



Big South Fork National River and Recreation Area

Geologic and Soil Resources Inventory Summary



A discovered and yet unnamed arch in the backcountry of Big South Fork National River and Recreation Area. Arches at the park form where resistant sandstone is layered atop less-resistant shales and siltstones. The underlying rocks weather away, leaving sandstone layers as arches, fins, or overhangs. NPS photograph.

Big South Fork National River and Recreation Area

Geologic and Soil Resources Inventory Summary

Trista L. Thornberry-Ehrlich

Colorado State University Research Associate
National Park Service Geologic Resources Division
Geologic and Soil Resources Inventory
PO Box 25287
Denver, Colorado 80225

Please cite this report as

Thornberry-Ehrlich, T. L. 2025. Big South Fork National River and Recreation Area: geologic and soil resources inventory summary. Unpublished report. National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2308002>.

Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) deliverables for Big South Fork National River and Recreation Area (BISO). It also provides information on current geology and soil resources management concerns with a focus on identified inventory needs related to geologic heritage, geohazards, and related soil features and processes. This document is intended to assist park staff with prioritizing technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

GRI hosted a baseline scoping meeting for BISO in 2007. Baseline bedrock and surficial geologic maps were delivered to the park in 2021. SRI delivered a legacy soil database and map to the park in 2010 and delivered updated data and an “enhanced report” in 2013.

Geologic heritage resources of particular interest include Big South Fork and gorge; stratotypes; paleokarst; periglacial features; rock shelters and first inhabitants; homesteading; oil, gas, and coal; unique, geologically controlled habitats and ecological relationships; and river rapids and recreation. Inventory needs include cliff surveys, climbing use studies, stratotype designations, field inventories, ecological flow studies, stone quarry identification, and streambed mapping.

Soils at BISO are generally thin and rocky on upper slopes with limited fertility. In the river floodplains and valley bottoms, the soils are thicker and more fertile but of limited spatial extent. Inventory needs include detailed correlations between soil type and vegetation communities and pH buffering capacity surveys.

Geologic resource management issues include abandoned mineral lands (oil, gas, and coal); fluvial issues; land use and visitor overuse; slope movements; and seismicity. Geohazards include flooding, extreme precipitation events, dam failure, landslides, earthquakes, shrink/swell soils, and toxicological soils. Inventory needs include cave and karst mapping, landscape evolution mapping, slope analyses, digitized mine maps, spoil area mapping, abandoned mineral land site identification, and clinker maps.

Additional guidance for BISO staff regarding proposal processes and timeframes for the new Inventories and Assessment (I&A) program is available on the [GSRI](#) and [I&A](#) SharePoint sites.

Table of Contents

Abstract	iii
Table of Contents	iv
List of Figures	vi
List of Tables.....	vii
Background of the GSRI	1
Baseline GSRI Products	1
Geology	1
Soils.....	3
Future GSRI Products	4
Geologic Setting and History	6
Geologic Heritage	11
Big South Fork and Gorge	11
Stratotypes.....	13
Paleokarst	13
Periglacial Features	13
Rock Shelters and First Inhabitants.....	14
Homesteading.....	16
Oil, Gas, and Coal	17
Unique, Geologically Controlled Habitats, and Ecological Relationships	20
River Rapids and Recreation.....	21
Resource Management Issues and Inventory Needs	23
Abandoned Mineral Lands (AML) and Oil and Gas Operations	23
AML	23
Oil and Gas.....	29
Fluvial Issues.....	30
Land Use and Visitor Overuse	34
Slope Movements	35
Seismicity	37
Inventory Needs	38
Legislatively Required Geologic Inventories.....	40
Caves and Karst.....	40

Geothermal Features and Springs	40
Paleontological Resources Inventory and Protection.....	41
Summary of Geologic and Soil Hazards	42
Acknowledgments.....	47
Scoping Participants.....	47
Summary Review	47
Summary Editing	47
GRI GIS Data Production	48
Literature Cited	49

List of Figures

Figure 1. Map showing the Cumberland Plateau between the Highland Rim and Valley and Ridge physiographic province 6

Figure 2. Block diagrams of the geologic evolution of the BISO landscape 9

Figure 3. Block diagram of surficial units forming on the BISO landscape 10

Figure 4. Block diagrams of rock formation evolution 12

Figure 5. Photograph of a rock shelter at BISO 15

Figure 6. Photograph of a coal seam exposed in an outcrop at BISO 19

Figure 7. Photograph of the rapids at Angel Falls..... 22

Figure 8. Diagram of abandoned coal mining features. 25

Figure 9. View from Devil’s Jump overlook toward remediated mine tailings areas..... 27

Figure 10. Photograph showing contaminated mine drainage entering Big South Fork at Worley..... 28

Figure 11. Decision tree to manage riverbank erosion..... 32

Figure 12. Illustrations of slope movements 36

Figure 13. National seismic hazard map 38

List of Tables

Table 1. Web Soil Survey areas	4
Table 2. List of identified geologic and soil resource inventory needs for BISO.....	39
Table 3. Geologic and soil hazards checklist.....	43

Background of the GSRI

The [Geologic and Soil Resources Inventory \(GSRI\)](#) is a new program encompassing the legacy Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) programs. To inform park management decisions and planning, GSRI aids in the collection of new data and derives new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes.

In the late 1990s, the GRI and SRI programs were established as two of the 12 original baseline inventories in the Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data across more than 270 parks with significant natural resources, which served as a common starting point for natural resource stewardship. For both GRI and SRI, the primary deliverable was a digital (GIS) map.

Between the 1990s and early 2020s, GRI also produced scoping summaries, geologic map posters, and GRI reports for most of the 270 parks. GRI and SRI baseline inventory products are available through the [NPS Geodiversity Atlas](#). These products are designed to enhance stewardship of park resources by providing valuable information about soils, geologic formations, hazards, and links between geology, history, and other natural resources. As of 2024, the I&M program is transitioning from a baseline inventory strategy to a park-proposed inventory strategy.

The GRI and SRI are now unified as one inventory program, GSRI, which is integrated into the new Inventories & Assessment (I&A) program. Through the new I&A program, parks will submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. See the [GSRI SharePoint site](#) for more information regarding this transition. During this transition period, 13 “priority” parks, including Big South Fork National River and Recreation Area (referred to as “BISO” herein), were identified as missing a baseline GRI report. This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the park’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for BISO and provides information on current geology and soil resources management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GSRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geology

The digital geologic map of BISO is available on the NPS DataStore, accessed through the Integrated Resource Management Applications (IRMA) portal (see <https://irma.nps.gov/DataStore/Reference/Profile/2194445>), and is compiled and adapted from the following 16 source geologic maps, reports, and databases:

- Clendening, R. J., A. B. Horton, and J. W. Jewell. 2009. Geologic map of the Stockton quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 115–NE. Tennessee Division of Geology, Nashville, Tennessee.
- Clendening, R. J., A. B. Horton, D. Gilmore, and W. Kerrigan. 2011. Geologic map and mineral resources summary of the Rugby quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 128A–SW. Tennessee Division of Geology, Nashville, Tennessee.
- Clendening, R. J., and A. B. Horton. 2010. Geologic map and mineral resources summary of the Honey Creek quadrangle, Tennessee (scale 1:24,000). Geologic Map 128A–NW. Tennessee Division of Geology, Nashville, Tennessee.
- Clendening, R. J., and A. B. Horton. 2012. Geologic map of the Oneida South quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 128A–NE. Tennessee Division of Geology, Nashville, Tennessee.
- Horton, A. B., R. J. Clendening, and M. L. Hoyal. 2013. Geologic map of the Oneida North quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 336–SE. Tennessee Division of Geology, Nashville, Tennessee.
- Horton, A., and M. Hoyal. 2016. Geologic map of the Barthell SW quadrangle, Tennessee (scale 1:24,000). Geologic Map 336–SW. Tennessee Division of Geology, Nashville, Tennessee.
- Hoyal, M., and A. Horton. 2015. Geologic map of the Sharp Place quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 335–SE. Tennessee Division of Geology, Nashville, Tennessee.
- Jewell, J. W. 1972. Geologic map and mineral resources summary of the Burrville quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 115–SE. Tennessee Division of Geology, Nashville, Tennessee.
- Kentucky Geological Survey. 2016. Oil and gas records database. Kentucky Geological Survey, Lexington, Kentucky.
<http://kgs.uky.edu/kgsweb/DataSearching/OilGas/OGSearch.asp> (accessed 18 January 2025)
- Pomerene, J. B. 1964. Geology of the Barthell quadrangle and part of the Oneida North quadrangle, Kentucky (scale 1:24,000). Geologic Quadrangle Map GQ–314. US Geological Survey, Reston, Virginia.
- Smith, J. H. 1976. Geologic map of the Nevelsville quadrangle, south–central Kentucky (scale 1:24,000). Geologic Quadrangle Map GQ–1326. US Geological Survey, Reston, Virginia.
- Smith, J. H. 1978. Geologic map of the Bell Farm quadrangle and part of the Barthell SW quadrangle, McCreary and Wayne counties, Kentucky (scale 1:24,000). Geologic Quadrangle Map GQ–1496. US Geological Survey, Reston, Virginia.

