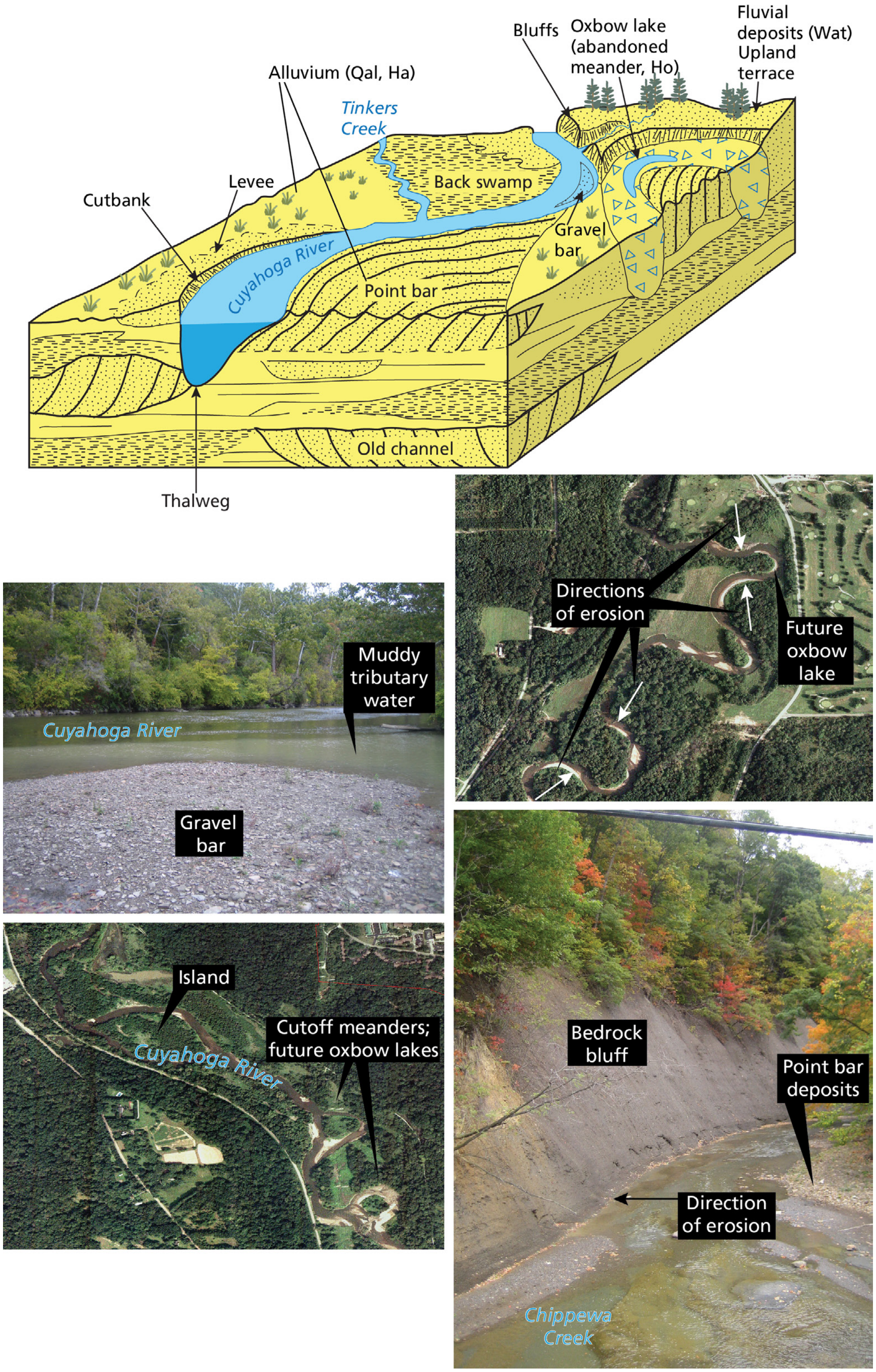



**Figure 9. Fluvial features schematic with park examples.**
**Many of the features presented on the schematic diagram occur along the lengths of the Cuyahoga River and its tributaries. Riprap and other shoreline stabilization efforts protect the infrastructure and cultural resources from natural erosion. Graphic by Trista Thornberry-Ehrlich (Colorado State University) using GRI GIS data with a basemap by ESRI World Imagery (accessed 18 January 2018). Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

when the narrow neck of land between two bends is breached. Oxbow lakes form where meanders are cut off; they preserve a former river course and provide snapshots of the previous channel substrate as well as preserve pollen records. Examples in the park include Beaver Marsh and Stumpy Basin (see Lacustrine features and wetlands).

The Cuyahoga River has both bedrock-confined channels such as at Pinery Narrows (geologic map unit **Doh** exposed) and Peninsula, and floodplain dominated channels in broader sections such as the area from Hillside Road northward (Swinford et al. 2003; Thornberry-Ehrlich 2010). Floodplain dominated channels experience more lateral meandering than a channel entrenched in erosion-resistant bedrock. Bedrock channels tend to be narrower and straighter with the incised meanders constraining the river course. The modern fluvial system developed as the last glacial ice retreated more than 10,000 years ago. The Pleistocene glaciations "reset" the river system, creating a new baseline.

The rugged gorge of the river runs between steep-sided valley walls with short tributaries lying nearly perpendicular to the river like the backbone of a fish (Nash 2009). Indeed, if obscuring vegetation were removed, much of the dissected upland areas would resemble badlands (Nash 2009). Most of the streams in the park are considered immature with their steep walls, and narrow V-shaped valleys as opposed to a mature broad, shallow valley with wide floodplains. This immaturity is also characterized by rapids and waterfalls along their courses (Nash 2008). The bedrock layering with resistant Berea Sandstone deposited atop less resistant shales of the Bedford Formation supports waterfall formation. The shales weather away from below leaving ledges of sandstone perched along stream courses. Approximately 50 waterfalls exist on many tributary streams including Mudcatcher Falls, Blue Hen Falls, Bridal Veil Falls, Chippewa Falls (fig. 10), Cat Falls and Brandywine Falls. The park's ravines are closely spaced and can drop nearly 180 m (600 ft) in only a few kilometers (Thornberry-Ehrlich 2010). Regional joint patterns in the bedrock serve to focus some stream channels, providing a faster drainage.

### Flooding

Flooding is common along the Cuyahoga River and its tributaries at all times of the year. Narrow channels are overwhelmed when heavy rains funnel through the drainages, resulting in flash floods (Nash 2009). Spring snowmelt, seasonal storms, or ice dams at the river's mouth can all cause local floods (Thornberry-Ehrlich 2010). Floods are the primary geomorphological agents shaping the fluvial environment and have an important role in controlling the pattern of riparian vegetation along channels and floodplains. During high flows or floods, a river deposits natural levees of sand and silt along its banks. These deposits represent the relatively coarse-grained component of a river's suspended sediment load and form a high area on an alluvial region's land surface. Flooding along the Cuyahoga and its larger tributaries also recharges riverine wetlands adjacent to their channels (see "Lacustrine Features and Wetlands"). US Geological Survey gauging stations at Old Portage and Independence reveal the Cuyahoga River floods 0-2 times during most years for an average duration of one or two days; however, some floods can last for weeks (Bingham et al. 2016).

Flooding is a natural process, but it becomes a resource management issue when significant cultural or natural resources are threatened. In 1913, a flood covered several archaeological sites along the river and deposited silt in the rafters of historic buildings along the Erie & Ohio Canal such as the Canal Visitor Center (Thornberry-Ehrlich 2010). The catastrophic July 2003 flood caused over $3 million in damages to Cuyahoga Valley National Park's railway (Thornberry-Ehrlich 2010), Towpath Trail, and other historic structures. In 2004, a 500-year flood occurred on Yellow Creek causing widespread erosion, instability, and landslides along its course. In 2005, flooding along the Cuyahoga River threatened the Towpath Trail near Chippewa Creek. Additional flooding in 2006 along the Cuyahoga River and its tributaries caused additional damage to park resources (Thornberry-Ehrlich 2010).

Climate change models predict more frequent and stronger storms to impact northern Ohio. Flooding resulting from these storms may become more frequent and cause increases in sediment load in park streams and rivers

### Management of Fluvial Processes and Flooding

Natural river meandering erodes streambanks, threatening the stability of natural and cultural resources along the Cuyahoga River and its tributaries. Trees regularly wash into the river after their roots are exposed through streambank erosion. Where the river erodes too closely to the hardened clays beneath the Towpath Trail, natural hydraulic head forces water through the clays and towards the canal, destabilizing the path from below. In areas where cultural resources such as the Ohio & Erie Canal, Towpath Trail, or Cuyahoga Scenic Railroad were threatened, stabilization projects (e.g., riprap; see fig. 25) attempted to stem lateral migration of the river channel. A piecemeal approach to riverbank stabilization is causing problems adjacent to and downstream of the riprap, as well as creating a hardened river channel that no longer

**Figure 10. Photograph of Chippewa Falls.**
**Waterfalls occur throughout the park where ledges of resistant sandstone (e.g., Berea Sandstone) are undercut along drainages by the erosion of the softer, underlying units (e.g., Bedford Shale). Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

flows naturally (Thornberry-Ehrlich 2010). The park's resource management plan (National Park Service 1999) identified having a naturally functioning riparian zone, unimpeded by humans, along the river corridor as a priority.

Flooding and stormwater management are continual at Cuyahoga Valley National Park. To understand how specific reaches of the river are changing with time, as of 2009, the park was conducting a 12-year riverbank monitoring program that involved areas with rebar positioned as baselines at 25 sites. The park was also considering designated overflow areas to accommodate increased flows (Thornberry-Ehrlich 2010). However, rapidly changing conditions required the allocation of resources elsewhere and the focus shifted from monitoring change to stabilizing assets (e.g., railroad beds and towpath) to restoring the floodplains on a larger scale (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). Restoring floodplain areas involve reducing the bank in some areas to allow the river to more easily access its floodplain. The park is cooperating with the US Army Corps of Engineers to produce sediment transport modeling, identifying locations to restore floodplain access (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018).

Cuyahoga Valley National Park resource managers currently follow a riverbank management plan (Cuyahoga Valley National Park 2004) that seeks to use monitoring and less intrusive techniques to incorporate both the historic preservation mandates and natural resource objectives of the park. Techniques include:

- Engineered and non-engineered measures at areas with less of an imminent threat to cultural resources

- Engineered log jams
- Root wads
- Planting of deep-rooted trees to increase stability
- Removing trees imminently threatened by erosion before they can fall into the channel
- Encouraging channel cutoffs or reestablishing meanders were appropriate

The Cuyahoga River Area of Concern (AOC) website (www.cuyahogariveraoc.org), formerly the Remedial Action Plan (RAP) site, hosts water quality data. County websites (www.co.summit.oh.us and www.cuyahogacounty.us) have waterway maps.

Protecting park geologic features and restoring disturbed areas were both stated in the park's resource management plan (National Park Service 1999) as primary goals. Specific features identified were ledges, springs, waterfalls, and caves. In the park's foundation document (National Park Service 2013a), the following geologic-related planning and data needs were presented for the Cuyahoga River ecosystem:

- River use management plan (high priority planning and data need)
- Natural resource restoration plans, designs, and compliance (including site specific designs)
- Approved trail plan (including water trails; high priority planning and data need)
- With assistance from the Great Lakes Restoration Initiative (https://www.glri.us/), the park is attempting to better manage stormwater and other runoff from impervious surfaces to increase the stability of tributary streams (e.g., Sand Run) and reestablish connections between the tributary stream and the Cuyahoga River floodplain beneath the towpath. These efforts include increased step pool stabilization, catchments placed within or near parking lots, and diversions to allow formerly buried streams to daylight (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). Innovative approaches and technology were employed at newer parking lots and the new visitor center to better control the impacts of stormwater flooding.

## Glacial Features

Pleistocene glaciers scoured and reshaped the landscape of the northeastern United States, including Cuyahoga Valley National Park. The most recent ice age (called the "Wisconsinan") completely covered northern Ohio with ice; the southernmost terminus of Wisconsinan glaciers trended northeast to southwest across central Ohio (figs. 11, 12, and 13). The two major categories of glacial features are (1) those created by glacial ice and (2) those deposited by rivers flowing beneath or out of glaciers, referred to as "glaciofluvial," or deposited in lakes near glaciers, referred to as "glaciolacustrine." The glaciers carried vast amounts of sediment that were dumped as the ice melted; the majority of the glacial deposits fall into four main categories (see fig. 11): till (geologic map units **Wt**, **WPLcg**, **Wmog**, **Wmoe**, **Wmoh**, **Wkee**, **Wne**, **Wt**, **Wlae**, **Whag**, **Whae**, **Whah**, **Whe**, **Whg**), lacustrine and outwash (**Wo**, **Wlg**), and ice-contact sand and gravel (i.e., kames, **Wic**, **Wk**; White 1984; Ford 1987; Pavey et al. 2000; Angle et al. 2003). Buried valleys, such as those in the park may contain a mix of glacial deposits (see fig. 3). The glacial sediments were then reworked by streams and lakes that formed as the ice melted. The sediment-rich system left sorted channel, floodplain, and delta deposits across the area among mantles of glacial till. Because each glacial advance tends to obscure or obliterate much of the evidence left by the previous glaciation, the glacial history of the area is complex and difficult to read.

Glacial features of the region include kames (**Wk**), eskers, complex end moraines (**Wmoe**, **Wkee**, **Wne**, **Wlae**, **Whae**, **Whe**), ground moraines (**Wmog**, **Whag**, **Whg**), dissected outwash terraces, weakly-developed grooves and striations, and widespread glacial erratics transported from Canada (White 1984; Ford 1987; Pavey et al. 2000; Nash 2009; Thornberry-Ehrlich 2010). Kames are irregularly shaped hills or mounds composed of sand, gravel and till that accumulate in a depression on a retreating glacier. Eskers are long, narrow, sinuous ridges of stratified sand and gravel deposited by a subglacial or ice-tunnel stream within a glacier. End moraines mark the furthest advance of a particular glacier, often a sinuous ridge of mixed sediments dumped in place as the glacier begins its retreat. Ground moraine is an irregular mantle of till deposited under the glacier. As the glacier melts, outwash streams rework many of the glacial sediments via fluvial processes.