- Sparks, T. N., W. H. Anderson, and X. Yang. 2011. Geologic map of the Corbin 30x60 minute quadrangle, south-central Kentucky (scale 1:100,000). Geologic Map Series KGS12_GM-27. Kentucky Geological Survey, Lexington, Kentucky.
- Zhang, Q. 2006. Spatial database of the Bell Farm quadrangle and part of the Barthell Southwest quadrangle, McCreary and Wayne counties, Kentucky (scale 1:24,000). Digitally Vectorized Geological Quadrangle DVGQ-12_1496. Kentucky Geological Survey, Lexington, Kentucky.
- Zhang, Q., and M. Stidham. 2006. Spatial database of the Nevelsville quadrangle, south-central Kentucky (scale 1:24,000). Digitally Vectorized Geological Quadrangle DVGQ-12_1326. Kentucky Geological Survey, Lexington, Kentucky.
- Zhang, Q., and M. Stidham. 2006. Spatial database of the Barthell quadrangle and part of the Oneida North quadrangle, Kentucky (scale 1:24,000). Digitally Vectorized Geological Quadrangle DVGQ-12_314. Kentucky Geological Survey, Lexington, Kentucky.

Additional GSRI documents include the GRI scoping report from the 2007 GRI scoping meeting (Thornberry-Ehrlich 2009).

- Thornberry-Ehrlich, T. L. 2009. Geologic Resources Inventory Scoping Summary Big South Fork National River and Recreation Area & Obed Wild and Scenic River. Geologic Resources Inventory Report. National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2250200>

Soils

Soil maps provide information on soil types, including scores of different characteristics and management considerations, including linear extensibility (“shrink-swell”) potential, erosion potential, soil stability, suitability for site development, suitability for recreation development (e.g., trails), and many other topics. [Perrone \(2023\)](#) provides an overview of the use of soil data at the NPS WASO level and lists soil data currently available in Web Soil Survey along with NPS-specific uses for the data. The Natural Resources Conservation Service (NRCS) plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020).

SRI delivered a legacy soil database and map to the park in 2010 and delivered updated data and an “enhanced report” in 2013. This is available on the NPS DataStore, accessed through IRMA (<https://irma.nps.gov/DataStore/Reference/Profile/1048823>). This map is part of a static dataset that will not be updated in the future as revisions or new data become available.

The most up-to-date soils data for BISO is available via [Web Soil Survey](#), which is updated and maintained regularly. Management-focused maps for BISO or potential project areas can be developed on demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data.

The Web Soil Survey data are broken down into county-level soil survey areas. Each soil survey area is assigned a code and a name (Table 1). BISO includes six soil survey areas. The soil survey status

is complete for BISO. Table 1 lists the soil survey areas and their completion status. In addition to the countywide soil survey areas, a park-specific soil survey area covers the land within the boundaries of BISO. To view the soil data for BISO on the [Web Soil Survey website](#), use the navigation pane on the left side of the main webpage to select the soil survey area of interest or the NPS unit and set it as the “area of interest” using the “AOI” icon along the top of the map. Use the “Soil Map” tab at the top to view the soil map and the “Soil Data Explorer” tab to view additional soil data, including linear extensibility and suitability for development. See additional Web Soil Survey [guidance](#) and [FAQs](#) or contact the [NRCS state soil scientist](#) for technical assistance.

Table 1. Web Soil Survey areas.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
KY231	Wayne County, Kentucky	Complete
KY630	McCreary-Whitley Area, Kentucky	Complete
TN607	Scott County Area, Tennessee	Complete
TN629	Morgan County Area, Tennessee	Complete
TN650	Big South Fork National River and Recreation Area, Kentucky and Tennessee	Complete
TN701	Fentress and Pickett Counties Area, Tennessee	Complete

Future GSRI Products

As the GSRI becomes integrated into the I&A program, future GSRI products will be determined by the project proposals submitted by the parks. The GSRI will fund projects that

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

GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological resources (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunamis, sinkholes), eolian, erosion, soil suitability and limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.

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

Please see the [Resource Management Guidance SharePoint](#) to find information regarding geologic resource management. Contacts therein can assist with geologic resource management questions.

Geologic Setting and History

Starting at the confluence of the New River and Clear Fork in northeastern Tennessee, Big South Fork of the Cumberland River (Big South Fork) and its tributaries have cut 180-m (600-ft) deep, V-shaped gorges in a dendritic (tree-like) pattern into the rolling hills of the Cumberland Plateau—a northeast–southwest trending tableland area stretching from northeast Kentucky to central Alabama (Figure 1; Fenneman 1938; National Park Service 2017). As the largest single drainage system of the plateau, the river flows freely through BISO for 60 km (37 mi) until it meets the Lake Cumberland reservoir for its remaining 13 km (8 mi) within BISO boundaries. As it flows northeastward into southern Kentucky, the river passes myriad geologic formations, including sedimentary rock layers and landforms formed by weathering and erosion of these layers.

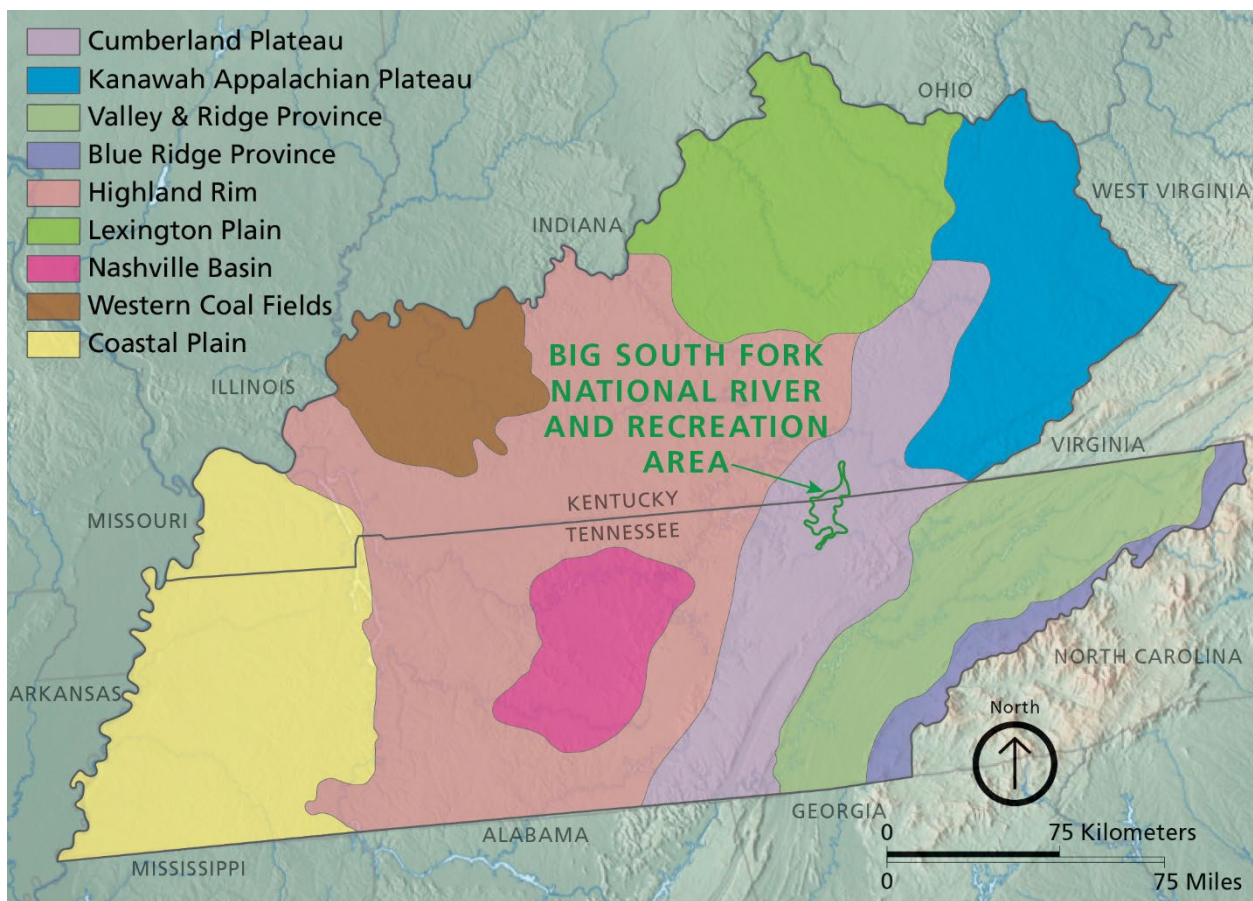


Figure 1. Map showing the Cumberland Plateau between the Highland Rim and Valley and Ridge physiographic province. Physiographic provinces are geographic regions characterized by distinct landforms, often shaped by specific geologic and climatic factors. Provinces are distinguished by their unique relief, subsurface rock types, and structural elements. The green outline indicates the approximate location of BISO. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), with information from the US Geological Survey, Kentucky Geological Survey, and Middle Tennessee State University. Basemap by Tom Patterson (National Park Service), available online: <http://www.shadedrelief.com/physical/index.html> (accessed 2 February 2025).

The present-day landscape at BISO, encompassing about 50,051 ha (123,679 ac), is a function of its geologic history (Anderson 2017). The following are notable geologic events that shaped the landscape:

- More than 320 million years ago, the oldest rocks at BISO were formed in unconstrained, warm, shallow marine basins and nearshore estuaries. These shales and thin limestones are the Mississippian (358.9 million–323.3 million years ago; Figure 2A) Monteagle Limestone, Hartselle Formation, Bangor Limestone, and Pennington Formation (Rice et al. 1979). These rocks tend to be soft, weather relatively easily, and are found at the bottom of the deepest gorges in BISO.
- Following a period of erosion or non-deposition (a gap in the geologic record known as an unconformity), regional uplift during the Allegheny Orogeny (mountain-building event) more than 300 million years ago caused the marine waters to recede and rivers to flow across the landscape (Figure 2B; Milici et al. 1979). These rivers carried sediments shed from the rising heights of the Appalachian Mountains to the east, depositing them as thick sandstones and conglomerates of the Pennsylvanian Period (323.2 million–298.9 million years ago), including the following:
 - Sewanee Conglomerate
 - Newton Sandstone
 - Lower Breathitt Group (sandstone members)
 - Bee Rock Sandstone (Rockcastle Sandstone and Pine Creek Sandstone members)
 - Grundy Formation (Hazel Patch Sandstone and Corbin Sandstone members)
 - Crossville Sandstone
 - Coalfield Sandstone
 - Lower Crooked Fork Group
 - Wartburg Sandstone
 - Slatestone Formation

In contrast to the older, underlying shale and limestone, sandstones and conglomerates are more resistant to erosion. In addition to “holding up” the tableland of the Cumberland Plateau, they also form the steep cliff walls lining the gorges. Erosion, regional dip (tilt of the rock layers), and fractures affect the formation of many stone overhangs, arches, mesas, chimneys, ledges, waterfalls, cracks, and shelters in the Pennsylvanian rocks at BISO.

- Throughout the Pennsylvanian, while rivers were flowing across the landscape, sea level rose periodically, causing incursions of marine or estuarine water across the landscape. These low-energy environments accumulated fine-grained shales, including the following:
 - Vandever Formation
 - Whitwell Shale

- Fentress Formation
- Alvy Creek Formation
- Dorton Shale
- Burnt Mill Shale
- Glenmary Shale

These settings also harbored extensive forests, vast swamps, and marshes. The organic material in these environments collected in thick layers that, with time, heat, and pressure upon burial, became coal seams (see Figure 2B). Coal seams include the Barren Fork, Nemo, Stearns, Stearns No. 1, Stearns No. 2, Morgan Springs, and Sawnee coal beds.

- The geologic record after the Pennsylvanian is missing at BISO. It either never accumulated, or more likely, accumulated and has since eroded away. Throughout the Mesozoic (251.9 million–66.0 million years ago) and Cenozoic (66.0 million years ago–present) Eras, Earth surface processes of weathering and erosion removed vast amounts of rock (Figure 2C), transporting them with wind and water downslope to ultimately become part of the coastal plain. Weathering, in concert with local topography, climate, and organic material, also created soils that support specific vegetation communities at BISO (see “Unique, Geologically Controlled Habitats, and Ecological Relationships”).
- During the Pleistocene Epoch (2.58 million–10,000 years ago), climate fluctuations caused a series of ice ages or continental-scale glacial advances. Although the ice sheets did not reach as far south as Kentucky or Tennessee, the colder climates (periglacial conditions) in proximity to the glaciers accelerated erosion and weathering. At BISO, colluvial blocks (a type of slope deposit) of sandstone are widespread and record intense erosional forces—some of the blocks are house-sized. Other surficial deposits include colluvium (mixed slope deposits) of boulders, cobbles, and pebbles.

Today, Big South Fork and its tributaries continue to cut through the geologic layers and transport sediment along their lengths. They deposit unconsolidated alluvium, gravel, sand, silt, and clay along their channels and narrow floodplains (Figure 3).

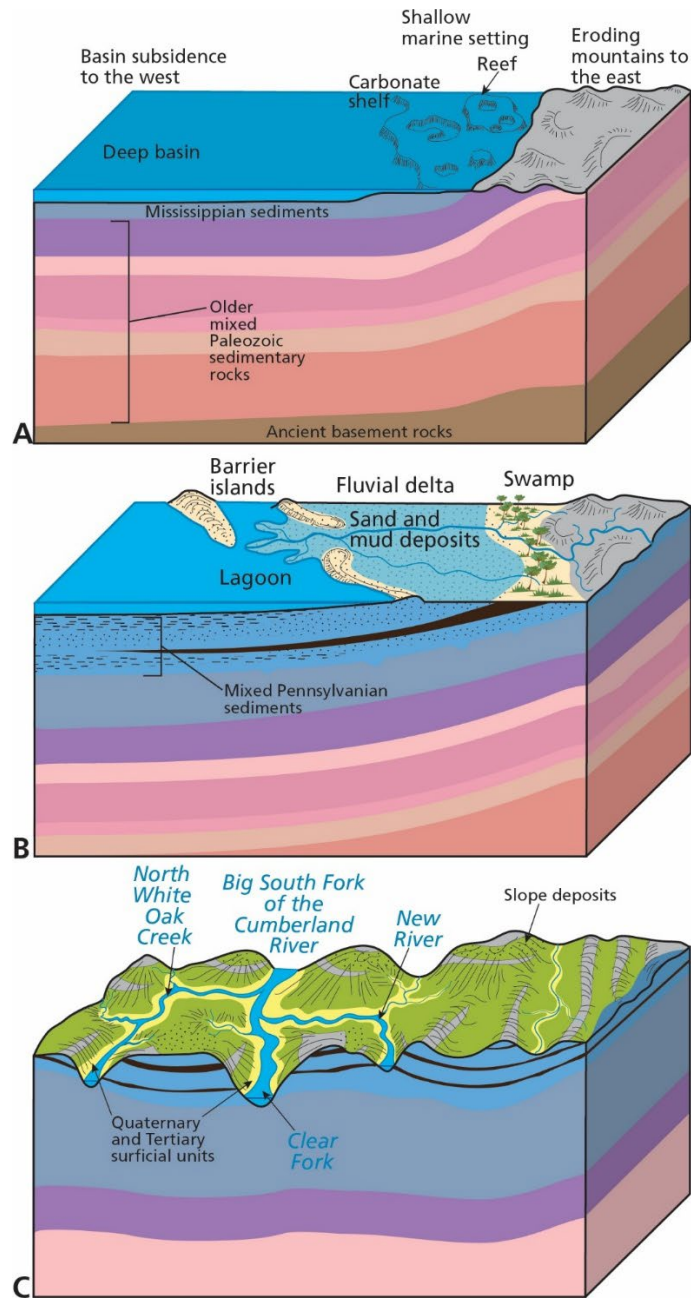


Figure 2. Block diagrams of the geologic evolution of the BISO landscape. A) About 320 million years ago, a marine environment accumulated fine-grained shales and limestones. B) After a period of erosion and non-deposition, about 300 million years ago, uplift of the area caused the sea level to drop, and rivers crossed the landscape, transporting and depositing sand and pebbles shed from the rising Appalachian Mountains to the east. This environment also fostered vast forests and swamps whose organic debris eventually became coal seams. Periodic marine incursions introduced more fine-grained layers into the mix. These layers constitute the Cumberland Plateau. Throughout the last 250 million years, weathering and erosion have removed vast amounts of material from the BISO landscape. C) The regional rivers and streams incised deep gorges, dissecting the tableland of the plateau. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), with information from Rice et al. (1979) and Milici et al. (1979).