Glacial grooves and striations, gouged where glaciers scratched the bare bedrock, are visible along the trail to the Ledges area (Corbett and Manner 1988). Glacial features include erratics, or rocks from elsewhere that were transported and subsequently dumped in place by glacial ice. Locally, these include boulders up to 2 m (6 ft) in diameter and are granite, gneiss, quartzite, greenstone, dolomite, and sandstone (White 1984; Ford 1987). No erratics are in the map data within park boundaries, but this does not preclude their presence there. Field mapping in 2011 revealed Gowganda Tillite (lithified glacial deposit) off-trail in a drainage area north of the Oak Hill trails (Greg Tkachyk, volunteer, Cuyahoga Valley National Park, conference

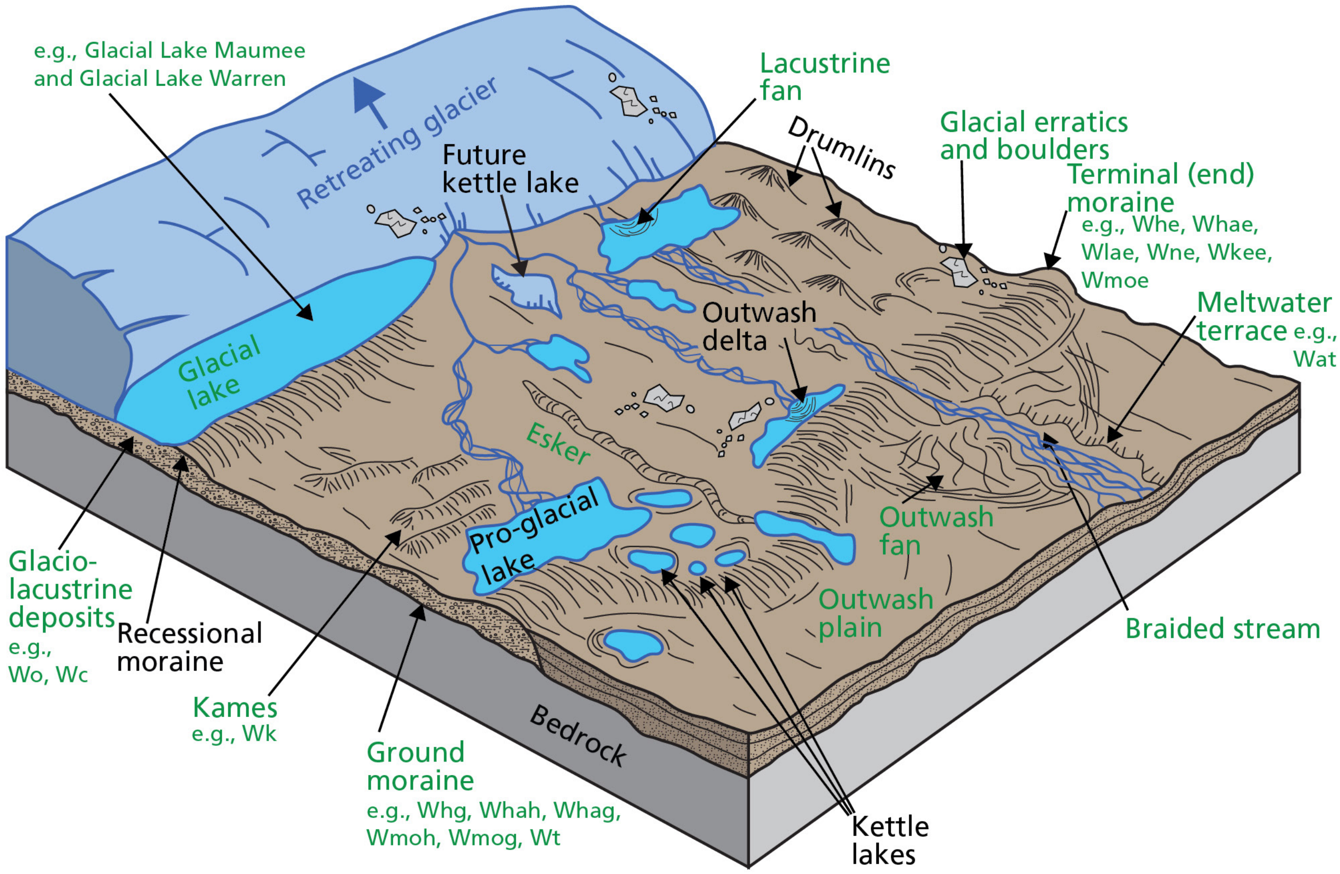



**Figure 11. Schematic illustration of glacial features and deposits.**
**Glacial features that occur within Cuyahoga Valley National Park are labeled in green and include the following: glacial lakes (e.g., Glacial Lakes Maumee and Warren), glaciolacustrine deposits (e.g., map units Wo and Wc), lacustrine fans, glacial erratics and boulders, terminal (end) moraines (e.g., map units Whe, Whae, Wlae, Wne, Wkee, and Wmoe), ground moraines (e.g., map units Whg, Whah, Whag, Wmoh, Wmog, and Wt), meltwater terraces (e.g., map unit Wat), braided streams, outwash fans, outwash plains, eskers, and kames (e.g., map unit Wk). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).**

call, 8 February 2018). Gowganda Tillite is originally located along the northern shores of Lake Huron and is part of a group of rocks known as the Lower Huronian Supergroup. It represents some of the oldest sedimentary rocks found in North America at 2.2 to 2.4 billion years old (Angle 2016). As the Huron shoreline portion of the Upper Great Lakes was glaciated during the Pleistocene, multiple pieces of the Gowganda Formation were eroded and carried along with other erratics into Ohio. The dark bluish-green or olive-green tinted erratics are distinctively dense and heavy for their size with quite smooth, well-rounded surfaces, and pink, orange, and black clasts commonly (fig. 13; Angle 2016).

Other glacial features include cyclic glacial-lacustrine deposits (**Wo**) formed by a series of glacial lakes behind ice dams (glacial lobes) at the front of the continental glacier (see “Geologic Setting and History”; White 1984; Ford 1987; Thornberry-Ehrlich 2010). These glacial lakes collected classic delta sequences as sediment-laden water flowing from melting glaciers and outwash streams reached the lakes and dumped their suspended sediment loads. These deltas have characteristic assemblages, consisting of bottomset beds that are farthest from the glacier’s position, angled foreset beds that cover the bottomset beds, and (3) topset beds that cover the entire sequence (fig. 14). As glacial ice melted and retreated farther northward, the delta was left as a relict, and the whole sequence repeated itself. Several examples of the ancient post-glacial Gilbert delta sequences occur along the length of the Cuyahoga River (e.g., at Mud Brook and along Rockside Road; Thornberry-Ehrlich 2010 from written communication M. Angle, Ohio Division of Geological Survey, geologist, 2009).

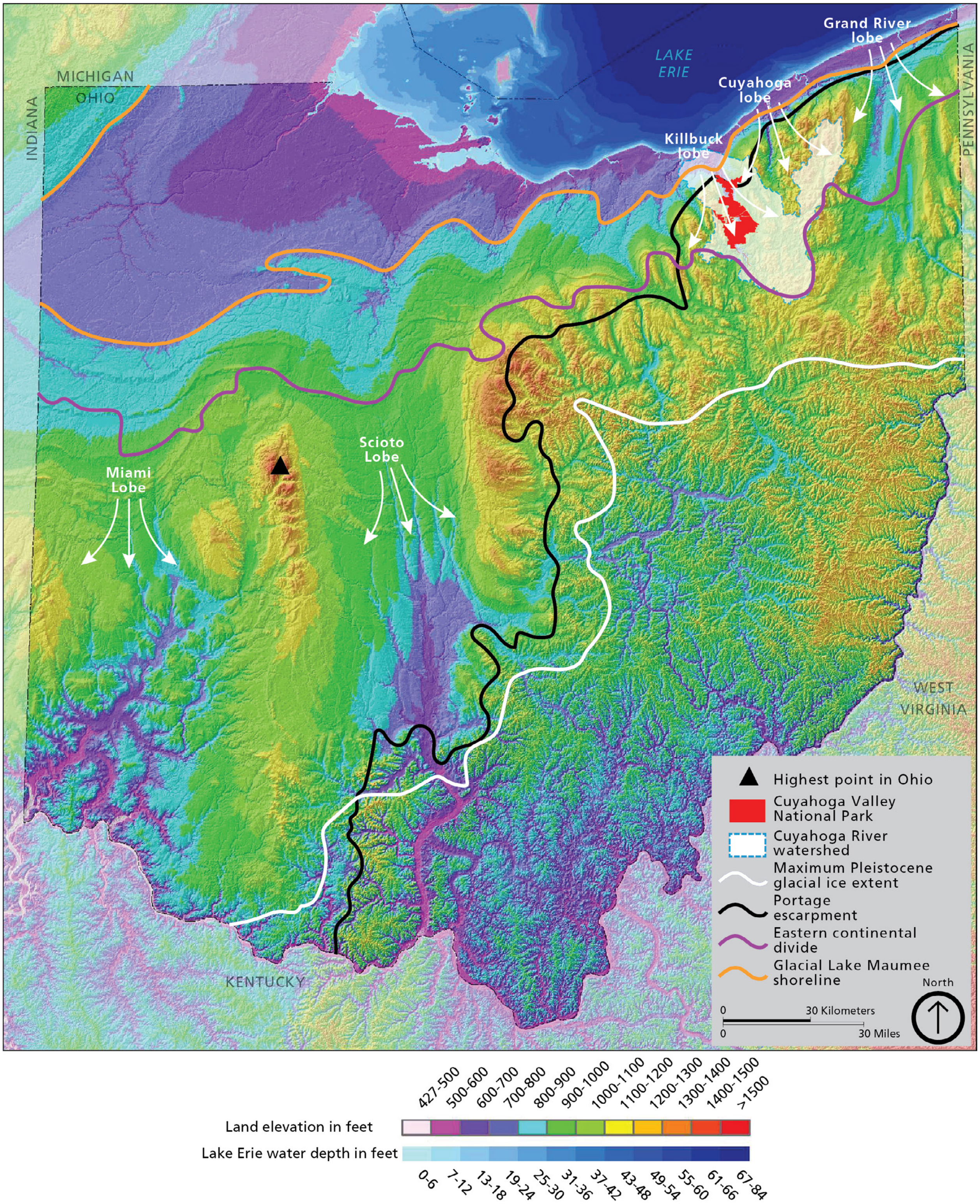



**Figure 12. Shaded relief map with glacial extent.**
**Several glacial lobes (e.g., Killbuck, Cuyahoga, Grand River) descended across the Cuyahoga Valley landscape. The Portage escarpment was an impediment to glacial flow. This resulted in a complex glacial geologic record in the area. . Cuyahoga River watershed (shaded white area) was strongly controlled by the glacial extent as well. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using basemap from the Ohio Division of Geological Survey and information from Ohio Division of Geological Survey (2002).**

**Figure 13. Photograph of a Gowganda glacial erratic.**
**Erratics are scattered across the park landscape commonly in stark contrast with the local bedrock types and ages. Gowganda tillite is about 2.2 to 2.4 billion years old. The source rock is in southern Canada, near Lake Huron. Photograph taken by Greg Tkachyk (Cuyahoga Valley National Park) on 20 June 2011.**

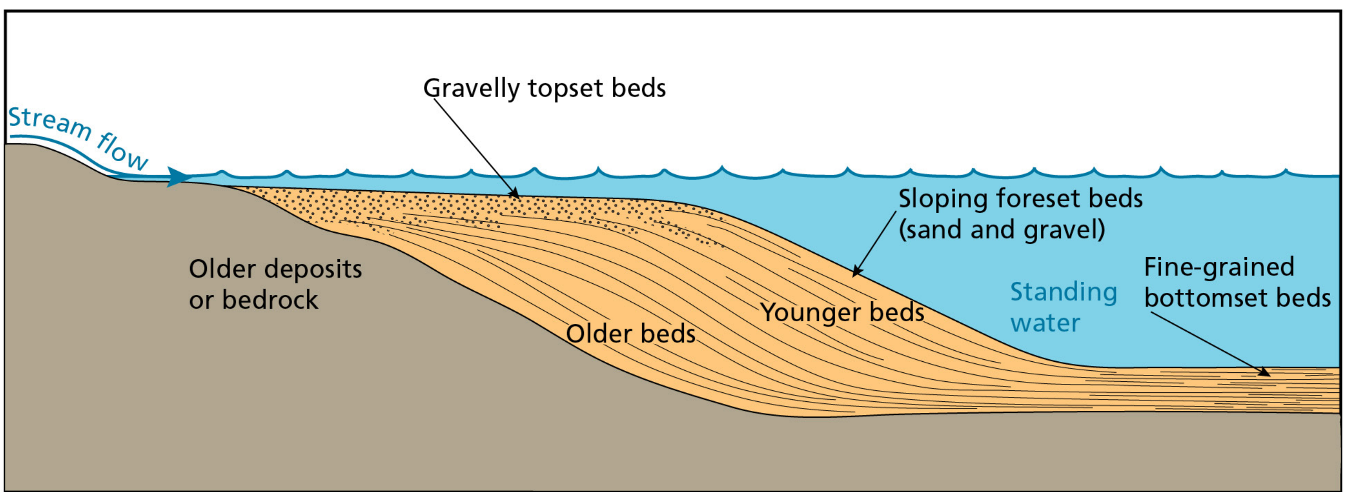



**Figure 14. Diagram of Gilbert delta characteristics.**
**Deltaic deposits are characterized by the presence of topset, foreset, and bottomset beds. Topset and foreset beds develop when high energy flows enter a lower–energy water environment. As the water's velocity drops, the sand and gravel that were transported along the bed of the channel as bedload come to a stop, resulting in deposition. The deposits accumulate in layers at an incline along the floor of the lake or sea. As time passes, subsequent deposition occurs on top of the previous foreset beds, creating topset beds. Fine-grained material such as mud and silt remains in suspension longer, and settles out in nearly horizontal layers farther from shore in the lower energy environment, creating bottomset beds. At Cuyahoga Valley National Park, glacial lakes accumulated thick deltaic deposits that are exposed in the valley walls today. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), after a figure by Tvelia (date unknown).**

## Bedrock Exposures

"Bedrock" is the solid old rock that underlies the younger unconsolidated surficial and glacial deposits of the park. Bedrock is dramatically exposed in several areas of the park including Brandywine Falls and The Ledges, as well as in some roadcuts, ravines, and cliffs. Bedrock can be sedimentary, igneous, or metamorphic. Sedimentary rocks form from fragments of other rocks or chemical precipitation (table 4). Igneous rocks form by the cooling of molten material. Metamorphic rocks are those that have been altered by high temperature, high pressure, and/or fluids. Only sedimentary rocks are present in bedrock outcrops in the park. Three main types of sedimentary rocks are clastic, chemical, and organic. Clastic sedimentary rocks are the products of weathering, erosion, transportation, and deposition of rock fragments called "clasts." Chemical sedimentary rocks form when ions (microscopic particles of rock dissolved during chemical weathering) precipitate out of water. Organic sedimentary rocks are composed of organic remains (e.g., coal) or were produced by the physiological activities of an organism (e.g., secretion of calcium carbonate to form limestones of coral reefs). The bedrock exposures within Cuyahoga Valley National Park includes layers of all three major sedimentary rock types and provide geologists with invaluable study areas in a region that is largely covered and obscured by unconsolidated glacial deposits (fig. 15; Thornberry-Ehrlich 2010).

A geologic formation is named for a geographic feature, such as a stream, road, or town located near its type locality, a geographic location where a rock formation is best displayed or first described. More particularly, an outcrop may display the formation so well as to become a reference location referred to as "type section." Type localities and type sections have both scientific and educational significance. Because type localities and type sections commonly occur where a formation was originally described and named, they also may have historical significance. Many of the geologic map unit names in the GRI GIS data refer to local geographic features and some were named for locations in the parks, as summarized on table 3. Information about any named geologic unit may be found at the USGS Geolex service: https://ngmdb.usgs.gov/Geolex/search.

More research is needed locally to sort the intricacies of the depositional history of the bedrock. The depositional setting of the Devonian, Mississippian, and Pennsylvanian rocks was extremely complex shifting from shallow seas, to deeper water marine, to fluvial-deltaic, to braided streams and back again. Geologists continue to refine the geologic history of these rocks and thereby the entire region. The Bedford Formation and Berea Sandstone were long considered to be Mississippian in age but were recently reassigned a Devonian age based on fossil conodont remains. In 2019, the GRI GIS data was updated to reflect this change.

**Table 4. Sedimentary rock classification and characteristics.**

* Claystones and siltstones can also be called "mudstone," or if they break into thin layers, "shale."
**Carbonate classification is based on Dunham's textural classification scheme (Dunham 1962).

| Sedimentary Rock Type | Rock Name | Texture | Depositional Environment | Cuyahoga Valley National Park geologic map unit examples |
|---|---|---|---|---|
| Inorganic Clastic | Conglomerate (rounded clasts) Breccia (angular clasts) | Clast size: >2 mm (0.08 in) | Higher Energy (swift river currents; strong winds) | Layers in **PNap** include congolomerate |
| Inorganic Clastic | Sandstone | Clast size: 1/16–2 mm (0.0025–0.08 in) | Higher Energy (swift river currents; strong winds) | Layers in **Dbb**, **Mc**, and **PNap** |
| Inorganic Clastic | Siltstone | Clast size: 1/256–1/16 mm (0.00015–0.0025 in) | Lower Energy (floodplains, lagoons, lakes) | Layers in **Dbb**, **Mc**, and **PNap** |
| Inorganic Clastic | Claystone | Clast size: <1/256 mm (0.00015 in) | Lower Energy (floodplains, lagoons, lakes) | Layers in **Doh**, **Dbb**, **Mc**, and **PNap** |
| Carbonate Clastic | Fossiliferous Limestone | Generic name for carbonate rock containing fossils | Primarily marine | Layers in **Doh** |
| Carbonate Clastic | Crystalline | Crystal supported; no fossil fragments, carbonate grains, or carbonate mud | No depositional features can be recognized | None mapped |

**Table 4, continued. Sedimentary rock classification and characteristics.**

| Sedimentary Rock Type | Rock Name | Texture | Depositional Environment | Cuyahoga Valley National Park geologic map unit examples |
|---|---|---|---|---|
| Carbonate Clastic | Boundstone | Composed entirely of fossils, fossil fragments, or carbonate mud fragments cemented together | Higher Energy Settings Bound together during deposition (ie., reefs) | None mapped |
| Carbonate Clastic | Grainstone | Grain (i.e., fossil fragments) supported with no carbonate mud | Intermediate Energy Settings Bound together following deposition | None mapped |
| Carbonate Clastic | Packstone | Grain (i.e., fossil fragments) supported with some carbonate mud | Intermediate Energy Settings Bound together following deposition | None mapped |
| Carbonate Clastic | Wackestone | Carbonate mud supported with more than 10% grains and less than 90% carbonate mud | Intermediate Energy Settings Bound together following deposition | None mapped |
| Carbonate Clastic | Mudstone | Carbonate mud supported with less than 10% grains and more than 90% carbonate mud | Lower Energy Settings Bound together following deposition | Layers in **Doh**, **Dbb**, **Mc**, and **PNap** |
| Chemical | Limestone (Carbonate Mud) | Generic name. Formed by the precipitation of calcium (Ca) and carbonate ($CO_3^{2-}$) ions from water | Freshwater (i.e., lakes) or marine environments | Layers in **Doh** |
| Chemical | Travertine | Precipitation of calcium (Ca) and carbonate ($CO_3^{2-}$) ions from freshwater | Terrestrial springs | None mapped |
| Chemical | Dolomite | Precipitation of calcium (Ca), magnesium (Mg), and carbonate ($CO_3^{2-}$) ions from water | Post-depositional alteration of limestone by Mg-rich ground-water or direct precipitation in shallow marine environments | Layers in **Doh** |
| Chemical | Evaporites (i.e., gypsum) | Precipitation of salts to form evaporite minerals | Hot, dry environment | None mapped |
| Chemical | Oolite | Precipitation of calcium carbonate in thin spherical layers around an original particle (i.e., fossil fragment) | Shallow marine environment; particles are rolled back and forth by the constant motion of tides or waves | None mapped |
| Organic | Coal | Peat (partly decomposed plant matter) is buried, heated, and altered over time | Lagoon, swamp, marsh | Layers in **PNap** |

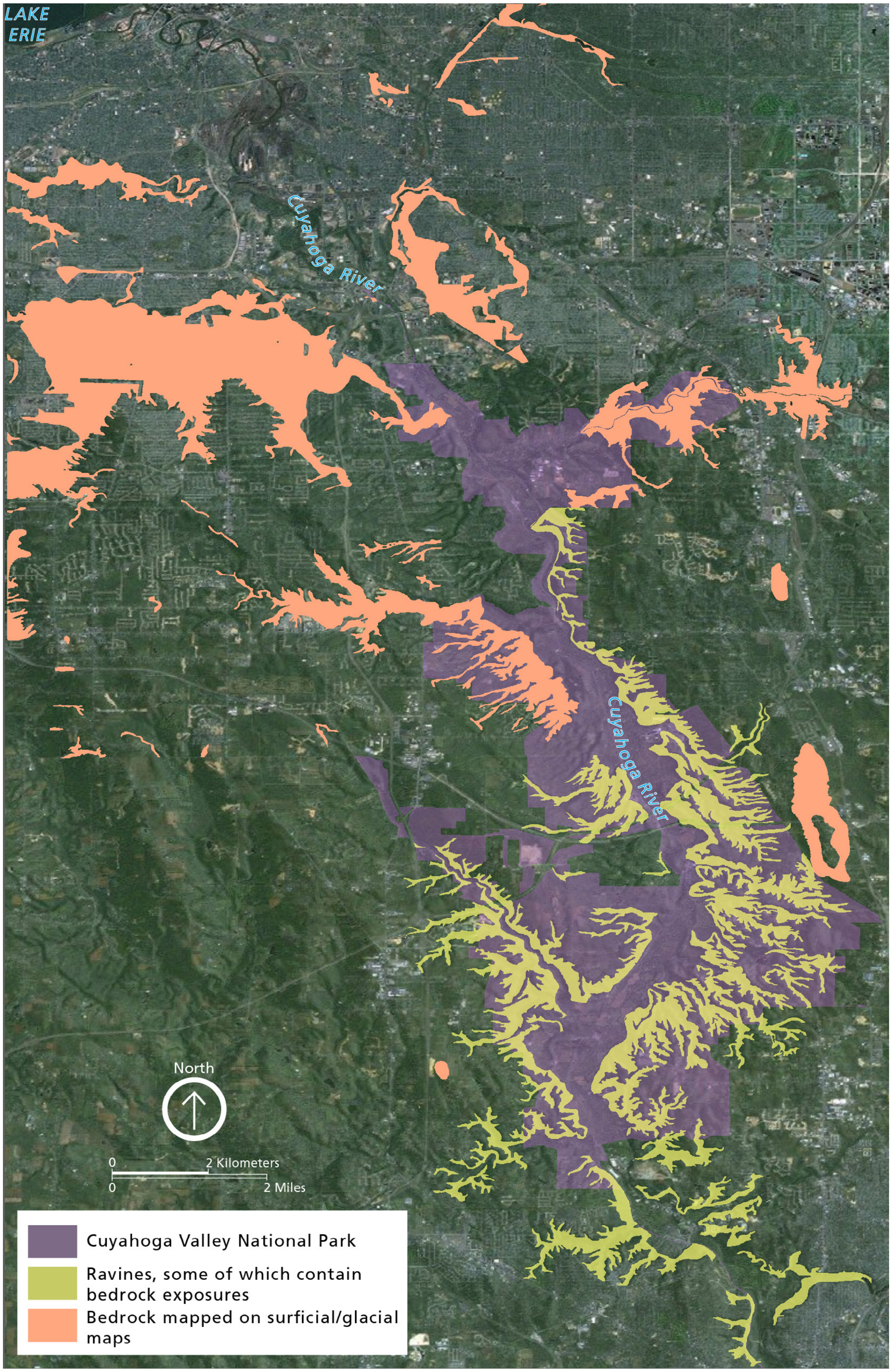



**Figure 15. Map overlay showing bedrock exposures and ravines in Cuyahoga Valley National Park. Bedrock is exposed in some ravines. The bedrock units mapped on the "sucu" data set, and shown in this figure, are well exposed in their mapped area. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) GRI GIS data and ESRI World Imagery basemap.**

## Ancient Sedimentary Features

Sedimentary rocks are particularly useful as records of geologic history. Certain depositional environments yield characteristic features in sedimentary rocks as testament of their setting. For example, high energy depositional environments, such as fast-moving streams, deposit larger (heavier) clasts while transporting smaller (lighter) clasts. The larger sand and gravel size clasts settle out to eventually lithify (solidify) into sandstone or conglomerate, respectively. Where water moves slowly or is stagnant, such as in lakes, the water cannot transport even the smallest clasts and they are deposited as clay layers, which become shale. Wind also transports and deposits sand-sized or smaller clasts. Detailed descriptions of the bedrock map units are available in the ancillary map information document (cuva_geology.pdf) in the GRI GIS data. Fossils are found in many of the bedrock units within the park (see "Paleontological Resource Inventory, Monitoring, and Protection").

The Berea Sandstone (geologic unit **Dbb**, **MDcbb**, **Db**, and **PNDsc**), described in detail by Duncan and Wells (1992), contains large cross beds and other sedimentary features that appear to be channels, but could also be soft-sediment slumps. Hypothesized depositional environments range from tidal zones to delta lobes to fluvial channels. This formation also locally contains excellent examples of soft sediment deformation including microfaults (see fig. 16) and mini-diapirs (domed core of sediment that moved upward to pierce the overlying layers). The Berea is nearly devoid of fossil remains which is also enigmatic given its depositional setting and the fossiliferous nature of the underlying and overlying units (Thornberry-Ehrlich 2010). The Chagrin Shale and Cleveland Shale members of the Ohio Shale (**Doh**, and **Ds**) contain organic muds and dark layers indicative of anoxic seas. These shales are black, fissile, carboniferous, radioactive (pose a radon threat; see "Geologic Hazards") and may be petroliferous (Thornberry-Ehrlich 2010 from written communication M. Angle, Ohio Division of Geological Survey, geologist, 2009). The Bedford Formation (**Dbb**, **MDcbb**, and **Ds**) has abundant oscillation ripples, formed as waves washed back and forth in shallow marine settings. The Bedford also has sole markings or narrow, linear furrows that formed as current-impelled objects gouged soft marine muds (Corbett and Manner 1988). Depositional features within the Sharon Conglomerate (**PNap**, **PNDsc**, and **PNp**) are tricky as they tend to appear as channels in a high energy environment, but careful study reveals these may be slump or eddy features. Much of the unit is sandy, braided river barform deposits (Ninke and Evans 2002; John Peck, geologist, University of Akron, written communication, 16 August 2018). The conglomerate has classic examples of overlapping, overturned cross beds (fig. 17) and many seep zones at the base of coarser, pebble-rich facies visible as stained areas on cliff faces (figs. 16 and 18). The source area for the quartz arenite of the Sharon Conglomerate is also an unusual geologic story (Foos 2003). The Appalachian orogenies were providing source material for rocks to the east and west of the mountains, but the quartz-rich Sharon Conglomerate is too pure (i.e. does not contain enough feldspar or other minerals) to be realistically sourced from the east. The quartz pebbles likely came from the north. These quartzite pebbles in part may have been recycled or eroded and redeposited many times (Thornberry-Ehrlich 2010 from written communication M. Angle, Ohio Division of Geological Survey, geologist, 2009).

## Bedrock Caves

Caves are naturally occurring underground voids that are sufficiently large for human entry and sufficiently long to extend into darkness. Many types of cave exist, and they vary in size, origin, and appearance. They include solution caves (commonly associated with karst), volcanic or lava tubes, sea caves, talus caves (voids among collapsed boulders), regolith caves (formed by soil piping), and glacier (ice-walled) caves (Palmer 2007; Toomey 2009). Caves and bedrock crevices may provide habitat for bats and other animals. In particular, outcrops of the Sharon Conglomerate (**PNap**, **PNDsc**, and **PNp**) have joints and crevices that provide ample roosting habitat for bats (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). As of September 2019, cave and/or karst resources are documented in 159 NPS areas, including Cuyahoga Valley National Park, which has at least two bedrock caves, Icebox Cave in the Virginia Kendall Ledges and Deer Lick Cave in the Brecksville Reservation (has cave formations or speleothems), as well as many sandstone rock overhang caves (Thornberry-Ehrlich 2010). Ice Box Cave has a square-shaped opening formed along joints and fractures within the Sharon Conglomerate (fig. 19). It formed where a seep emerged along joints and bedding and the blocks of rock pulled apart (Thornberry-Ehrlich 2010).

Speleothems in Deer Lick Cave are vulnerable to damage and vandalism. Ice Box Cave has approximately 18 m (60 ft) of passageway that becomes very narrow, slippery, and treacherous. Visitors have become trapped in the cave and have had to be rescued (Thornberry-Ehrlich 2010). National Park Service (2013) identified overuse at Ledges and Ice Box Cave as threats to the condition of the park's fundamental resources. The

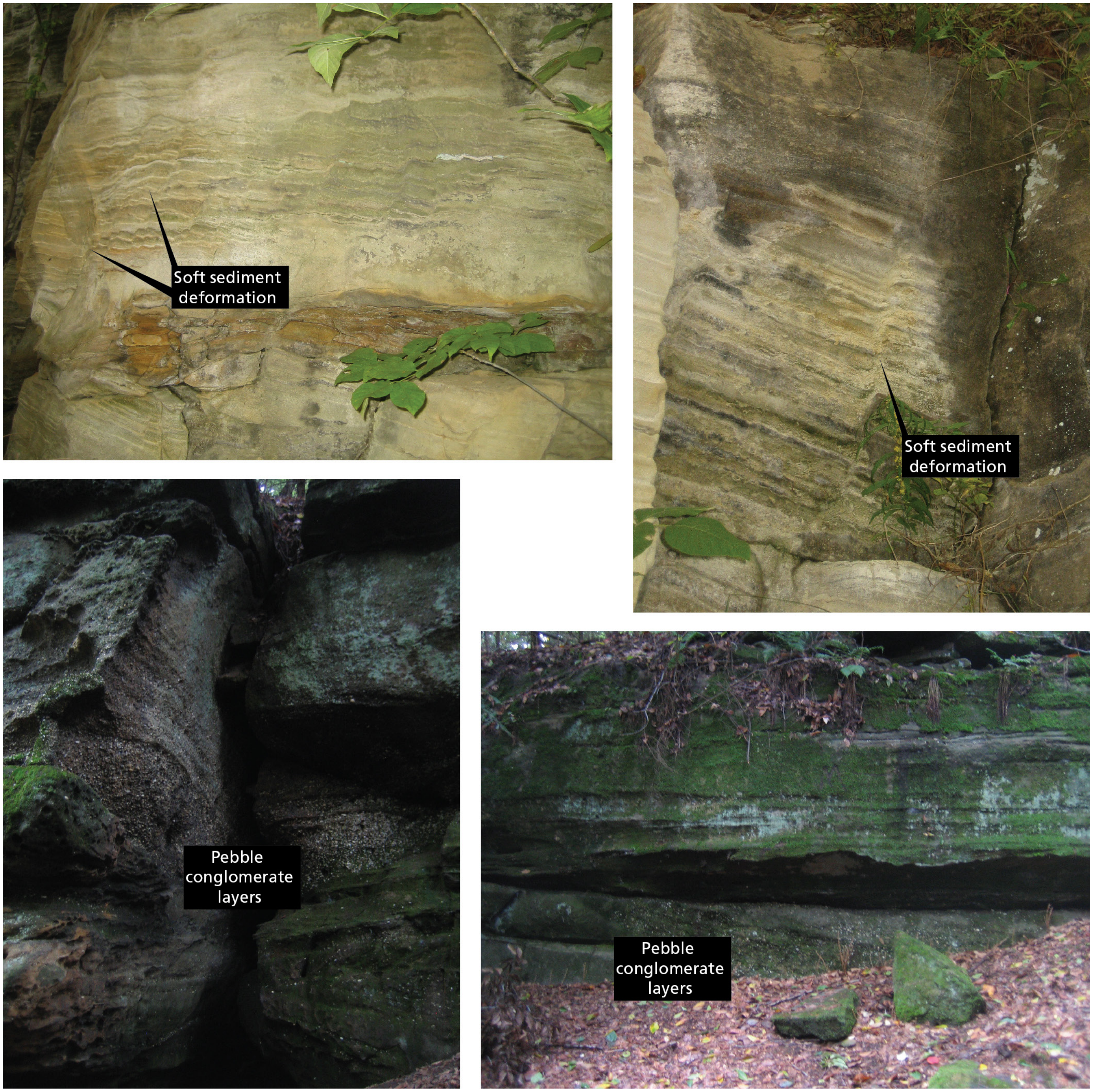



**Figure 16. Photographs of soft sediment deformation and pebble conglomerates.**
**The sedimentary bedrock units at the national park include soft-sediment deformation features, pebble conglomerates, ripple marks, cross beds. The upper two photographs are in Berea Sandstone; the lower two photographs are in the Pottsville Group, Sharon conglomerate. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

park identified the need to stabilize the slab of rock at the ceiling entryway to Ice Box Cave. A mine safety inspector from the Ohio Department of Natural Resources recommended using long bars, drilled into the side walls, directly beneath the ceiling. Once the entrance is stabilized, other reaches of the cave can be evaluated for stabilization needs (National Park Service 2013b). The entrance to Ice Box Cave is gated and signage indicates to visitors that the cave is closed to entry due to threat of white nose syndrome to the local bat population. It is probable the cave will not reopen (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). Refer

**Figure 17. Photograph of overturned crossbeds and petroglyphs in the Sharon Conglomerate. These petroglyphs near the Ledges area are not older American Indian petroglyphs; these are more recent. The sandstone layer above the petroglyps displays overturned crossbeds formed by shear by subsequent flows on already deposited sediment (John Peck, geologist, University of Akron, written communication 16 August 2018). Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

to the NPS white nose syndrome website for additional information: https://go.nps.gov/wns.