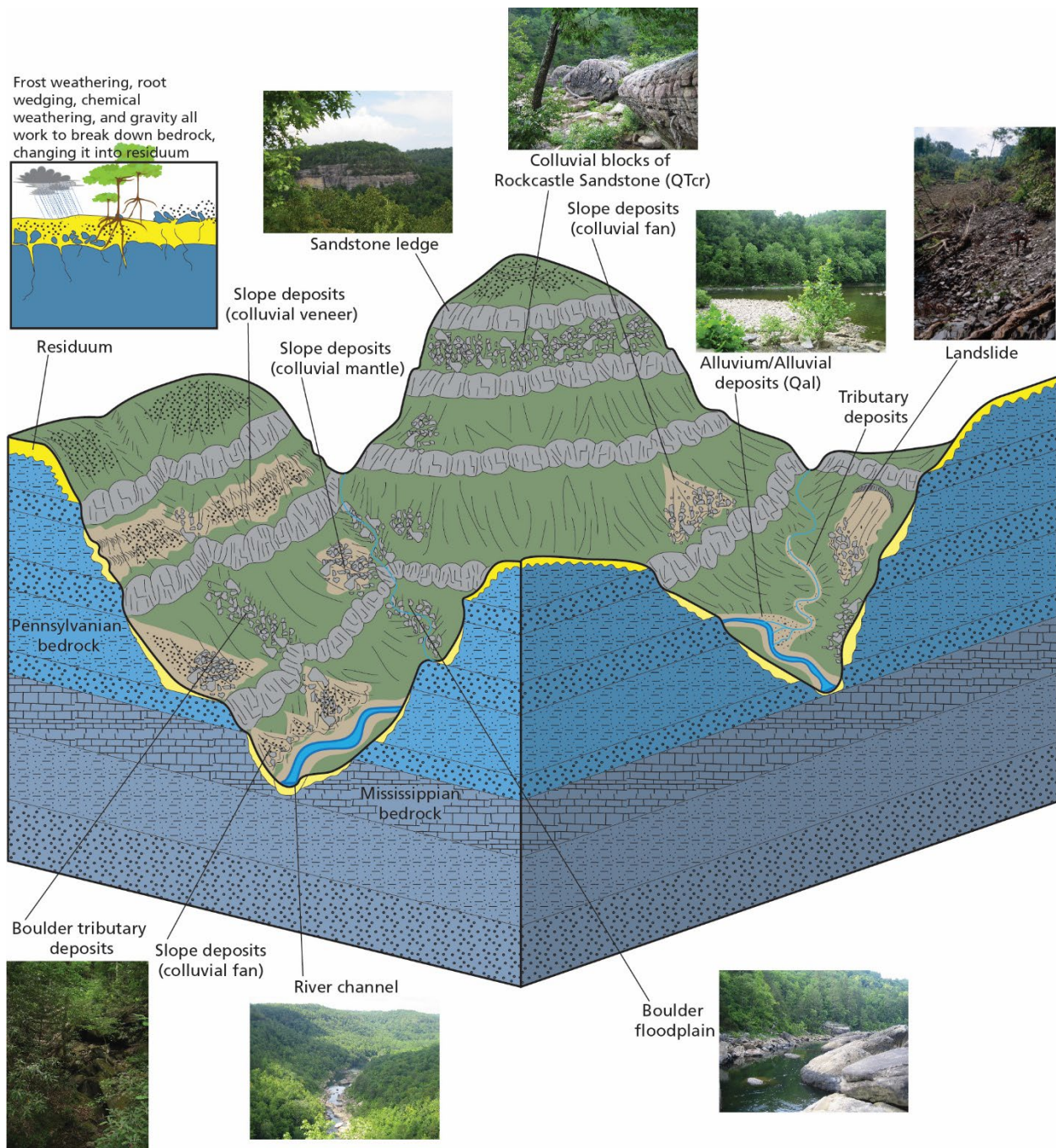


Figure 3. Block diagram of surficial units forming on the BISO landscape. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), with information from Yates and Kite (2014; 2015), and Kite (2016).

Geologic Heritage

Geologic heritage, or geoheritage, exists where geology overlaps with human experiences and values. It is our history told through the lens of geology. It encompasses the significant geologic features, landforms, and landscapes characteristic of our nation, which are preserved for the full range of scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values that society places on them. Geoheritage sites are conserved so that their lessons and beauty endure as a legacy for future generations. Such areas generally have great potential for scientific studies, use as outdoor classrooms, and enhance public understanding and enjoyment. Geoheritage sites are fundamental to understanding dynamic Earth systems, the succession and diversity of life, climatic changes over time, the evolution of landforms, and the origin of mineral deposits. Currently, the United States does not have a comprehensive national registry that includes all geoheritage sites, but many entities, including the NPS and the US Geological Survey (USGS), are working to introduce and advance the idea of geologic heritage for the American people (https://apps.usgs.gov/geoheritage_sites_of_the_nation/).

Geoheritage is prominent in BISO's 1974 enabling legislation (US Congress, page 43):

[BISO is established] for the purposes of conserving and interpreting an area containing unique cultural, historic, geologic, fish and wildlife, archeologic, scenic, and recreational values; preserving as a natural, free-flowing stream the Big South Fork of the Cumberland River, major portions of its Clear Fork and New River stems, and portions of their various tributaries for the benefit and enjoyment of present and future generations; the preservation of the natural integrity of the scenic gorges and valleys; and the development of the area's potential for healthful outdoor recreation.

Big South Fork and Gorge

The free-flowing Big South Fork and its tributaries flow for more than 760 km (90 mi) and carve 180-m (600-ft) deep scenic gorges and valleys through the layers of ancient bedrock of the Cumberland Plateau at BISO. This area is the most rugged territory on the plateau (Worsham et al. 2013; National Park Service 2017). State designations for Big South Fork include Outstanding National Resource Water, Exceptional Tennessee Waters, and Kentucky Wild River, attesting to its natural character (National Park Service 2017). From the water's surface to the rim of the canyon, breathtaking views of the area's natural scenery, sheer cliffs, rock formations, and waterfalls are valued by visitors (National Park Service 2017).

At BISO, erosion and weathering of the sedimentary rock layers above Big South Fork form myriad geologic features such as arches (defined as a hole in the rock with an opening of at least 1 m [3 ft]), overhangs, balanced rocks, chimneys, and rock shelters (Figure 4). Notable examples of these types of features at BISO include Chimney Rocks, Twin Arches, Split Bow, and Needle Arch. This concentration of arches may rival those at Arches National Park in Utah (Thornberry-Ehrlich 2009; Worsham et al. 2013). At BISO, arches tend to form in resistant Pennsylvanian sandstones, which are

locally undercut by erosion of less resistant underlying shales and siltstones. A single ridge can host a suite of features ranging in erosional development from an overhang to a fin to an arch followed by a chimney or balanced rock, which are the last erosional remnants of a ridgeline (Thornberry-Ehrlich 2009). The names of these notable places reflect their association with local stories.

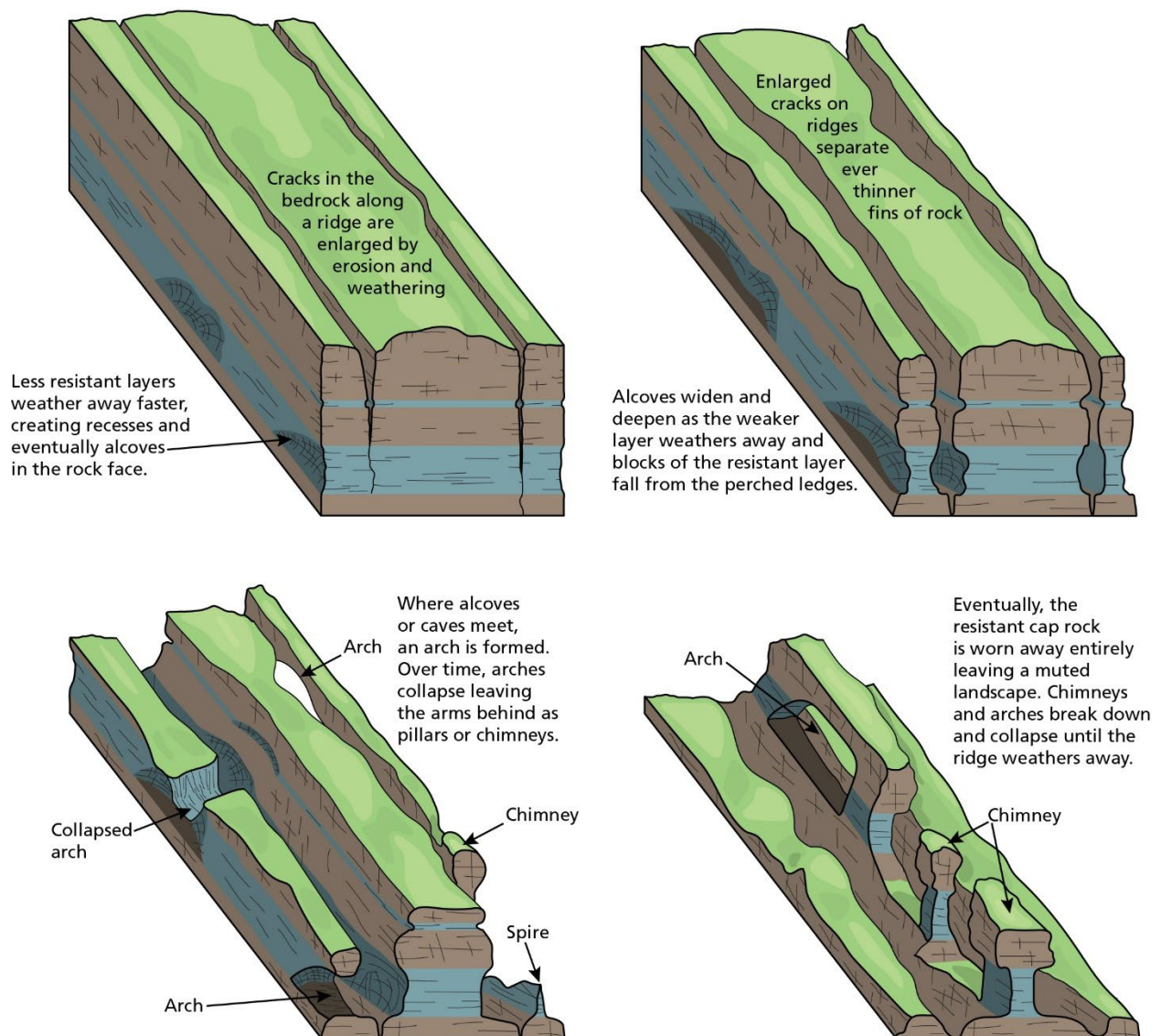


Figure 4. Block diagrams of rock formation evolution. At BISO, massive layers of resistant sandstone, interbedded with layers of less resistant siltstone or shale, set the stage for the formation of arches, alcoves or shelters, chimneys, ledges, and spires. The process causes ridges of rock to slowly be whittled away to thinner and thinner fins, which are breached in some places, forming an arch or window. Then, over time, the arch collapses and the fins are muted to mere bumps on the topography. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Stratotypes

Stratotypes are important geologic reference exposures that help identify, define, and correlate geologic units from one location to another. When geologists propose or describe a new layer or body of rock, a stratotype is assigned to exposures containing all (or most) of the unique diagnostic criteria. Stratotypes have significant scientific value and are often easily accessible, world-class locations to study outcrops of rock. Akin to natural libraries of Earth history, stratotypes preserve meaningful clues to the past and serve as geologic classrooms. The stratotype concept is ingrained in the modern system of geologic nomenclature, as many formal geologic unit names are derived from geologic or geographic features found near stratotype locations (e.g., the Cretaceous Mesaverde Group named for Mesa Verde National Park, Colorado). There are two kinds of stratotypes that are relevant to BISO: type section and type locality. A type section is an important reference exposure for a named stratified (layered) geologic unit. It presents a relatively complete and representative example of this unit. Once a type section is assigned, it is never changed. Type localities are specific geographic locations encompassing the type section of a formally recognized and defined geologic unit (North American Commission on Stratigraphic Nomenclature 2021; Henderson et al. 2022).