Cave features are non-renewable resources. As noted in the NPS 2006 Management Polices (§4.8.2.2), in accordance with the Federal Cave Resources Protection Act of 1988, recreational use of undeveloped caves will be governed by a permit system, and cave use will be regulated or restricted if necessary to protect and preserve cave resources. Under 43 CFR Part 37 regulations for the act, all caves in the national park system are deemed to be significant. As further established by this act, specific locations of significant cave entrances may be kept confidential and exempted from FOIA requests.

The following resources may provide further guidance for karst management:

- National Cave and Karst Research Institute: http://www.nckri.org/.
- NPS Geologic Resources Division Cave and Karst Resources website: https://www.nps.gov/subjects/caves/index.htm
- In the *Geological Monitoring* chapter about caves and associated landscapes, Toomey (2009) described methods for inventorying and monitoring cave-related vital signs, including the following: (1) cave meteorology, such as microclimate and air composition; (2) airborne sedimentation, including dust and lint; (3) direct visitor impacts, such as breakage of cave formations, trail use in caves, graffiti, and artificial cave lighting; (4) permanent or seasonal ice; (5) cave drip and pool water, including drip locations, rate, volume, and water chemistry, pool microbiology, and temperature; (6) cave microbiology; (7) stability issues associated with breakdown, rockfall, and partings; (8) mineral growth of speleothems, such as stalagmites and stalactites; (9) surface expressions and processes that link the surface and the cave environment, including springs, sinkholes, and cracks; (10) regional groundwater levels and quantity; and (11) fluvial processes, including underground streams and rivers.


**Figure 18. Photographs of ripple marks and cross beds.**
**The sedimentary bedrock units at the national park include soft-sediment deformation features, pebble conglomerates, ripple marks, cross beds. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

**Figure 19. Photograph of the opening to Ice Box Cave.**
**The cave formed as joints in the bedrock spread apart and blocks of bedrock fell into the opening. The cave is formed in the Sharon Conglomerate (geologic map unit PNap). The cave now has a metal (bat) gate across the entrance and is closed due to white-nose syndrome. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

## Groundwater Availability

Despite the presence of many localized, perched groundwater lenses, the overall lack of widespread groundwater resources in the Cuyahoga River valley strongly influenced the human history here. People settled in larger numbers where wells would produce reliable groundwater. Those that chose to settle in the valley often manipulated or engineered the system to retain surface water (e.g., damming drainages to create farm ponds; see "Lacustrine Features and Wetlands"). The lack of abundant groundwater precluded heavy settlement of the area and ultimately ensured a tract of relatively natural land was available for the formation of the national park (Thornberry-Ehrlich 2010 Hydrogeologists refer to the local setting as the 'glaciated central;' it is characterized by a complex network of buried valley systems across the area. An extensive network of pre-glacial and interglacial (between glaciations) rivers created the buried valleys that incised the bedrock before being buried with glacial deposits. Groundwater yields are therefore highly variable spatially and vertically (i.e., perched false water tables) (Angle et al. 2003; Nash 2009). One aquifer site at the former Jaite Mill historically pumped 500 gallons per minute (gpm) from fairly coarse, thick sand and gravel outwash deposits (e.g., geologic map unit **Wsg**, **Wlg**; Pavey et al. 2000; Angle et al. 2003; Nash 2009; Thornberry-Ehrlich 2010). Local aquifers also include poor quality shale aquifers, and glacial lake deposits (clay-rich) aquifers that may only yield 5 gpm (Angle et al. 2003; Nash 2009; Thornberry-Ehrlich 2010). The Ohio Statewide Aquifer Mapping Program lists four state-classified unconsolidated aquifers for the park: Cuyahoga complex aquifer, Cuyahoga buried valley aquifer, and Brecksville thin upland aquifer. Their maps are available at: http://water.ohiodnr.gov/maps/statewide-aquifer-maps.

Highly fractured sandstones (e.g., **PNap**) may yield as much as 100 gpm to wells depending on the proportion of sandstones to finer grained rocks and fracture abundance (Swinford et al. 2003; Angle et al. 2003). Regional joint sets, commonly intersecting at 90° angles (fig. 20), are nearly omnipresent in both the shales and coarser bedrock units throughout the park. Their exact origin is still a matter of debate. These joints strongly influence the permeability of the bedrock units. The bedrock aquifers, because of their dependence on fractures, are susceptible to anthropogenic changes. For example, local blasting to build the Ohio Turnpike through the park changed the groundwater paths. The groundwater essentially drained out through the newly blasted roadcuts (Thornberry-Ehrlich 2010). Abundant groundwater resources occur south of Cuyahoga Valley National Park, across an ancient drainage divide that predates the Pleistocene glaciations, within a buried river valley in Akron (Thornberry-Ehrlich 2010).

**Figure 20. Photograph of jointed bedrock near Mary Campbells Cave.**
**Through-going joints and fractures provide conduits for trickling groundwater as well as provide planes of weakness that preferentially weather and may break when the stress is applied to the bedrock. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

According to groundwater resource maps from the Ohio Division of Geological Survey website (http://geosurvey.ohiodnr.gov/major-topics/ground-water-hydrology#MAP), scant water-well data are available for the central part of the Cuyahoga Valley (Thornberry-Ehrlich 2010). Understanding vulnerability to groundwater contamination is an important resource management goal at Cuyahoga Valley National Park. Detailed knowledge of the complex hydrogeologic system of the valley remains a resource management need. Knowledge of the presence and extent of buried valleys and the composition of the local glacial deposits are critical. Geophysical techniques including resistivity and seismic surveys may be used to determine the depth of unconsolidated material over bedrock in areas where reliable water well or oil and gas well data are lacking (Thornberry-Ehrlich 2010). Angle et al. (2003) presented a groundwater pollution potential map for Summit County using a scheme that takes into account: depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media, and hydraulic conductivity of the aquifer. Mapped hydrogeologic settings include (1) glacial till over bedded sedimentary rocks, (2) glacial till over sandstone, (3) glacial till over shale, (4) sand and gravel interbedded in glacial till, (5) outwash, (6) outwash over bedded sedimentary rock, (7) buried valley, (8) alluvium over bedded sedimentary rock, (9) alluvium over glacial till, and (10) thin glacial till over bedded sedimentary rock (Angle et al. 2003). Similar methods could be applied to the entire park to understand how

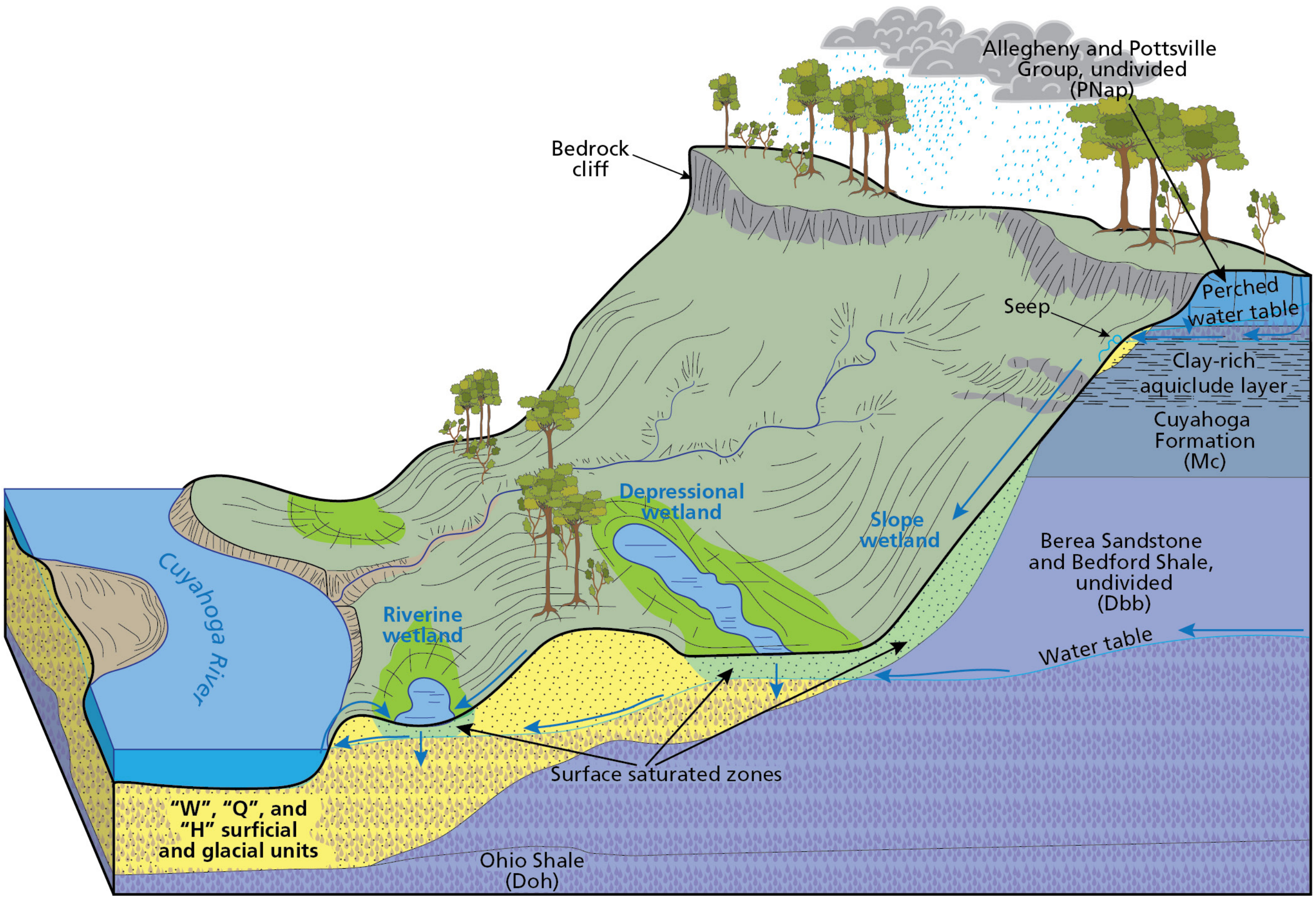



**Figure 21. Cross-sectional view of wetland types across Cuyahoga Valley.**
**Three major types of wetlands occur in different settings throughout Cuyahoga Valley National Park: riverine, depressional, and slope wetlands. Underlying geology controlling topography and groundwater chemistry, availability, and movement influences the formation and longevity of wetlands in the park. Graphic adapted from figure 3 in Bingham et al. (2016) by Trista L. Thornberry-Ehrlich (Colorado State University).**

groundwater is circulating to help direct resources and land use activities to appropriate areas or assist in protection, monitoring, and restoration efforts (Angle et al. 2003). During the restoration of the Krecji site, deep well monitoring data were collected and are available to park resource managers (Sonia Bingham, wetland biologist, Heartland Network, conference call, 8 February 2018); similar monitoring at other wells may provide parkwide hydrologic information.

## Lacustrine Features and Wetlands

"Lacustrine" refers to lakes and deposits that accumulate in standing water. Because of a lack of reliable groundwater in the area, many early settlements created earthen dams to impound ponds to use as their water supply—at least 70 manmade ponds were once part of the park (Thornberry-Ehrlich 2010). Within Cuyahoga Valley National Park, several manmade ponds are managed as lake features. Cockrell (1992) described 65 ponds within the park that were analyzed and less than 12 that were retained for recreational use by 1987, including Kendall Lake, Horseshoe Pond, Goosefeather Pond, Indigo Lake, and Armington Pond. Ponds with unacceptable dissolved oxygen, depth, and size were removed and restored.

Wetlands (fig. 21) are transitional areas between land and water bodies, where water periodically floods the land or saturates the soil and includes marshes, swamps, seeps, pools, and bogs. Wetlands in the park are covered in shallow surface water or have water within the root zone most of the year or are wet only seasonally. Wetlands provide several significant functions, including (1) provision of bird and other wildlife habitat, (2) surface water detention, (3) nutrient transformation, and (4) retention of sediments. Wetlands at Cuyahoga Valley National Park reduce flooding (Bingham et al. 2016). Over 485 ha (1,200 ac)

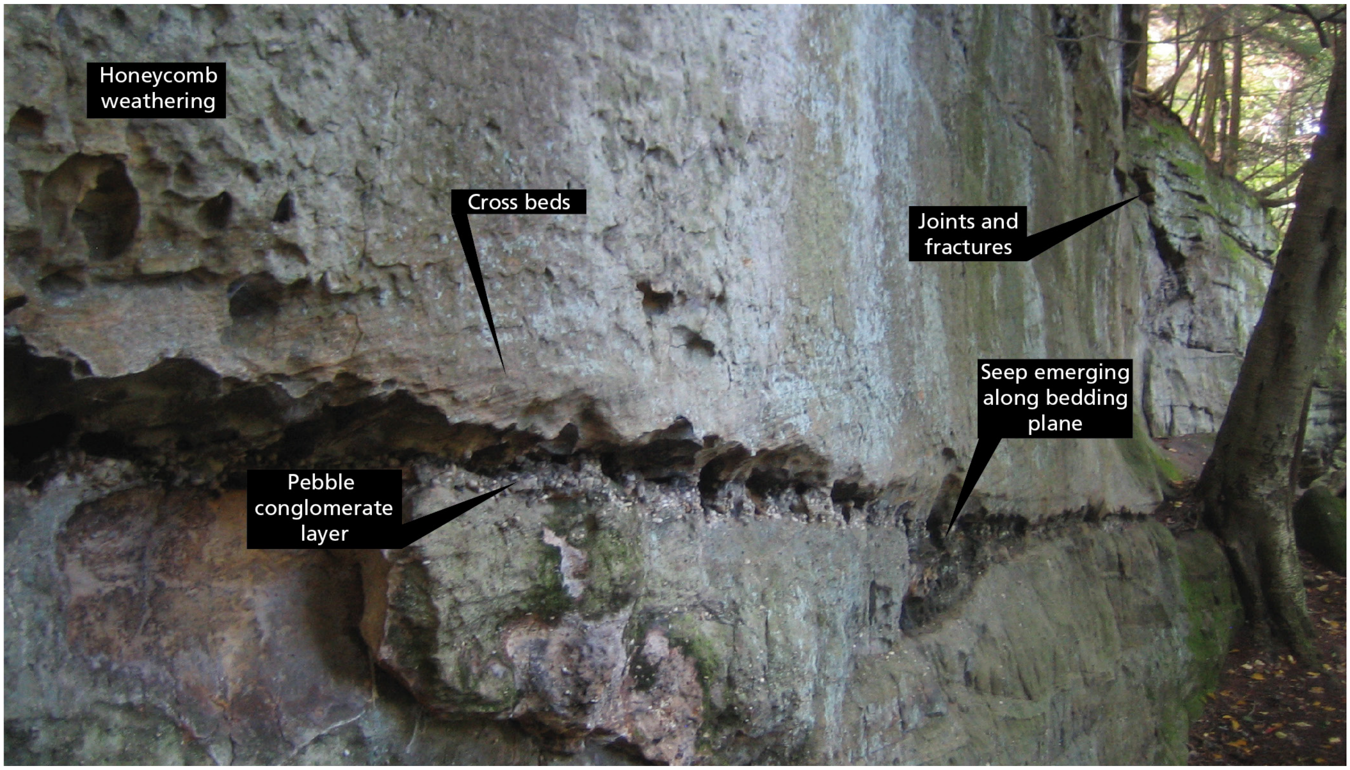



**Figure 22. Photograph of groundwater seeping along a bedding plane.**
**Certain layers within the local bedrock are more permeable than others. In this instance, water percolating through joints and fractures intersects a horizontal layer that is more permeable (e.g., pebble conglomerate) than the layer below it and flows laterally to emerge on a nearly vertical bedrock face. Honeycomb weathering may be a result of cyclic wetting and drying of the bedrock. Location is Virginia Kendall Ledges within the Allegheny and Pottsville Group, undivided (PNap). Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

of wetlands occur in the park (Thornberry-Ehrlich 2010). Three dominant wetland types are present: about 350 riverine wetlands adjacent to river and stream courses with alluvial soil characteristics, about 700 headwater and slope wetlands near seeps with peat-rich soils, and about 350 depression wetlands where topography and clay-rich soil substrates create an area for water to accumulate and stay (Thornberry-Ehrlich 2010; Bingham et al. 2016). These dominant types are clearly connected with the underlying geologic foundation of the park (figs. 21 and 22).