There are no designated stratotypes identified within the boundaries of BISO. However, the Pennsylvanian Burnt Mill Shale was named by Wilson et al. (1956) from exposures near Burnt Mill Bridge along the Clear Fork inside BISO in Scott County, eastern Tennessee. These key exposures lack proper stratotype designation. Within 48 km (30 mi) of BISO boundaries, eight identified stratotypes occur: the Mississippian Kidder Limestone Member of the Monteagle Formation (type section), the Pennsylvanian Crooked Fork Group (type section and type locality), Glenmary Shale (type locality), Slatestone Formation (type section), Coalfield Sandstone (type locality), Dorton Shale (type locality), and the Rockcastle Sandstone Member of the Bee Rock Formation (type locality; Henderson et al. 2021).

Paleokarst

Karst is a landscape that forms through the dissolution of soluble rocks, commonly carbonate rocks such as limestone or dolomite (Toomey 2009). The oldest rocks in BISO, Mississippian limestones exposed in the deepest reaches of the gorge, are carbonate rocks. Given the limited exposure of these rocks and the predominance of less soluble sandstones in the Pennsylvanian rocks, karst formation is limited in BISO. However, within the Pennington Formation is evidence of paleokarst (karst that formed coincidentally or shortly after the rocks formed; Humbert 2001). This evidence includes buried paleo-dolines (sinkholes), breccias (chaotic assemblages of rough, sharp fragments), solution holes, and depressions within the layers of limestone (Humbert 2001). Acting as a natural laboratory, these features shed light on the environment at BISO more than 320 million years ago.

Periglacial Features

Entrenchment of the gorges at BISO may have interesting connections to the evolution of the Ohio River Valley drainage before and after the Pleistocene ice ages (Thornberry-Ehrlich 2009; Phillips et al. 2010). The continental glaciers (ice sheets) did not extend as far south as BISO; however, the colder climate and impacts from the adjacent ice sheet altered the landscape. Prior to the advances of

continental glaciers, the Ohio River was a small tributary to the Mississippi River. The major drainage of the Appalachian area was further north as part of the Tertiary (66.0 million–2.58 million years ago) Teays River system. During the ice ages, glaciers dammed this northern drainage route, and water was forced to carve the Ohio River Valley relatively rapidly, shortening the distance to the base level (the lowest point to which it can flow or erode) of major tributaries, thus increasing slope gradients and triggering incision (Anthony and Granger 2007; Phillips et al. 2010). This major downcutting of regional rivers, including the Cumberland River system, proceeded quickly in geological terms, as tributaries maintained their base levels. Incision of the Cumberland River was initiated about 3.5 million years ago with pulses of quicker incision at 2 million and 1.5 million years ago (Anthony and Granger 2007; Phillips et al. 2010). The colder climate also accelerated weathering and erosion, leading to more slope movements regionally. These connections are complex and not yet well understood but have implications for regional geologic history, paleoecology, and geomorphology.

Rock Shelters and First Inhabitants

Thousands of rock shelters, arches, overhangs, and alcoves protected the earliest inhabitants of the area from the elements (Figure 5; Neff 1981; Ferguson 1988). These early people left behind cultural remains of pottery and lithic artifacts at approximately 1,350 documented sites in BISO (Neff 1981; National Park Service 2017). Lithic artifacts are stone tools made by humans: projectile points, axes, knives, spears, shards, etc. Archeologists look at the style and composition of the stone tools to determine their age (Ferguson 1988).

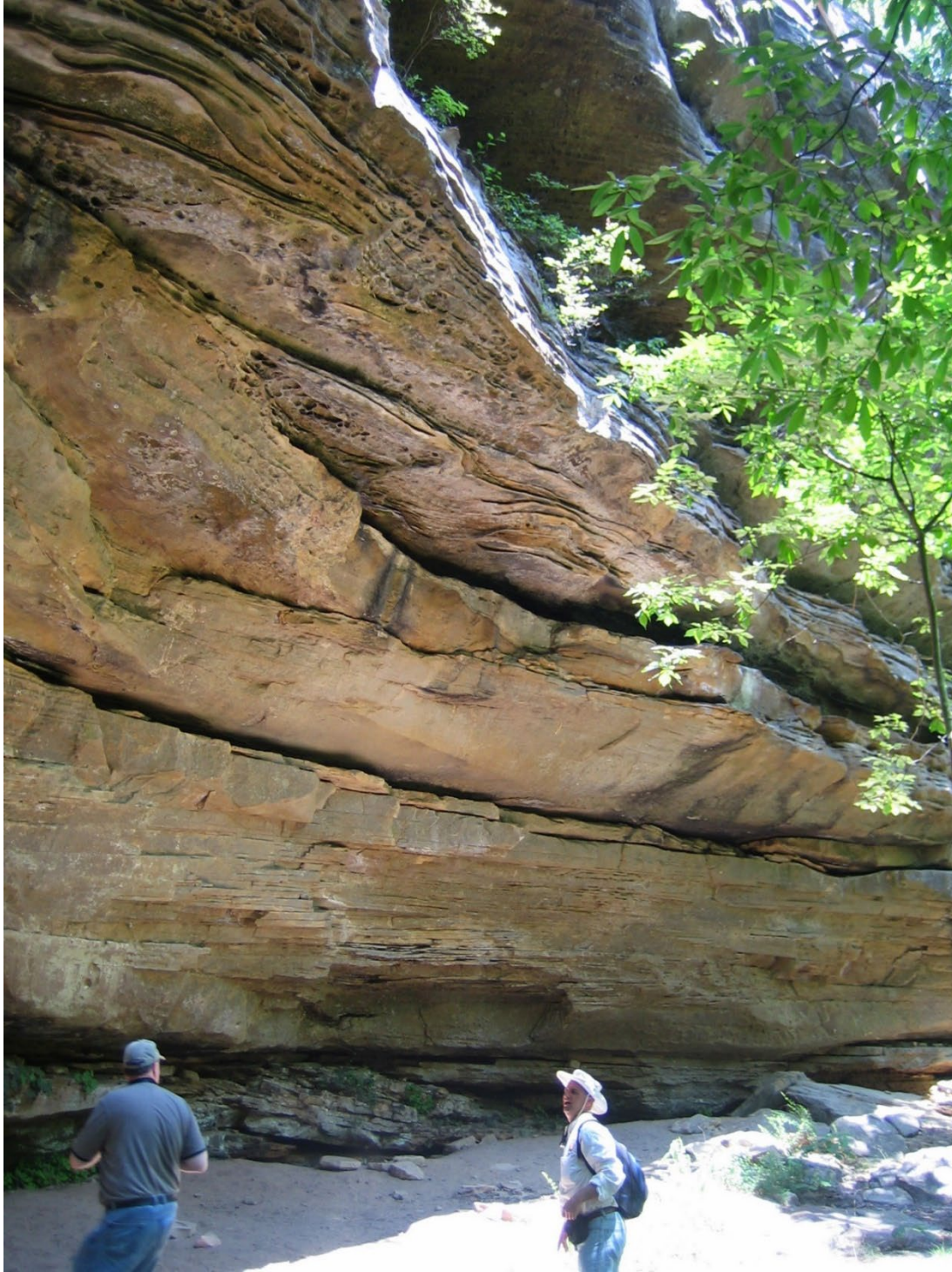


Figure 5. Photograph of a rock shelter at BISO. Resistant sandstone and conglomerate are left as ledges and overhangs when less resistant underlying layers are weathered or eroded away. This forms natural shelters that humans have used for thousands of years, leaving a rich archeological record at BISO. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University), taken in 2007.

In 1988, 45 sites in the uplands above the Big South Fork River valley were selected for lithic artifact analyses by the University of Tennessee and Tennessee Historical Commission to help determine behavioral patterns. These analyses showed that the earliest and most intensive use of lithic resources at BISO occurred during the early Archaic period (some 10,000 years ago), mainly in open upland environments rather than gorge rock shelters (Ferguson 1988). Another period of light occupation (possibly due to drier climate) was during the late Archaic/early Woodland periods (around 3,200 years ago). Indigenous groups intensified their use of the area during the middle Woodland period (about 1,800 years ago) with a preference for gorge rock shelters. This was followed by moderate use during the late Woodland period (more than 400 years ago; Ferguson 1988).