Wetlands are typically only mentioned in GRI reports where particular geologic connections exist to their development or resource management. The NPS Water Resources Division (https://go.nps.gov/waterresources) is the primary contact for technical and policy assistance regarding wetlands. Preserving, protecting, and restoring natural and significant artificial wetlands was identified as a primary resource management goal in National Park Service (1999). Bingham et al. (2016) prepared a wetland monitoring protocol for the park's nearly 2,000 wetlands, including intensive surveys, hydrological data, water chemistry, water levels, and vegetation indices of biotic integrity. Their methods were applied to chosen wetlands of management concern (e.g., Pleasant Valley, Fawn Pond, Stumpy Basin, Virginia Kendall, Beaver March, Rockside, Krejci, and Stanford wetland complexes, as well as a subset of randomly selected wetlands throughout the park). Some wetlands occur because of artificial dams. These dams may flood or fail (e.g., Haskell Run dams have failed at least five times). Dams are discussed further in "Abandoned Mineral Lands and Disturbed Lands". As of 2018, 100 wetlands are monitored in the park for biological health, water levels, eight years of well data exist, and the park has access to an extensive wetlands GIS layer (Sonia Bingham, wetland biologist, Heartland Network, conference call, 8 February 2018).

### Geologic Hazards

Primary resource management issues in the park are geologic hazards from slope movements and earthquakes. Radon is an additional hazard. A geologic hazard ("geohazard") is a natural or human-caused geologic condition or process that may impact park resources, infrastructure, or visitor safety. Risk is the probability of a hazard to occur combined with the expected degree of damage or loss that may result from exposure to a hazard, or the likelihood of a hazard causing losses (see Holmes et al. 2013).

### *Slope Movements and Erosion*

Slope movements, also called "mass movements" or referred to generally as "landslides", have occurred and will continue to occur the park. Slope movements are the downslope transfer of material (e.g., soil, regolith, and/or rock) (figs. 23 and 24). Slope movements can occur rapidly (e.g., debris flows or rockfall) or over long periods of time (e.g., slope creep). The magnitude of slope failures depends on slope, aspect, soil type, and geology. Within the park, much of the landscape is moderate to steep slopes including bedrock or glacial-deposit lined ravines.

Heterogenous glacial deposits ("**W**" glacial and surficial geologic map units) are particularly unstable on slopes or when undercut by erosion (White 1984; Ford 1987; Pavey et al. 2000). State Route 303 buckles due to the high silt and clay content of the underlying glacial deposits; homes along Riding Run experienced "exploding" windows due to internal stresses imposed by glacial-deposit foundation issues. Yellow Creek area is particularly unstable and should be carefully considered for any future use (Thornberry-Ehrlich 2010). Slope creep has hastened trail closures in the Wetmore system. The Old Carriage Trail has erosion and slumping issues (Thornberry-Ehrlich 2010).

The resistant sandstones and conglomerates (e.g., **PNap**, **PNp**, **PNDsc**) that form the caprock for many of the upland areas and waterfalls are prone to blockfalls when undercut by the erosion of softer, underlying units (Swinford et al. 2003). Pervasive joint sets, commonly intersecting at 90° angles in these resistant units, form natural spalling surfaces. Tree-root wedging and frost weathering also cause bedrock instability in Cuyahoga Valley (Thornberry-Ehrlich 2010). Blockfall was a recent issue along the Blue Hen Falls trail at Boston, Ohio. Blockfall also occurred at The Glens area of Tinkers Creek within the Bedford Reservation. The Ritchie Ledges area of the park offers great examples of blockfall processes and results. Weathering and mass wasting of the Devonian shales at Station Road Bridge trailhead (near the Brecksville Station and Chippewa Road) causes slumping over the railroad tracks (Thornberry-Ehrlich 2010).

Throughout much of Cuyahoga Valley National Park, thick glacial-deltaic and glacial-lacustrine deposits frequently form active slumps and debris flows (figs. 23 and 24). These slumps supply sediment to the valley causing narrowing of the downstream floodplain (Thornberry-Ehrlich 2010). The sloping uplands within Cuyahoga Valley National Park contribute as much as 60% of the total suspended sediment to the Cuyahoga River system. Erosion of the uplands followed by sedimentation throughout the watershed has been a perpetual problem, particularly at the river's mouth in Cleveland (Cockrell 1992). Keeping upland areas forested and undisturbed is recommended for soil stability and reduced erosion (Cockrell 1992).

If funding permits, resource managers could consider obtaining quantitative information to assess the frequency and magnitude of rockfall (and other slope movements) in high visitation areas. A photomonitoring program is one possibility. The Geoscientist-in-the-Parks program is an option to support such a project. The NPS Geologic Resources Division Photogrammetry website (http://go.nps.gov/grd_photogrammetry) provides examples of how photographic techniques support structural analysis of rockfall areas. The Unstable Slopes Management Program (https://www.nps.gov/subjects/geohazards/managing-risk-and-mitigating-hazards.htm) is a cooperative effort between the National Park Service, Federal Highways, University of Montana and others is working to create a central database of unstable slopes with ranking systems. This database will support an unstable slope management tool to allow prioritization of mitigation to reduce slope hazard risks. The slopes of Cuyahoga Valley National Park would be ideal candidates for inclusion in the effort (contact Eric Bilderback, geomorphologist, NPS Geologic Resources Division).

Unstable soils and slumping were identified as threats to the trail, water, and rail network fundamental resources in the park's foundation document (National Park Service 2013a). The following references provide additional background information, suggested vital signs, and resources for assessing and documenting slope movements:

- In the Geological Monitoring chapter about slope movements, Wieczorek and Snyder (2009) described five vital signs for understanding and monitoring slope movements: (1) types of landslide, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessment of landslide hazards and risks.
- US Geologic Survey publication: The landslide handbook—A guide to understanding landslides (Highland and Bobrowsky 2008)
- US Geological Survey landslides website (http://landslides.usgs.gov/)

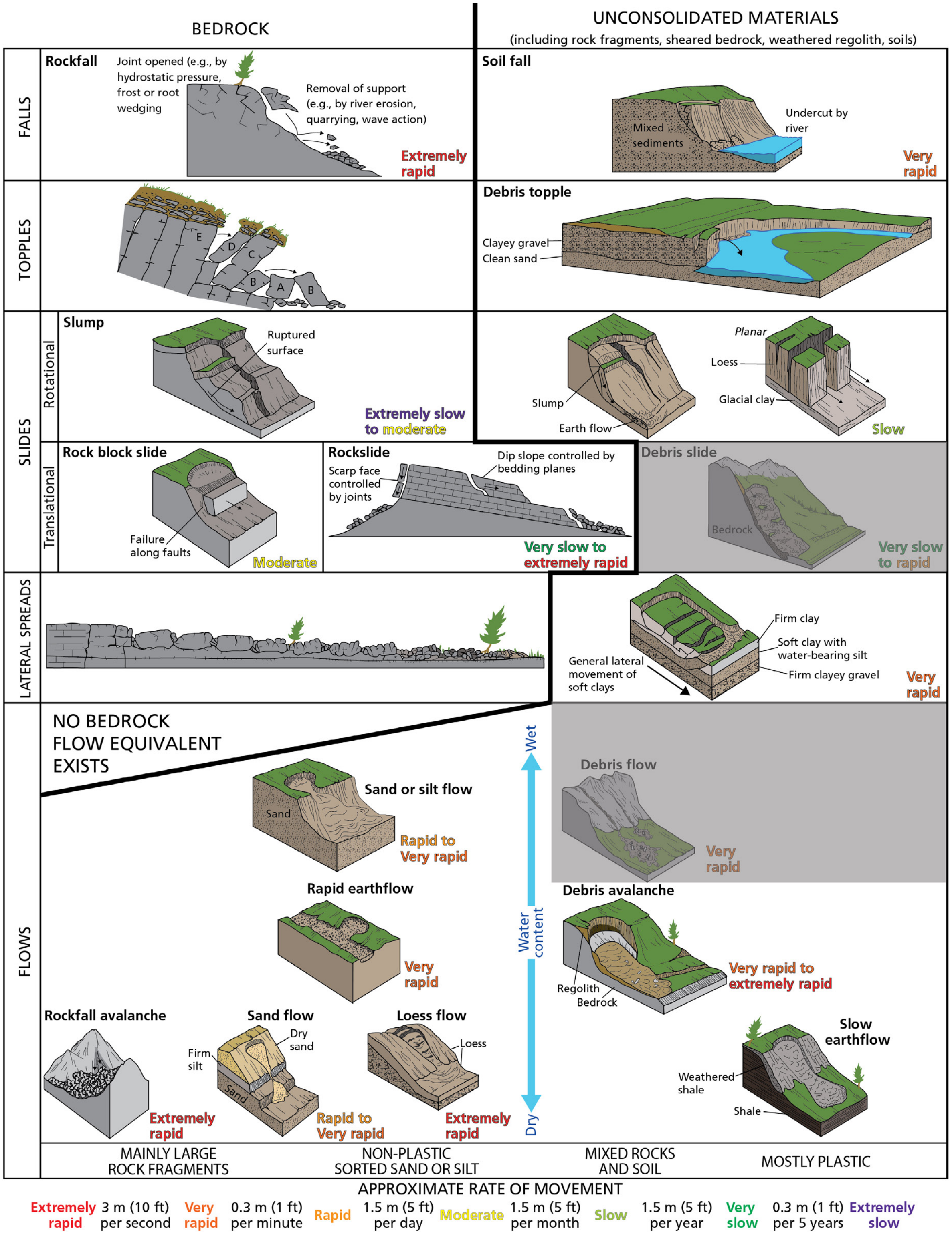



**Figure 23. Illustrations of slope movements.**
**Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at Cuyahoga Valley National Park. The abundant vegetation in the parks stabilizes some slopes, but slope issues could be exacerbated by factors such as natural or anthropogenic removal of vegetation and climate change. Graphic by Trista Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).**

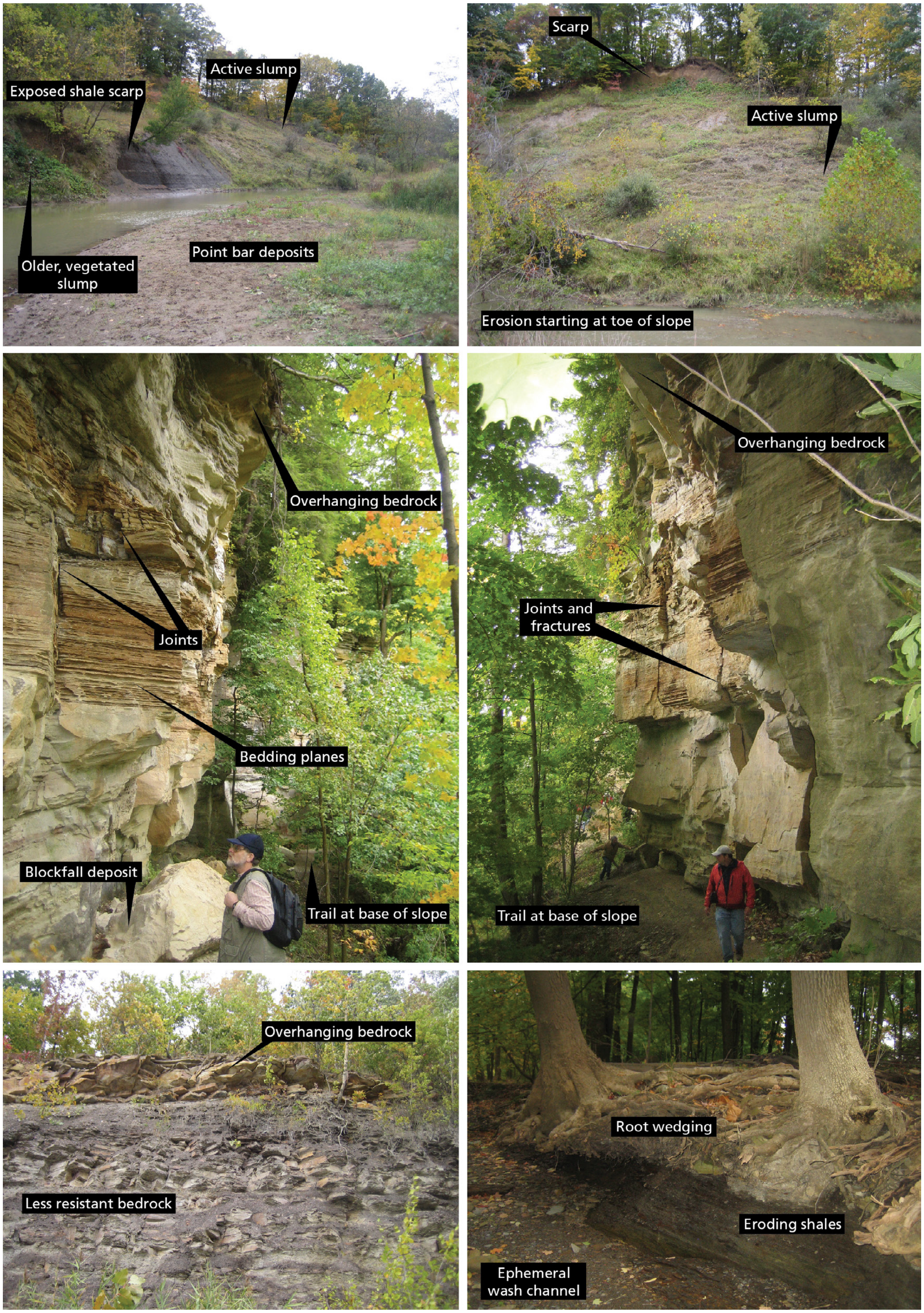



**Figure 24. Photographs of slope movements and eroding areas.**
**Unstable slopes are present within Cuyahoga Valley National Park. Slopes along the river channel are experiencing slumping. Steeper cliffs are prone to blockfall. Bedrock overhanging trails create blockfall hazards and risk for trail users. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

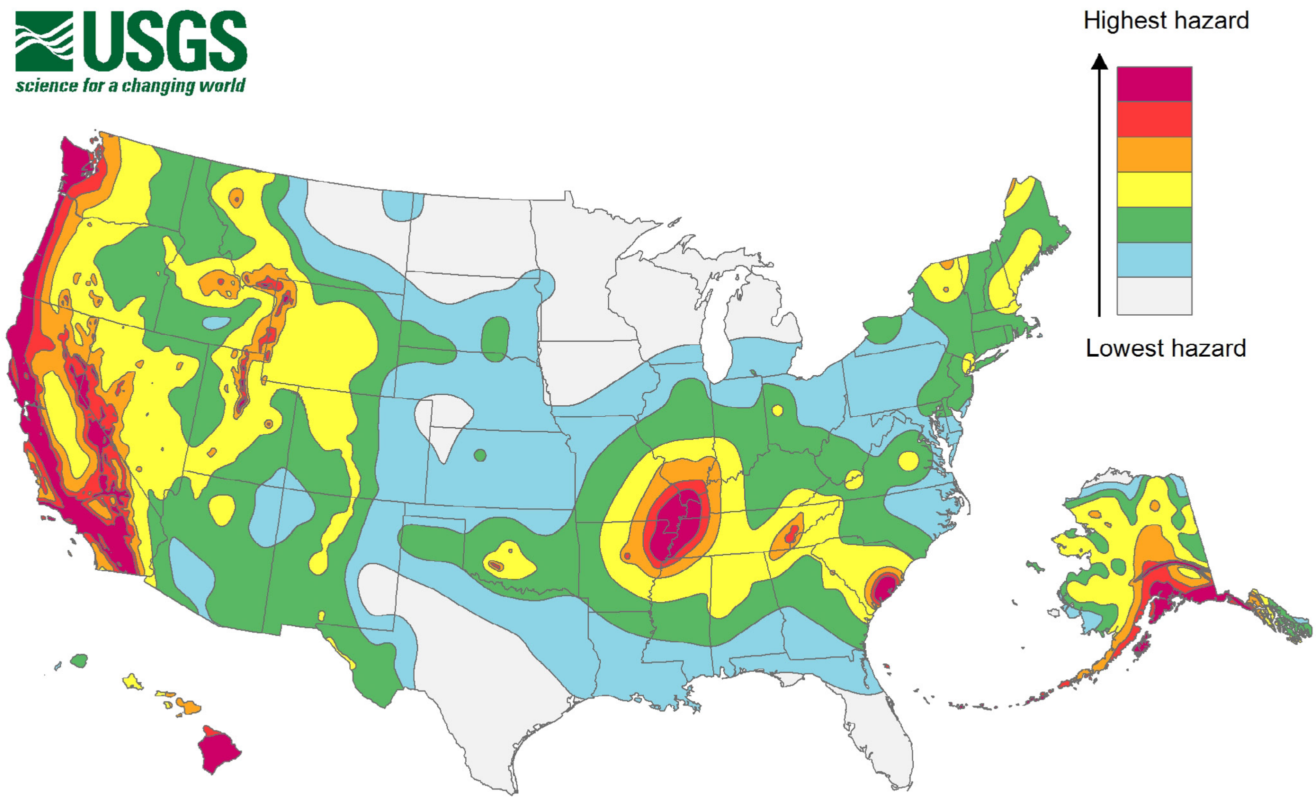



**Figure 25. Map of relative seismic hazard for the United States.**
**Northern Ohio is in an area of lower hazard for an earthquake over the next 50 years. US Geological Survey map produced in 2018, available online: https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map. Additional US Geological Survey earthquake hazard information is available here: https://www.usgs.gov/natural-hazards/earthquake-hazards.**

- NPS Geologic Resources Division Geohazards website (http://go.nps.gov/geohazards)
- NPS Geologic Resources Division Slope Movement Monitoring website (http://go.nps.gov/monitor_slopes)
- Natural hazards science strategy: Holmes et al. (2013)
- Landslide hazards and climate change: Coe (2017)
- County websites (www.co.summit.oh.us and www.cuyahogacounty.us) have slope maps.

### *Earthquakes*

Earthquakes are ground vibrations—shaking—that occur when rocks suddenly move along a fault, releasing accumulated energy (Braile 2009). Earthquake intensity ranges from imperceptible by humans to total destruction of developed areas and alteration of the landscape. The "Richter magnitude" is a measure of the energy released by an earthquake. Earthquakes can directly damage park infrastructure or trigger other hazards such as slope movements that may impact park resources, infrastructure, or visitor safety. Figure 25 shows the relative seismic hazard for the United States over the next 50 years. Northern Ohio is in a lower hazard area. The park is not located near a known active seismic zone; however, earthquakes with magnitudes between 2 and 3 are not uncommon. In 2019, a 4.0 magnitude earthquake struck just north of Eastlake, Ohio near Cleveland. More than 6,000 people felt shaking from this earthquake. More than 100 earthquakes have rattled northeastern Ohio since 1836, but the exact cause of the earthquakes requires more study (Schmidt 2019).

According to geologists at the Ohio Division of Geological Survey, the risk for earthquakes at Cuyahoga Valley National Park is small, but exists. Even moderate seismic shaking could trigger slope movements (e.g., slumps, landslides, and blockfalls). Susceptible areas could include those with unconsolidated glacial deposits exposed on steep and/or undercut slopes, or those with large blocks of jointed rocks perched precipitously on the edge of steep slopes or cliffs (Thornberry-Ehrlich 2010). The Ohio Division of Geological Survey website (http://geosurvey.ohiodnr.gov/) has records of earthquake epicenters over at least the last 55 years. The NPS Geologic Resources Division Seismic Monitoring website (http://go.nps.gov/seismic_monitoring), and the US Geological Survey Earthquakes Hazards website (http://earthquake.usgs.gov/) provide more information about seismic hazards. In the *Geological Monitoring* chapter about earthquakes and seismic activity, Braile (2009) described the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics.

### *Radon*

Radon is a heavier-than-air, colorless, odorless, radioactive gas and a natural decay product from also naturally occurring uranium and thorium in the bedrock and tufa beneath the park. Long term exposure to elevated levels of radon creates an increased risk for lung cancer. Refer to the Environmental Protection Agency (EPA) radon website for additional information: http://www.epa.gov/radon/. Radon naturally accumulates in caves, basements, and other subterranean cavities. Limited air circulation in these spaces concentrates radon gas to levels appreciably higher than outside. The Environmental Protection Agency's (EPA) recommended maximum level of radon gas concentration is 4 picocuries per liter (pCi/L) (EPA 2013). Because radon is naturally occurring, remediation of the threat requires monitoring and ventilation. At Cuyahoga Valley National Park, layers in the Devonian shales (**Doh**, **Ds**) are radioactive and naturally emit radon (Swinford et al. 2003; Thornberry-Ehrlich 2010 from written communication M. Angle, Ohio Division of Geological Survey, geologist, 2009).

The park currently monitors all building basements for radon levels (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). Refer to the Environmental Protection Agency (EPA) radon website for additional information: http://www.epa.gov/radon/.

## Abandoned Mineral Lands

Abandoned mineral lands (AML) are lands, waters, and surrounding watersheds that contain facilities, structures, improvements, and disturbances associated with past mineral exploration, extraction, processing, and transportation, including oil and gas features and operations, for which the NPS takes action under various authorities to mitigate, reclaim, or restore in order to reduce hazards and impacts to resources. According to the NPS Abandoned Mineral Lands (AML) database and Burghardt et al. (2014), Cuyahoga Valley National Park contains 18 AML features at 16 sites. Of these, seven are in Cuyahoga County and the remaining 11 are in Summit County. All sites but one are oil and gas wells; one site is a sand and gravel borrow pit. Thornberry-Ehrlich (2010) listed 90 active oil and gas wells located within Cuyahoga Valley National Park, 37 of which are on National Park Service land, four are on NPS/less than fee lands, and 49 are on private land. As of 2018, no new drilling is planned for within the park (Meg Plona, biologist, Cuyahoga Valley National Park, conference call, 8 February 2018). Fifteen wells within the park remain orphaned and in need of plugging. The National Park Service had plugged 56 wells prior to 2018 with more planned for remediation (Meg Plona, biologist, Cuyahoga Valley National Park, written communication, 9 February 2018). Two shallow shale gas wells are described as "leaking". One well is located in a wetland (see "Lacustrine Features and Wetlands"). Vegetation is described for each site ranging from healthy to struggling to nonexistent. The GRI GIS data include at least 15 mine features (e.g., gravel pits, sand pits, and quarries) within park boundaries (NPS access only). Thornberry-Ehrlich (2010) described several historic quarries and one active quarry within the park boundary (DeGeronimo Aggregates "haydite" quarry in Independence). As of 2018, this quarry is still in operation with different iterations to extend its lease with the city of Independence (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). The Euclid bluestone (coarse facies of the Bedford Shale [geologic map units **Dbb**, **MDcbb**, **Ds**]) was quarried off Granger Road. Indigo Lake is a former quarry. The Hemlock Area, Virginia Kendall Ledges area, and Deep Lock quarry all were quarried historically. The Berea Sandstone (also known as the Berea grit; **Dbb**, **MDcbb**, **PNDsc**, **Db**) was widely quarried for flagstone, building material, marbles, and gristmills (Swinford et al. 2003; Thornberry-Ehrlich 2010). AML Features may include adits, prospects, shafts, structures, open pits, tunnels, waste rock piles, mills, wells, and landform modifications such as service roads, drainage diversions, and drill pads. Cockrell (1992) describes the history of natural resource management at Cuyahoga Valley National Park, including a brief summary of mineral interests.

AML features pose a variety of resource management issues such as visitor and staff safety and environmental quality of air, water, and soil. AML features can also provide habitat for bats and other animals, some of which may be protected under the Endangered Species Act or state species listings. Resource management of AML features requires an accurate inventory and reporting. All AML features should be recorded in the Servicewide AML Database (the NPS Geologic

Resources Division will provide assistance). An accurate inventory identifies human safety hazards and contamination issues, and facilitates closure, reclamation, and restoration of AML features. When appropriate for resource management and visitor safety, AML features can also present opportunities for interpretation as cultural resources (Burghardt et al. 2014). The NPS AML website, http://go.nps.gov/aml, provides further information. The Ohio Division of Geological Survey website (http://geosurvey.ohiodnr.gov/) has locations of active quarries in Ohio.

Mitigating or removing the presence of hazardous materials was identified as a primary goal in the resource management plan as was eliminating, reducing, or mitigating mineral development of remnants of past mineral development in the park (National Park Service 1999). Cockrell (1992) identified oil and gas extraction as a primary threat to the overall health of the national park. Oil and gas exploration is listed as a threat to the fundamental resource or value: forest ecosystem at Cuyahoga Valley National Park (National Park Service 2013a). Objectives stated in the park's resource management plan included inventorying, describing, and monitoring active and inactive mineral development, including oil and gas wells (National Park Service 1999). The park is located on the western edge of the Marcellus Shale—a regional natural gas producing unit; however, interest in drilling the shale has waned recently and resource managers are not currently concerned about new exploration, but plan to remain vigilant (Moss 2009; Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). National Park Service regulations at 36 CFR Part 9, Subpart B (the "9B" regulations) require the owners/operators of nonfederally owned oil and gas rights to (1) demonstrate bona fide title to mineral rights; (2) submit a plan of operations to NPS describing where, when, how they intend to conduct operations; (3) prepare/submit a reclamation plan; and (4) submit a bond to cover reclamation and potential liability. The Ohio Division of Geological Survey website (http://geosurvey.ohiodnr.gov/) has a database of case incident reports regarding oil and gas wells. The NPS Energy and Minerals website, https://www.nps.gov/subjects/energyminerals/index.htm, provides additional information. The NPS Geologic Resources Division completed an energy and minerals management handbook in 2017 that provides legal guidance for resource management issues.

### Disturbed Lands

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development, including facilities, military bases, roads, dams, and abandoned campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use (fig. 26). Perhaps the most well-known disturbed land feature of the park is the Ohio & Erie Canal; however, its historic significance makes it one of the identified fundamental resources of the park (National Park Service 2013a). The canal runs the length of the park and varies in condition from the watered section between Brecksville Dam to lock 38 (a 6-km [4-mi] section of this is a national historic landmark), to the ruins of the unwatered section. The watered section of the canal provides freshwater habitat whereas the unwatered section is becoming vegetated and supports wetlands. The GRI GIS data contain map unit, **m**, which defines disturbed areas large enough to appear at the specific map scale within the park and surrounding areas (see "Geologic Map Data"; White 1984; Ford 1987; Pavey et al. 2000). Some of these features may be of historical significance, but most are not in keeping with the mandates of the National Park Service. Cockrell (1992) listed several disturbed sites that had been restored including dumps on Hines Hill Road, Hillside Road, and Station Road. Thornberry-Ehrlich (2010) summarized 40 major disturbed sits covering over 178 ha (440 ac) that were restored since 1984, including sand and gravel pits, dumps, roads, and topsoil mines. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities. Restoration activities return a site, watershed, or landscape to some previous condition, commonly some desirable historic baseline. The park's 1987 degraded site restoration plan addressed problem areas like steep slopes, restrictive soil conditions, and poor drainage areas that were hampering attempts to restore natural succession (Cockrell 1992).

Disturbed lands evaluation and restoration is ongoing at Cuyahoga Valley National Park. The 16-ha (39-ac) Krejci dumpsite was recently under restoration at Hines Hill Road east of the Boston Store area. Restoration efforts are completed and the park is awaiting the final paperwork to declare the site clean and restored (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). Another recent restoration was the Ipsaro site, adjacent to the Rockside Road Station in Independence as part of wetland mitigation (Thornberry-Ehrlich 2010; Meg Plona, biologist, Cuyahoga Valley National Park, written communication, 9 February 2018). As of 2018, the park is working on restoring the Jaite Mill site, an old papermill that is now part of the contaminated sites program (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018).

**Figure 26. Photographs of water-control features. Riprap (top image) along was installed on shorelines to mitigate erosion and lateral meandering. Locks (middle image) and dams (bottom image) were constructed in many locations along the river. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

AMLs and disturbed lands such as quarries and topsoil removal sites are commonly not able to support forests or other large plants besides grass. The park is working with Kent State University to restore forests at five sites, including planting thousands of trees (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018).

An estimated 15 dams occur within park boundaries, most of which are farm ponds. Nearly 60 dams are located within the Cuyahoga River watershed with five dams on the main stem of the river (fig. 27; Thornberry-Ehrlich 2010). Dams act as sediment traps and removing and restoring dammed reaches requires multi-organizational cooperation and great care to avoid flooding the system with unwanted sediment or contaminants. Notably, the Gorge Metropark (Ohio Edison) Dam, approximately 13 km (8 mi) upstream of the park boundary, is believed to be a significant sediment sink. Plans are in place and funding being sought to remove this dam safely without washing excess sediment downstream (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018). Geologists at the University of Akron are researching the quantification of the sediment yield that will impact the river downstream when the dam is removed (John Peck, geologist, University of Akron, conference call, 8 February 2018). In cooperation with the Ohio Environmental Protection Agency (EPA), the cities of Kent and Monroe Falls recently removed two concrete, lowhead dams on the Cuyahoga River upstream from the park boundary. Within the park are two lowhead dams: the Peninsula Dam and the Brecksville Dam (also known as the Canal Diversion Dam). The Brecksville Dam, near Chippewa Creek, and the Gorge Dam (fig. 27) have been identified by the Ohio EPA as sources of harm to water quality (National Park Service 2013a; Thornberry-Ehrlich 2010). Dam-removal planning needs to include sediment transport modeling and floodplain restoration. The Brecksville Dam is slated for removal in 2020 (Lisa Petit, chief of resources, Cuyahoga Valley National Park, conference call, 8 February 2018).

Removal of dams to restore a free-flowing river is among the opportunities identified in National Park Service (2013), as well as continued restoration of river, riparian corridor, wetlands, and floodplains. The Ohio Division of Geological Survey website (http://geosurvey.ohiodnr.gov/) maintains a dam safety information site and data for over 600 dams in the Cuyahoga region. Peck and Kasper (2013) present a multiyear assessment of the sedimentological impacts of removing the Munroe Falls Dam. Similar impacts could be applied to other dam-removal proposals.