In addition to studying when and where Indigenous groups were occupying the Big South Fork River valley, understanding where the lithic material was sourced yields information about procurement strategies, territoriality, and mobility. The materials used at BISO (like chert, chalcedony, and other microcrystalline rocks) were quarried or sourced from areas ranging from 14 to 26 km (7 to 16 mi) away from BISO's rock shelters, most likely from the Mississippian rocks of the eastern Highland Rim physiographic province to the west and the Mississippian and Ordovician (485.4 million–443.8 million years ago) rocks within the Valley and Ridge physiographic province to the east (see Figure 1). The Pennsylvanian rocks at BISO only have scant microcrystalline rocks and thus were not a significant lithic source. An abundance of exotic (not locally sourced) raw materials suggests settlement and trade activities in adjacent regions, predominantly from the west (Ferguson 1988).

Homesteading

As early as 1780, people of European descent were hunting and exploring in the BISO area. Homesteaders soon followed, and by 1800, there were several permanent homesteads. Natural rock shelters also became early homes for settlers (Thornberry-Ehrlich 2009). The rugged landscape was unforgiving, as suggested by local names such as Troublesome, Difficulty, and No Business Creeks. Soils atop the tablelands were sparse, and the slopes were steep and rocky. The only fertile land was confined to small, narrow areas along the rivers and streams, and these areas were prone to flooding.

Hardy pioneers thrived on the relative isolation and independence of the Cumberland Plateau, and innovators found ways to make money. Miners extracted potassium nitrate (saltpetre or “nitre”) from sediments in small overhangs and shelters. Saltpetre is an oxidizing component that is combined with charcoal and brimstone (sulfur) to make gunpowder. Mining for saltpetre from cliff mines at BISO flourished around the time of the War of 1812, and there was a local resurgence during the American Civil War.

In addition, some remote areas of BISO were used to obfuscate the operations of moonshine distilleries from the late 1800s through the early to mid-1900s (National Park Service 2015a). However, opportunities were limited for these early settlers, and most communities slowly vanished after World War II. All that remains are scattered cemeteries and chimney stacks (Neff 1981; National Park Service 2015a). Some 58 cemeteries are located throughout BISO, with the oldest one dating to 1848 at No Business Creek. Gravestones and hearthstones were sourced locally from the Mississippian and Pennsylvanian sedimentary rocks, which make attractive building materials and

flagstones. Early German settlers mined rocks to crush for aggregate along Williams Creek and Cub Branch during the late 19th and early 20th centuries. Most of the roadways in Scott County contain material from this early quarrying (Thornberry-Ehrlich 2009). On the western side of Big South Fork, beyond BISO boundaries, the Rockcastle Sandstone is still quarried for dimension stones for local developments.

Oil, Gas, and Coal

The Mississippian rocks at the base of the gorge at BISO contain oil and gas resources. These resources contributed to a long local history of oil and gas development in BISO. In 1818, Marcus Huling used a foot-powered drill to accidentally establish the first commercial oil well in Kentucky (and arguably the entire US) on a 306-ha (757-ac) lease from Martin Beatty (a furnace operator at Cumberland Gap turned salt producer), near the confluence of Big South Fork and Bear Creek at BISO. The “Beatty well,” drilled to 61 m (200 ft), was so deep, local lore says they feared they were drilling into “hell.” Drilling in this area was initially seeking salt brine (salt licks or seeps were nearby) to produce salt—a valuable resource at the time, which was used for food preservation, tanning hides, and seasoning (Filson 1784; Shepherd 1988; Nuttall 2014; National Park Service 2015a). However, instead of salt brine, a black, smelly, sticky liquid came oozing out of the pipe. Ignorant of what this flammable substance was, a man was sent downriver on a raft with a sample of the substance for examination. However, superstition ruled the day, and when the raft capsized in the worst rapids, the raftsmen claimed the Devil himself leaped from the large rocks onto the raft, sinking it, and reclaiming his stolen property—the “Devil’s Tar.” Since then, the rapid has been known as Devil’s Jump (National Park Service 2015a).

The Beatty well was very productive. At its peak, it was producing 100 barrels of oil per day. This oil was used throughout the US, and some was even exported to Europe. Overland routes carried oil to manufacturers of British Oil, Seneca Oil, Mustard Liniment, and other medicinal preparations (Jillson 1952; Nuttall 2014). Oil would periodically overflow into the river as black slicks that covered the water’s surface, drifted downstream, and wreaked havoc. It was once possible to sample oil from the site at BISO; however, in 2011, the Beatty well was plugged from a depth of 30 m (98 ft) to the surface by the National Park Service (Shepherd 1988; Nuttall 2014; Etta Spradlin, biological science technician, Big South Fork National River and Recreation Area, written communication, 21 May 2025).

Oil and gas development left a lasting legacy at BISO. Since 1990, no new wells have been drilled within BISO boundaries; however, at least 326 oil and gas sites remain (e.g., wells, tank batteries, compressors, abandoned wells, and peripheral sites; Thornberry-Ehrlich 2009; Worsham et al. 2013). BISO’s enabling legislation prohibits oil and gas extraction and development within the gorge area but allows for permitted development in the adjacent areas. As technology advances and economic interest increases, exploration for deeper reservoirs and resources may accelerate in the BISO area. Wells to the west of BISO and other areas of the Cumberland Plateau have been drilled as deep as over 3,000 m (10,000 ft). New wells may encounter natural gas reservoirs, which produce for a

longer period than traditional oil wells and have a longer impact on the environment (Thornberry-Ehrlich 2009).

The Pennsylvanian rocks, so well exposed in the steep-sided gorges, contain abundant coal seams (Figure 6). The earliest recorded coal mining activity at BISO was in the 1820s, when coal was extracted at the surface and floated downstream on river barges (Barclay and Parsons 1983; Leary 1991). During the industrial revolution, coal mining camps dotted the BISO landscape as steam engines fueled by coal became a vital means of transportation for the growing country (Blair 2010). Extensive coal mining occurred throughout the BISO area from the 1880s to the 1960s (AMEC Earth and Environmental, Inc. 2001). The largest coal mining operation in the Cumberland River watershed was by the Stearns Coal and Lumber Company, founded in 1902. At its peak in 1929, the Stearns coal zones produced 1 million tons of coal, employing more than 1,300 miners (AMEC Earth and Environmental, Inc. 2001). While mining continues in the area today, BISO legislation prohibits mining within the gorge but permits limited (no surface or strip mining) extraction on the Cumberland Plateau. Approximately 8,100 ha (20,000 ac) at BISO have private mineral rights (Thornberry-Ehrlich 2009).



Figure 6. Photograph of a coal seam exposed in an outcrop at BISO. Heterogeneous layers of sedimentary deposits characterize the Pennsylvanian rocks, recording shifting environmental conditions during their deposition. The coal seam (yellow arrow) records the existence of an ancient, long-standing swamp or marsh in this location. Organic material accumulated in the marsh and was later buried, heated, and compressed by overlying deposits to form coal. When the seams are thick enough, they become economically viable to mine and extract for heating and energy production. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University), taken in 2007.

Unique, Geologically Controlled Habitats, and Ecological Relationships

Important relationships exist between flora, fauna, soils, and geologic outcrops at BISO. The Cumberland Plateau is the world's longest expanse of hardwood-forested plateau (The Nature Conservancy 2003; Hughes et al. 2018). Weathering of the geologic units plays a major role in the formation of soils that support the forests. Landscape position, parent material, local climate, organic input, and time are important factors in determining the amount of available plant nutrients in any given soil (Blair 2010). The rock underlying the gorges, escarpments, hillsides, and ridgetops in BISO gives rise to relatively nutrient-poor soils. Whereas soils derived from the rock and alluvium underlying the floodplains have more essential nutrients (Natural Resources Conservation Service 2013).

The BISO area straddles several climate zones and contains more families of woody plants than the Great Smoky Mountains (Thornberry-Ehrlich 2009). Globally rare vegetation communities at BISO have strong geologic connections as reflected in their names, including Cumberland Plateau rockhouse, Cumberland riverside scour prairie (also known as Cumberlandian cobble bar habitats), mountain laurel–huckleberry Cumberland sandstone heath glade, and Cumberland Plateau clifftop sandstone barren (Nordman 2011; Worsham et al. 2013). Carbonate rocks (e.g., limestone or dolomite) or rocks containing intergranular carbonate cement (the “glue” material between grains of rock) support localized colonies of aquatic life, plants (ferns), birds, and mammals. Other distinct plant communities are associated with moist, north-facing slopes, steep sandstone cliffs, and the contacts between shale/coal and sandstone layers (Thornberry-Ehrlich 2009; National Park Service 2107). Sandstone heath glades (sandstone caprock with dry shallow soils) are specialized habitats on the dissected upland areas between gorges (National Park Service 2017).

The rivers themselves harbor unique aquatic and riparian habitats. Within the river channels are Cumberlandian cobble bar habitats (known as river scour prairies) that are only found in this part of Kentucky and Tennessee (National Park Service 2017). These habitats are adapted to frequent flooding events, which limit the number of competing woody species and facilitate mainly riparian species such as herbs, grasses, shrubs, and forbs, some of which are species of concern (Worsham et al. 2013). The river also harbors 45 species of mussels, some of which are adapted to living in cobbles and boulders in the Big South Fork gorge, making it one of the most diverse mussel assemblages for any river in the US. Ten of the mussel species are endangered, one is threatened, and two are proposed as endangered. Four mussel species have federally designated critical habitats within BISO (National Park Service 2017; Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025). Mussels are adapted to the cobble and boulder habitats, including the various-sized rocks, sand pockets, and flowing shallow water. The river is mostly large pools, with occasional riffles occurring where streams enter the main channel. Cobble bars are the result of erosion from the side streams dumping cobbles and boulders into the main channel, which creates the cobble boulder habitat (Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025). Lentic (still water) conditions in Lake Cumberland are stressors to the mussel community at BISO (Worsham et al. 2013). In areas where acid mine drainage has

lowered pH, the mussels are absent. In areas where the high acidity is diluted/buffered between New River and Bear Creek, populations are flourishing (Thornberry-Ehrlich 2009). Detailed geologic mapping at BISO could help focus ecological research.

The many rock shelters and alcoves at BISO provide unique habitats for bats, plants (e.g., sandwort and a newly described lily), and other creatures seeking shelter in the region. Threatened and endangered Indiana bats roost in stone shelters and overhangs in the area during summer feeding seasons. The sandstone cliffs lining the gorges at BISO provide habitat for plant communities, including vascular plants (e.g., ferns), bryophytes (e.g., mosses), and lichens, whose distribution and condition depend on factors such as slope aspect, slope angle, and surface heterogeneity (Boggess et al. 2017).

River Rapids and Recreation

The sheer cliffs along the gorges at BISO are striking geologic features and testaments to the extreme local relief. The relief contributes to many waterfalls. Prevalent among them are Slate Falls in Tennessee and Yahoo Falls in Kentucky, the tallest in the state. The watercourses host abundant recreational opportunities, including canoeing, kayaking, rafting, and fishing. The flow of water around the bedrock layers and large blocks that have fallen from the cliffs above creates exciting rapids and obstacles for water enthusiasts. Big South Fork and its tributaries include many named rapids (e.g., Washing Machine, Rion's Eddy, Jake's Hole, Devil's Jump, and Angel Falls), some of which are class IV, meaning they are long and powerful rapids with standing waves and boiling eddies that require power and precise maneuvering (Figure 7; Thornberry-Ehrlich 2009; Gordon 2025). The difficulty of rapids is directly correlative with the local geology and geomorphology of the river channels. At BISO, the steepness of the channel, the resistant bedrock layers forming ledges, scouring floods, the pool-riffle sequences, the coarse bedload (material along the river bottom: large sandstone blocks, boulders, cobbles), and the winding nature of the gorges all work together with the water flow to create thrilling but potentially dangerous rapids (Thornberry-Ehrlich 2009; Maner 2010; Phillips et al. 2010).



Figure 7. Photograph of the rapids at Angel Falls. Large boulders of sandstone and conglomerate litter the base of the slopes along the Big South Fork gorge. In places where the river narrows and the geomorphology of the channel is appropriate, rapids, whirlpools, and eddies form. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University), taken in 2007.

Resource Management Issues and Inventory Needs

This section briefly summarizes the geologic resource management issues, inventory needs, and geologic hazards that have been identified through park documents and discussions with BISO staff. Geologic issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what is needed to ensure best management practices at BISO. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Refer to the [Guidance for Resource Management SharePoint](#) for more information regarding geologic resource management.

Abandoned Mineral Lands (AML) and Oil and Gas Operations

Geologic resources (mostly hydrocarbons) at BISO have fueled human interest for more than 200 years. The legacy of this ongoing history is profound and long-reaching. The NPS Energy and Minerals programs fund and support issues associated with AML and orphaned oil and gas wells. Please see the [GRD Energy and Minerals Branch SharePoint](#) and the [Guidance for Geologic Resource Management](#) for more information regarding the management of mining and minerals, AML, and oil and gas. Short issue descriptions are included here for reference and to highlight connections with other resource management issues.

AML

AML are areas that contain facilities, structures, improvements, and disturbances associated with past mineral exploration, extraction, processing, and transportation. The NPS acts under various authorities to mitigate, reclaim, or restore these areas to reduce hazards to and impacts on resources. The NPS AML database identified 394 sites and 541 features within BISO (Burghardt et al. 2014; Brian Barbaris, physical scientist, Big South Fork National River and Recreation Area, written communication, 5 May 2025); however, the exact number remains unknown due to remoteness of past activity and current vegetative cover, and thus an inventory is needed (Thornberry-Ehrlich 2009). These data are ranked with hazard ratings, priority, accessibility, significance, and resource impacts (Burghardt et al. 2014). Some criteria warrant revisiting and revising (Brian Barbaris, physical scientist, Big South Fork National River and Recreation Area, written communication, 5 May 2025). The number of coal-specific features and sites are 172 and 26, respectively, with nearly half still requiring mitigation (Brian Barbaris, physical scientist, Big South Fork National River and Recreation Area, written communication, 28 May 2025).

Some of the earliest AML at BISO are associated with saltpetre mining in alcoves and small caves. Remnants from this activity include old workings as well as wooden supports, which may pose a collapse hazard in certain areas. At Hatfield Ridge, 150-year-old oak posts support large sandstone boulders associated with this mining (Thornberry-Ehrlich 2009; Etta Spradlin, biological science technician, Big South Fork National River and Recreation Area, written communication, 21 May 2025).

Local coal mining is a big part of BISO's story and continues today. Legislation prohibits mining within the gorge but permits extraction on the plateau uplands provided it does not involve surface or strip mining. Private mineral rights encompass about 8,100 ha (20,000 ac) at BISO. Coal mines were active in the New River basin, upstream of BISO, causing water quality issues downstream (e.g., increased sediment loading, heavy mineral content, acid mine drainage; see "Contaminated Mine Drainage" section). BISO's enabling legislation grants some jurisdiction over the water quality of the New River and influence on land-use activities there, which must comply with the Surface Mining Control and Reclamation Act of 1977. Advances in energy technology have made it possible to use less refined or pure coals, leading to renewed interest in areas that were once considered unviable due to the low quality of the coal, including the area surrounding BISO (Thornberry-Ehrlich 2009). However, energy production and industry shifted to natural gas (see "Oil and Gas") because it is abundant, cheaper, and cleaner, causing the economics of coal to collapse somewhat in Tennessee (Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025).

The legacy of historical coal mining is far-reaching. More than 3,000 inactive coal mines are located within the New River watershed (National Park Service 2017). BISO contains at least 112 mine openings, the majority of which are in Kentucky. Most of these old mines were deep shafts that followed a coal seam and incorporated local streams and ventilation punchouts on a nearby slope face (Figure 8; Thornberry-Ehrlich 2009).