**Figure 27. Photograph of the dam at the Gorge Metropark.**
**The dam was originally constructed to support hydroelectric power generation and was later used to provide cooling water for a coal-fired power plant (now razed). Today, such features impede natural river flow and pose water quality hazards. Several park dams have been removed or are being considered for removal, including this dam. Photo by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

### *Ohio & Erie Canal Management*

The Brecksville Dam provides water for the watered section of the canal; however, it disrupts natural water flow in the Cuyahoga River and is a target of removal in 2019-2020. Similar to the Cuyahoga River itself, current threats to canal conditions are breaches, sedimentation, erosion, and deteriorating water control structures. Frost weathering degrades canal walls. Increases in adjacent impervious surfaces increase canal flooding potential as does the increased precipitation accompanying climate change. Opportunities to manage the canal include (1) modest stabilization and control of vegetation encroachment to slow the deterioration of canal structures (fig. 28), (2) create a canal management plan for detailed assessment of canal structure, condition, and treatment recommendations, (3) monitor riverbank stability, and (4) climate change scenario planning. The foundation document (National Park Service 2013a) lists the existing information about the canal for resource management.

Akin to the canal, the Valley Railway is both considered a cultural resource and at risk of degradation from geologic processes such as weathering and erosion. Increased flooding and local impervious surface development threaten railway culverts and embankments. Riverbank stability monitoring is recommended as a planning and data need to protect and maintain the railway (National Park Service 2013a).

## Paleontological Resource Inventory, Monitoring, and Protection

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). All fossils are nonrenewable. Body fossils are any remains of the actual organism such as bones, teeth, shells, or leaves. Trace fossils are evidence of biological activity; examples include burrows, tracks, or coprolites (fossil dung). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources. As of September 2019, 271 parks had documented paleontological resources in at

**Figure 28. Photograph of vegetated portion of the unwatered Ohio & Erie Canal.**
**Some portions of the canal are maintained. Vegetation obscures the former canal. Powerlines cross many areas of the park. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009.**

least one of these contexts. Fossils were noted within park boundaries as part of Devonian and Mississippian geologic map units **Doh**, **Dbb**, and **Mc** (figs. 29 and 30). The potential for fossil remains exists in **PNap** where fossils are known from elsewhere, as well as more recent fossil remains in the Pleistocene and Holocene surficial and glacial deposits "**W**", "**Q**". and "**H**" units (White 1984; Ford 1987; Pavey et al. 2000; Swinford et al. 2003). Brandywine Falls, Brandywine Creek, and Tinkers Creek are noteworthy paleontological locations (Hunt et al. 2008). Tweet et al. (2016) listed Cuyahoga Valley National Park as having at least three locations wherein fossil taxa were named, so-called type specimens, analogous to a geologic type locality.

Cuyahoga Valley National Park has geologic units known to be locally fossiliferous and the potential for fossils in rocks or unconsolidated deposits. All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act. The park's resource management plan identifies preserving and protecting paleontological resources as a primary resource management goal (National Park Service 1999).

Hunt et al. (2008) prepared a paleontological resource summary for the parks of the Heartland Network, including Cuyahoga Valley National Park. The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists, but no field-based investigations. An on-the-ground paleontological survey would be an ideal GIP project. Resource-management recommendations from Hunt et al. (2008) for the park included:

- Encourage park staff to observe exposed gullies, other erosional bedrock, and streams for fossil material while conducting their usual duties.
- Photodocument and potentially monitor any occurrences of paleontological resources that may be observed in situ.
- Consider long-term monitoring of paleontological sites.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Other resources for guidance on paleontological issues include:

- The NPS Fossils and Paleontology website, http://go.nps.gov/paleo.
- Kenworthy and Santucci (2006) presented a summary of National Park Service fossils in a cultural resource context.
- Santucci et al. (2009) details paleontological resource monitoring strategies.
- Feldmann and Hackathorn (1996) provided a comprehensive guide to fossil resources of Ohio.

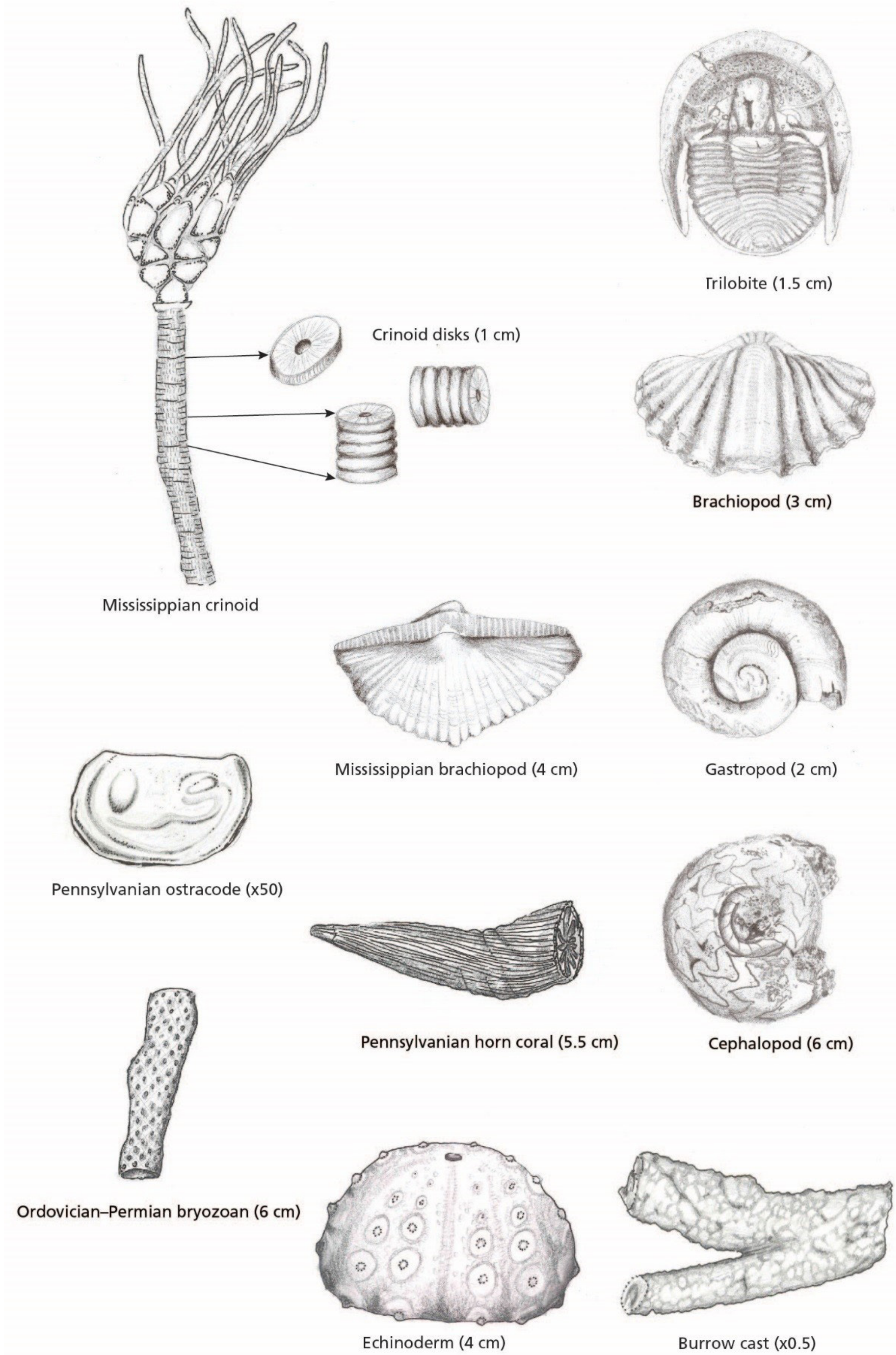



**Figure 29. Fossil sketches.**
**The sandstone, siltstone, shale, and coal layers in the park are fossiliferous. These sketches are representative of some of the fossil types and ages that may be present in the park's geologic units. Fossils are at risk of burial or degradation by natural and anthropogenic slope processes, as well as theft. Sketches by Trista L. Thornberry-Ehrlich (Colorado State University).**

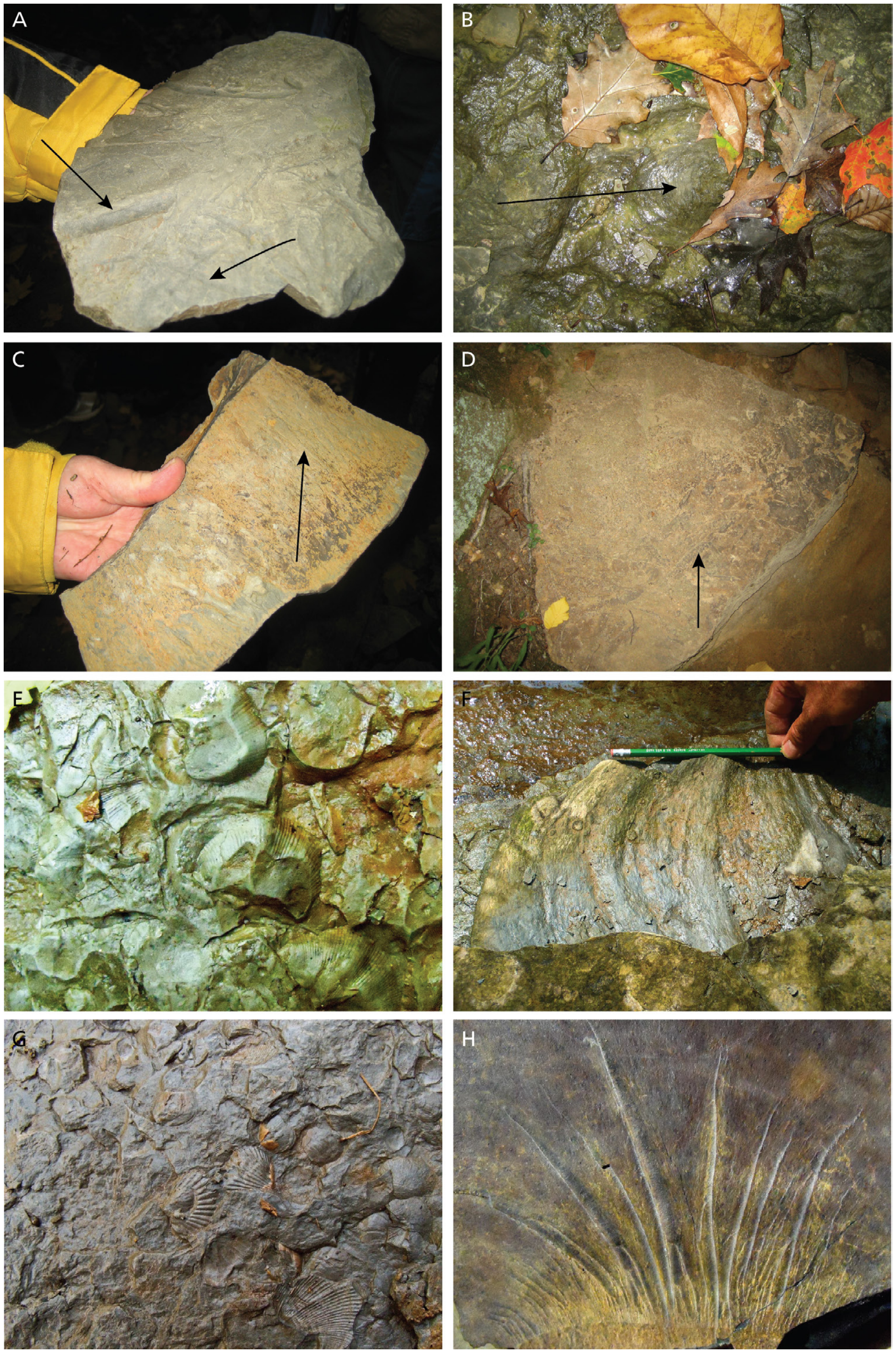



**Figure 30. Photographs of fossils found within Cuyahoga Valley National Park.**
**Fossils are found both in loose float and in situ at bedrock exposures. Fossil resources are protected and non-renewable. Panel A shows *Planolites* (the longer, narrower form) and probably *Trichophycus* (the wider, deeper form). Panel B is likely a bivalve. Panels C and D show burrow trace fossils. Panels E and F were taken along Slipper Run and show brachiopods (E) and zoophycos (F). Panels G and H were from Tinkers Creek and show brachiopods (G) and an unidentified fossil (H). Some fossil identification provided by James Thomka, geologist, University of Akron, written communication, 17 August 2018. Photographs A–D by Trista L. Thornberry-Ehrlich (Colorado State University) taken in autumn 2009; photographs E–H by Greg Tkachyk taken in August 2010 and October 2009.**

# Geologic Map Data

*A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the park follows the source maps listed here and includes components described in this chapter. Posters (in pocket) display the data over imagery of the park and surrounding area. Complete GIS data are available at the GRI publications website: http://go.nps.gov/gripubs.*

*Refer to the GRI GIS Data Addendum following the Executive Summary (p. x) for updates to the GRI GIS data following the submittal of this manuscript for publication.*

## Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age (see table 1 and fig. 3) and lowercase letters indicating the formation's name. Other symbols depict structures such as faults or folds, locations of past geologic hazards that may be susceptible to future activity, and other geologic features. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website, http://www.americangeosciences.org/environment/publications/mapping, provides more information about geologic maps and their uses.

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

## Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and compiles and converts digital data to conform to the GRI GIS data model. The GRI GIS data set includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are included in the cuva_geology.pdf. The GRI team used the following sources to produce the GRI GIS data set for Cuyahoga Valley National Park. These sources also provided information for this report.

- Bedrock Map (four-letter code: cuva): Swinford et al. (2003), Slucher (1996a), Slucher (1996b), Larsen and Slucher (1996a), Larsen and Slucher (1996b), Larsen and Slucher (1996c), Larsen and Slucher (1996d), Larsen and Slucher (1996e), Larsen and Slucher (1996f), Larsen and Slucher (1996g), Slucher and Larsen (1996), Larsen (1996a), Larsen (1996b), Slucher and Vorbau (1997)
- Surficial Map (four-letter code: clvn): Pavey et al. (2000)
- Glacial and Surficial Map (four-letter code: sucu): White (1984) and Ford (1987)

## GRI GIS Data (see Addendum, p. x)

The GRI team standardizes map deliverables by using a data model. The GRI GIS data for Cuyahoga Valley National Park was compiled using data model version 2.1, which is available is available at http://go.nps.gov/gridatamodel. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI website (http://go.nps.gov/gri) provides more information about the program's products.

GRI GIS data are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) Data Store portal https://irma.nps.gov/DataStore/Search/Quick. Enter "GRI" as the search text and select a park from the unit list.

The following components are part of the data set:

- A GIS readme file (cuva_gis_readme.pdf) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology (tables 5, 6, and 7);

- Federal Geographic Data Committee (FGDC)–compliant metadata;
- An ancillary map information document (cuva_geology.pdf) that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross-sections, and figures;
- ESRI map documents (cuva_geology.mxd, sucu_geology.mxd, and clvn_geology.mxd) that display the GRI GIS data; and
- A version of the data viewable in Google Earth (cuva_geology.kmz; table 5).

### GRI Map Posters

Posters of the GRI GIS draped over shaded relief images of the park and surrounding area are included with this report. Not all GIS feature classes are included on the posters (tables 5, 6, and 7). Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data, but are available online from a variety of sources. Contact GRI for assistance locating these data.

**Table 5. GRI GIS data layers for bedrock map (cuva) Cuyahoga Valley National Park.**

| Data Layer | On Poster? | Google Earth Layer? |
|---|---|---|
| Faults | Yes | Yes |
| Mine Area Feature Boundaries | No | No |
| Mine Area Features | No | No |
| Mine Point Features | No | No |
| Geologic Contacts | Yes | Yes |
| Geologic Units | Yes | Yes |

**Table 6. GRI GIS data layers for glacial and surficial map (sucu) Cuyahoga Valley National Park.**

Google Earth version was not produced for sucu data.

| Data Layer | On Poster? |
|---|---|
| Geologic Line Features | No |
| Glacial Area Feature Boundaries | Yes |
| Glacial Area Features | Yes |
| Glacial Feature Lines | Yes |
| Glacial Feature Points | Yes |
| Mine Point Features | No |
| Structure Contours on Bedrock Surface | No |
| Surficial Contacts | No |
| Surficial Units | Yes |

**Table 7. GRI GIS data layers for surficial map (clvn) Cuyahoga Valley National Park.**

Google Earth version was not produced for clvn data.

| Data Layer | On Poster? |
|---|---|
| Surficial Contacts | No |
| Surficial Units | Yes |

### Use Constraints

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

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

### Further Geologic Data Needs

The current GRI GIS data were incorporated into the Heartland Network's park atlas (Anthony Gareau, GIS specialist, Heartland Network, conference call, 8 February 2018). However, since the GRI GIS data were finalized, additional geologic mapping, at a detailed scale has provided new insights into the local geologic resources and story (see Skaggs 2014; Anthony Gareau, GIS specialist, Heartland Network, conference call, 8 February 2018). At the GRI scoping meeting and follow-up conference call, participants identified the following digital/geologic data needs:

- Improve existing maps. Detailed mapping and stratigraphic analysis has yielded refinements to the local geologic map units. For example, the Cuyahoga Formation has several other bedrock types than previously known. Use data including locations and elevations of bedrock contacts, well log data, and structure contour information presented in Scaggs (2014) and compiled by Anthony Gareau (NPS Heartland Network).
- Contacts between the Bedford Shale and Berea Sandstone need further mapping and refinement.
- Develop park-wide cross sections using new surface data points and well data.
- Developing a hydrogeologic model of the area based on well logs and monitoring. This would allow resource managers to understand how groundwater was moving through the subsurface at the park, develop groundwater resources, and potentially

predict areas at risk of slope issues due to emerging seeps and springs.

- Prepare a point-of-view geologic guide to educate kayakers and other river recreationists, making the river the focal point. Such a guide would detail geologic outcrops, views, and other features visible from the river (Christina Tenison, geoscientist-in-the-park, Cuyahoga Valley National Park, conference call, 8 February 2018).
- Include geologic features in a visual resource inventory quantifying scenic views. Contact NPS Air Resources Division; the visual resource inventory is underway as of fall 2019.

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*These references are cited in this report. Contact the Geologic Resources Division for assistance in obtaining them.*


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# Additional References

*These references, resources, and websites may be of use to resource managers. Refer to Appendix B for laws, regulations, and policies that apply to NPS geologic resources.*

### Geology of National Park Service Areas

- NPS Geologic Resources Division (Lakewood, Colorado) Energy and Minerals; Active Processes and Hazards; Geologic Heritage: http://go.nps.gov/grd
- NPS Geodiversity Atlas: http://go.nps.gov/geodiversity_atlas
- NPS Geologic Resources Division Education Website: http://go.nps.gov/geoeducation
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscientist-In-the-Parks (GIP) internship and guest scientist program: http://go.nps.gov/gip
- NPS Mosaics In Science (MIS) internship program: http://go.nps.gov/mosaics

### NPS Resource Management Guidance and Documents

- Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html
- 1998 National parks omnibus management act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf
- NPS-75: Natural resource inventory and monitoring guideline: https://irma.nps.gov/DataStore/Reference/Profile/622933
- NPS Natural resource management reference manual #77: https://irma.nps.gov/DataStore/Reference/Profile/572379
- Geologic monitoring manual (Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado): http://go.nps.gov/geomonitoring
- NPS Technical Information Center (TIC) (Denver, Colorado; repository for technical documents): https://www.nps.gov/dsc/technicalinfocenter.htm

### Climate Change Resources

- NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm
- US Global Change Research Program: http://www.globalchange.gov/home
- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

### Geological Surveys and Societies

- Ohio Division of Geological Survey: hhttp://geosurvey.ohiodnr.gov/
- US Geological Survey: http://www.usgs.gov/
- Geological Society of America: http://www.geosociety.org/
- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/

### US Geological Survey Reference Tools

- National geologic map database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- Geologic names lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/search
- Geographic names information system (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- GeoPDFs (download PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")
- Publications warehouse (many publications available online): http://pubs.er.usgs.gov
- Tapestry of time and terrain (descriptions of physiographic provinces): http://pubs.usgs.gov/imap/i2720/

# Appendix A: Scoping Participants

*The following people attended the GRI scoping meeting, held on 5-6 October 2009, or the follow-up report writing conference call, held on 8 February 2018. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website: http://go.nps.gov/gripubs.*

**2009 Scoping Meeting Participants**

| Name | Affiliation | Position |
|---|---|---|
| Mike Angle | Ohio Division of Geological Survey | Geologist |
| Melissa Arnold | NPS Cuyahoga Valley National Park | Museum technician |
| Tim Connors | NPS Geologic Resources Division | Geologist |
| Jim Evans | Bowling Green State University | Geologist |
| Annabelle Foos | University of Akron | Geologist |
| Anthony Gareau | NPS Cuyahoga Valley National Park | GIS specialist |
| Tom Nash | NPS Cuyahoga Valley National Park | Volunteer |
| Lisa Norby | NPS Geologic Resources Division | Geologist |
| John Peck | University of Akron | Geologist |
| John Szabo | University of Akron | Sedimentologist |
| Trista Thornberry-Ehrlich | Colorado State University | Geologist/GRI report author |
| Greg Tkachyk | NPS Cuyahoga Valley National Park | Volunteer |
| Roy "Scott" Van Horten | NPS Cuyahoga Valley National Park | Interpreter |

**2018 Conference Call Participants**

| Name | Affiliation | Position |
|---|---|---|
| Douglas Aiden | Ohio Division of Geological Survey | Geologist, karst and glacial mapping |
| Mike Angle | Ohio Division of Geological Survey | Geologist |
| Melissa Arnold | NPS Cuyahoga Valley National Park | Museum technician |
| Sonia Bingham | NPS Heartland I&M Network | Wetland biologist |
| Jason Kenworthy | NPS Geologic Resources Division | Geologist, GRI reports coordinator |
| Anthony Gareau | NPS Heartland I&M Network | GIS specialist |
| John Peck | University of Akron | Geologist |
| Lisa Petit | NPS Cuyahoga Valley National Park | Chief of Resources |
| Meg Plona | NPS Cuyahoga Valley National Park | Biologist |
| Christina Tenison | NPS Cuyahoga Valley National Park | Geoscientist-in-the-Park |
| Trista Thornberry-Ehrlich | Colorado State University | Geologist/GRI report author |
| Gregory Tkachyk | NPS Cuyahoga Valley National Park | Volunteer |

# Appendix B: Geologic Resource Laws, Regulations, and Policies

*The NPS Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to NPS minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available. Information is current as of December 2018. Contact the NPS Geologic Resources Division for detailed guidance.*

| Resource | Resource-specific Laws | Resource-specific Regulations | 2006 Management Policies |
|---|---|---|---|
| **Caves and Karst Systems** | **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/Agriculture to identify "significant caves" on Federal lands, regulate/restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester.<br>**National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources.<br>**Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry. | **36 CFR § 2.1** prohibits possessing/ destroying/disturbing…cave resources…in park units.<br>**43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/ releasing confidential information about specific cave locations to a FOIA requester. | **Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts.<br>**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.<br>**Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact cave environment, and to remove existing developments if they impair caves.<br>**Section 6.3.11.2** explains how to manage caves in/ adjacent to wilderness. |
| **Paleontology** | **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of paleontological resources and objects.<br>**Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa et seq.** provides for the management and protection of paleontological resources on federal lands. | **36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof.<br>**Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted.<br>**43 CFR Part 49** (in development) will contain the DOI regulations implementing the Paleontological Resources Preservation Act. | **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.<br>**Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria. |

| Resource | Resource-specific Laws | Resource-specific Regulations | 2006 Management Policies |
|---|---|---|---|
| **Recreational Collection of Rocks Minerals** | **NPS Organic Act, 54 USC. § 100101 et seq.** directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law.<br>**Exception: 16 USC. § 445c (c)** Pipestone National Monument enabling statute. Authorizes American Indian collection of catlinite (red pipestone). | **36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units.<br>**Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown.<br>**Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment. | **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. |
| **Geothermal** | **Geothermal Steam Act of 1970, 30 USC. § 1001 et seq. as amended in 1988**, states<br>● No geothermal leasing is allowed in parks.<br>● "Significant" thermal features exist in 16 park units (the features listed by the NPS at **52 Fed. Reg. 28793-28800** (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead).<br>● NPS is required to monitor those features.<br>● Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects.<br>**Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features. | None applicable. | **Section 4.8.2.3** requires NPS to<br>● Preserve/maintain integrity of all thermal resources in parks.<br>● Work closely with outside agencies.<br>● Monitor significant thermal features. |

| Resource | Resource-specific Laws | Resource-specific Regulations | 2006 Management Policies |
|---|---|---|---|
| **Mining Claims (Locatable Minerals)** | **Mining in the Parks Act of 1976, 54 USC § 100731 et seq.** authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas.<br><br>**General Mining Law of 1872, 30 USC § 21 et seq.** allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA.<br><br>**Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities. | **36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law.<br><br>**36 CFR Part 6** regulates solid waste disposal sites in park units.<br><br>**36 CFR Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability.<br><br>**43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska. | **Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at **36 CFR Parts 6 and 9A**.<br><br>**Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries. |
| **Nonfederal Oil and Gas** | **NPS Organic Act, 54 USC § 100751 et seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).<br><br>Individual Park Enabling Statutes:<br>● **16 USC § 230a** (Jean Lafitte NHP & Pres.)<br>● **16 USC § 450kk** (Fort Union NM),<br>● **16 USC § 459d-3** (Padre Island NS),<br>● **16 USC § 459h-3** (Gulf Islands NS),<br>● **16 USC § 460ee** (Big South Fork NRRA),<br>● **16 USC § 460cc-2(i)** (Gateway NRA),<br>● **16 USC § 460m** (Ozark NSR),<br>● **16 USC § 698c** (Big Thicket N Pres.),<br>● **16 USC § 698f** (Big Cypress N Pres.) | **36 CFR Part 6** regulates solid waste disposal sites in park units.<br><br>**36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights outside of Alaska to<br>● demonstrate bona fide title to mineral rights;<br>● submit an Operations Permit Application to NPS describing where, when, how they intend to conduct operations;<br>● prepare/submit a reclamation plan; and<br>● submit a bond to cover reclamation and potential liability.<br><br>**43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska. | **Section 8.7.3** requires operators to comply with 9B regulations. |

| Resource | Resource-specific Laws | Resource-specific Regulations | 2006 Management Policies |
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| **Federal Mineral Leasing (Oil, Gas, and Solid Minerals)** | **The Mineral Leasing Act, 30 USC § 181 et seq., and the Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq.** do not authorize the BLM to lease federally owned minerals in NPS units.<br>**Combined Hydrocarbon Leasing Act, 30 USC §181**, allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in GLCA, which is the only park unit that contains a STSA.<br>**Exceptions: Glen Canyon NRA (16 USC § 460dd et seq.), Lake Mead NRA (16 USC § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC § 460q et seq.)** authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration.<br>American Indian Lands Within NPS Boundaries Under the **Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108**, all minerals on American Indian trust lands within NPS units are subject to leasing.<br>**Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units. | **36 CFR § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law.<br>**BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing.<br>**43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.<br>Regulations re: Native American Lands within NPS Units:<br>• **25 CFR Part 211** governs leasing of tribal lands for mineral development.<br>• **25 CFR Part 212** governs leasing of allotted lands for mineral development.<br>• **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development.<br>• **25 CFR Part 224** governs tribal energy resource agreements.<br>• **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the **Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938** (codified at **25 USC §§ 2101-2108**).<br>• **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases.<br>• **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases.<br>• **30 CFR §§ 1206.50-1206.62 and §§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases.<br>• **30 CFR § 1206.450** governs the valuation coal from Indian Tribal and Allotted leases.<br>• **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM. | **Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs. |

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| **Nonfederal minerals other than oil and gas** | **NPS Organic Act, 54 USC §§ 100101 and 100751** | NPS regulations at **36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a **§ 5.3** business operation, and **§ 5.7 – Construction of buildings or other facilities**, and to comply with the solid waste regulations at **Part 6**. | **Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1 and 5**. |
| **Coal** | **Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 et. seq.** prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights. | **SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation, and employee protection. **Part 7** of the regulations states that National Park System lands are unsuitable for surface mining. | None applicable. |
| **Uranium** | **Atomic Energy Act of 1954** Allows Secretary of Energy to issue leases or permits for uranium on BLM lands; may issue leases or permits in NPS areas only if president declares a national emergency. | None applicable. | None applicable. |
| **Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)** | **Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units.<br>**Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas.<br>**16 USC §90c-1(b)** authorizes sand, rock and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area, for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area. | None applicable. | **Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and:<br>● only for park administrative uses;<br>● after compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment;<br>● after finding the use is park's most reasonable alternative based on environment and economics;<br>● parks should use existing pits and create new pits only in accordance with park-wide borrow management plan;<br>● spoil areas must comply with Part 6 standards; and<br>● NPS must evaluate use of external quarries.<br>Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director. |

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| **Coastal Features and Processes** | **NPS Organic Act, 54 USC § 100751 et. seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).<br><br>**Coastal Zone Management Act, 16 USC § 1451 et. seq**. requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone.<br><br>**Clean Water Act, 33 USC § 1342/ Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit.<br><br>**Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs.<br><br>**Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas.<br><br>*See also "Climate Change"* | **36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands.<br><br>**36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area.<br><br>*See also "Climate Change"* | **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress.<br><br>**Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.<br><br>**Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/ park facilities/ historic properties.<br><br>**Section 4.8.1.1** requires NPS to:<br>● Allow natural processes to continue without interference,<br>● Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions,<br>● Study impacts of cultural resource protection proposals on natural resources,<br>● Use the most effective and natural-looking erosion control methods available, and avoid new developments in areas subject to natural shoreline processes unless certain factors are present.<br><br>*See also "Climate Change"* |

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| **Climate Change** | **Secretarial Order 3289** (Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources) (2009) requires DOI bureaus and offices to incorporate climate change impacts into long-range planning; and establishes DOI regional climate change response centers and Landscape Conservation Cooperatives to better integrate science and management to address climate change and other landscape scale issues.<br>**Executive Order 13693** (Planning for Federal Sustainability in the Next Decade) (2015) established to maintain Federal leadership in sustainability and greenhouse gas emission reductions. | *No applicable regulations, although the following NPS guidance should be considered:*<br>**Coastal Adaptation Strategies Handbook (Beavers et al. 2016)** provides strategies and decision-making frameworks to support adaptation of natural and cultural resources to climate change.<br>**Climate Change Facility Adaptation Planning and Implementation Framework**: The NPS Sustainable Operations and Climate Change Branch is developing a plan to incorporate vulnerability to climate change (Beavers et al. 2016b).<br>**NPS Climate Change Response Strategy** (2010) describes goals and objectives to guide NPS actions under four integrated components: science, adaptation, mitigation, and communication.<br>**Policy Memo 12-02** (Applying National Park Service Management Policies in the Context of Climate Change) (2012) applies considerations of climate change to the impairment prohibition and to maintaining "natural conditions".<br>**Policy Memo 14-02** (Climate Change and Stewardship of Cultural Resources) (2014) provides guidance and direction regarding the stewardship of cultural resources in relation to climate change.<br>**Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.<br>*Continued in 2006 Management Policies column* | **Section 4.1** requires NPS to investigate the possibility to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities. This would include climate change, as put forth by Beavers et al. (2016).<br>*NPS guidance, continued:*<br>**DOI Manual Part 523, Chapter 1** establishes policy and provides guidance for addressing climate change impacts upon the Department's mission, programs, operations, and personnel.<br>**Revisiting Leopold: Resource Stewardship in the National Parks** (2012) will guide US National Park natural and cultural resource management into a second century of continuous change, including climate change.<br>**Climate Change Action Plan** (2012) articulates a set of high-priority no-regrets actions the NPS will undertake over the next few years<br>**Green Parks Plan** (2013) is a long-term strategic plan for sustainable management of NPS operations. |

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

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

**NPS 644/171106, July 2020**

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**U.S. Department of the Interior**

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