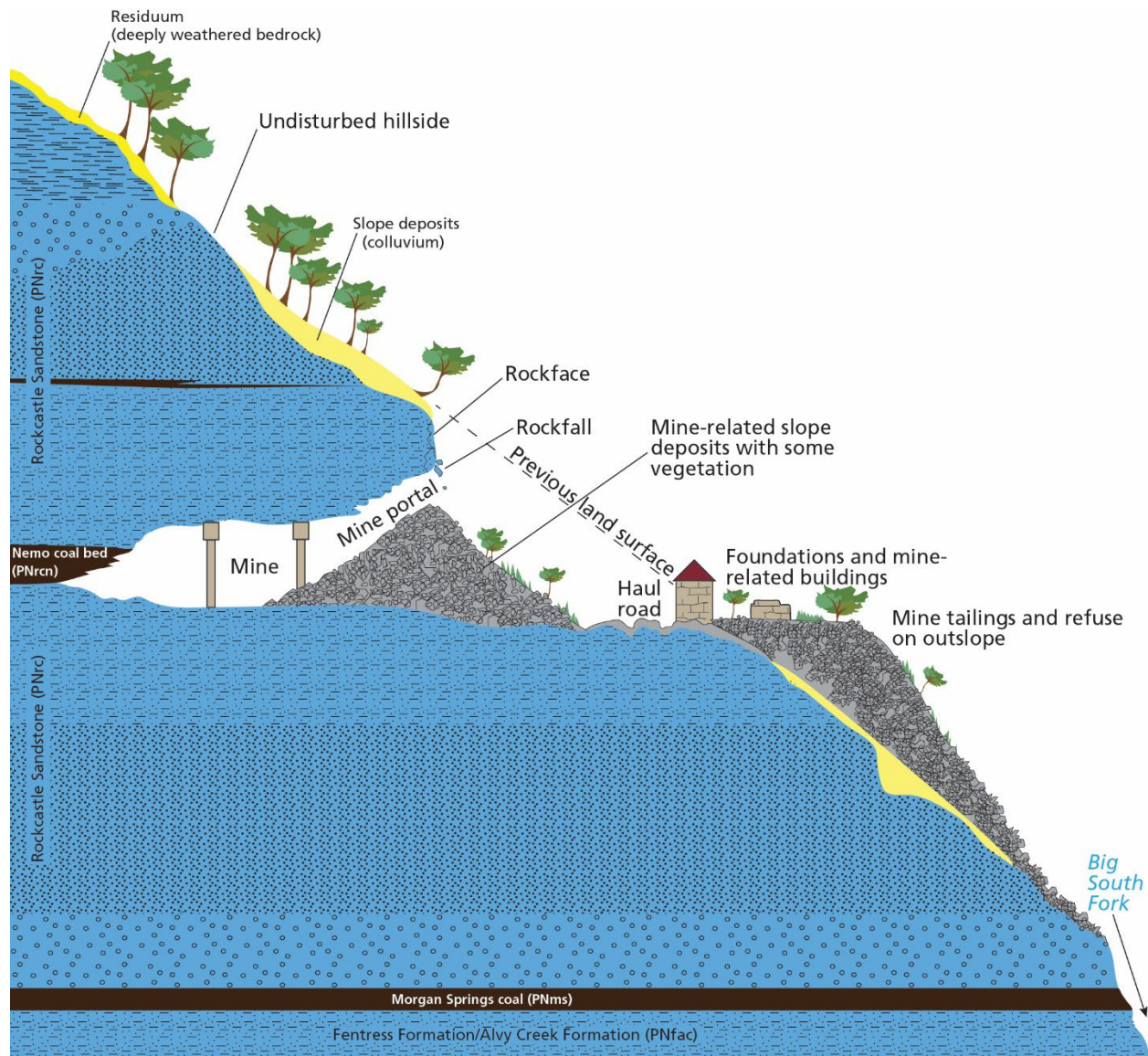


Figure 8. Diagram of abandoned coal mining features. Many abandoned coal mines are present within BISO. Even with deep mines, the natural land surface is highly altered. Note the previous land surface (dashed line). Landform change continues as the mines collapse and tailings (refuse or spoil) piles undergo exacerbated slope movement processes. Vegetation is slow to reestablish on mine tailings. Units were chosen to represent a mine into the Nemo coal bed (geologic map unit PNrcn). Graphic adapted from diagram 1 in Pollio (1991) by Trista L. Thornberry-Ehrlich (Colorado State University).

Other mining-related issues at BISO include hazards from remaining shafts and subsidence holes. Open shaft mines are dark, deep, uneven, and pose serious risks to human safety. In the Kentucky portion of BISO, two subsidence holes are the result of the collapse of underlying coal mine features. Piles of soil and rock plug most abandoned mine openings, but as this unconsolidated material settles, slumps, or erodes away, some openings are exposed. Some exposed openings have metal gates (barred bat gates are the preferred mine closure to allow bats to access cave habitat; Thornberry-Ehrlich 2009).

Unconsolidated mine tailings or spoils are prone to slope failures. At Blue Heron, a failure event resulted in the movement of large masses downslope and the opening of large crevasses. Below the Devils Jump Overlook, mine spoil piles and an old railroad bed flank the eastern edge of the river. The spoil piles are slow to revegetate, and today they appear as a conspicuous grassy slope (Figure 9). In 2021, this slope and the associated mine spoils were recontoured and covered with riprap by the US Army Corps of Engineers (USACOE) to reduce slope failure and to reduce the impact of the river eroding the toe (base) of the slope. This project was done to address Endangered Species Act (ESA) Section 7 mitigations from lowering Wolf Creek Dam when it was repaired (Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025). Water can flow through the bottom of spoil piles, resulting in contaminated mine waste flowing into Big South Fork. At Worley, eroding unburned “paper” shales, which contain naturally occurring arsenic and cyanide, wash off the upland hillsides and into the river, causing local contamination (Thornberry-Ehrlich 2009). In the New River corner of the basin, outside BISO boundaries, steeper gradients associated with spoil piles have resulted in large, 11 ha (26-ac) slides (Thornberry-Ehrlich 2009).



Figure 9. Views from Devil's Jump overlook toward remediated mine tailings areas 2007 and 2025.

The tailing pile slopes are covered with grass but stand out because there is less vegetation compared to the surrounding forest, even after nearly 20 years. Vegetation grows more slowly on the remediated mine tailings than in the surrounding landscape. Mine tailings or spoil piles are prone to mass wasting and are slow to recover a natural appearance after being abandoned. Riparian vegetation along the river's edge has been making a strong recovery since 2007. Top photograph by Trista L. Thornberry-Ehrlich (Colorado State University), taken in 2007. Bottom two photographs are NPS photographs taken in May 2025 by Brian Barbaris.

Contaminated Mine Drainage

Coal mining artificially exposes coal to air and water. When high-sulfur coal and pyritic shale deposits are exposed to air and water, oxidation reactions produce acidic runoff or drainage. High acidity then increases the solubility of some potentially harmful heavy metals exposed in coal and mine tailings, which then come out of solution as precipitates when the water is neutralized (Worsham et al. 2013). Where acid mine drainage in BISO contains iron, heavy metals, or trace amounts of hydrocarbons in solution, it is commonly referred to as contaminated mine drainage (CMD), which can then degrade local soils and harm plant and animal life (Figure 10; Thornberry-Ehrlich 2009; Worsham et al. 2013; National Park Service 2017).



Figure 10. Photograph showing contaminated mine drainage entering Big South Fork at Worley. Acid mine drainage leaches heavy metals that then come out of solution to coat river cobbles and pebbles with an orange-colored precipitate. High pH and heavy metal contamination can create dead zones in BISO streams. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in 2007.

Over 40 sites with CMD occur within BISO (Brian Barbaris, physical scientist, Big South Fork National River and Recreation Area, written communication, 5 May 2025). The sites have characteristic feature types:

- Open mine entries with CME (clearly need remediation)
- Closed mine entries with CMD (need mitigation)
- Large (>0.4 ha [>1ac]) CMD pools at a distance and separate from the mine source
- Random seeps that are not obviously connected to a mine entry (possible coal seam seepage)
- Mine spoils pile drainage

Various local streams and springs drain abandoned coal mines and produce acidic runoff, or CMS. At least 15 streams affected by acid mine drainage are known within BISO; low pH streams are commonly devoid of aquatic life. Streams such as Bear and Rock Creeks had pH levels ranging between 2 and 4.5 prior to remediation. Mine areas susceptible to CMD include Blair Creek, Bowen, Bertram, Zenith, and White Oak (Thornberry-Ehrlich 2009; Brian Barbaris, physical scientist, Big South Fork National River and Recreation Area, written communication, 5 May 2025). When compared with watersheds that have not been disturbed by mining activities, watersheds such as New River have impacted water quality (e.g., pH oscillations; elevated calcium, magnesium, iron, and manganese; and increased sulfate and solids in suspension or sediment loading) regardless of how long ago the mining occurred (Minear and Tschantz 1976; Worsham et al. 2013; National Park Service 2017).

BISO staff wants to increase pH in affected areas (Thornberry-Ehrlich 2009); doing this usually involves preventing low pH waters from forming in the first place (i.e., preventing the air, water, and sulfidic minerals from mixing) or treating the low pH waters chemically or passively (e.g., anoxic limestone drains, constructed wetlands, or polishing ponds; AMEC Earth and Environmental, Inc. 2001). Natural buffering occurs where carbonate-rich rocks or intergranular cements underlie acidic streams. At BISO, streams with limestone parent material, mostly in the western half, have higher pH than those flowing over sandstone (Worsham et al. 2013). Overall, the soils developed from sandstone, shale, and siltstone have a low capacity to buffer acidic inputs (Natural Resources Conservation Service 2013; Hughes et al. 2018). Many methods used to treat CMD include wetlands and bogs, ponds, chemical reaction pools, and limestone neutralization. Some treatments may require importing materials.

Treatment or remediation of many sites at BISO is limited by the size of the exposed creek bed, abundance of local carbonate rock, and rugged local topography. Some techniques involve the formation of a series of pools, each controlling a particular chemical reaction to neutralize the water and collect heavy metal precipitates. However, some streams have a limited area available for constructing the pools needed to neutralize the water before it enters Big South Fork. For example, at Worley, 3 ha (8 ac) are necessary to remediate the mine drainage, but only 1.6 ha (4 ac) are available (Thornberry-Ehrlich 2009). More research is needed to determine multi-faceted, low-impact approaches to remediating CMD at BISO.

Oil and Gas

Wells, tank batteries, compressors, abandoned wells, peripheral sites, and unreclaimed areas are among the 326 oil- and gas-related sites within BISO (Thornberry-Ehrlich 2009). Beginning with the

first well in 1818, most of the oil and gas development occurred before the 1974 enabling legislation. The enabling legislation prohibits oil and gas extraction and development within the gorge area but allows for permitted development of privately retained mineral rights in the adjacent areas. Since 1990, no new wells have been drilled within BISO (Thornberry-Ehrlich 2009; Etta Spradlin, biological science technician, Big South Fork National River and Recreation Area, written communication, 21 May 2025).

Most oil and gas operations at BISO were/are conducted by small oil and gas companies, some of whom in the past did not properly maintain infrastructure or correct problems associated with their operations (Thornberry-Ehrlich 2009). Oil and gas activities in the area include shothole drilling and detonation, construction of roads, well pads, production facilities, flowlines, pipelines, and all-terrain vehicles (ATV) and truck access roads. Poor drilling practices and lack of maintenance have caused erosion, rutting, and compaction of access roads and well pads; loss of soil productivity; leaking pumpjacks, flowlines, and pipelines; contaminated pits; leaking gas wells; leaking tank batteries and loading areas; and brine water contamination. These issues have negatively impacted vegetation and riparian areas, leading to the degradation of the natural environment (Thornberry-Ehrlich 2009). Lack of fencing around wellsites poses public safety problems. For most oil and gas production sites, the main sources of human health and ecosystem risk are hydrocarbons (especially the fraction that is dissolved in groundwater), brine water extracted with the hydrocarbons, and radionuclides, principally radium found in the brine water or its associated scale and sludge (Otton and Zielinski 2000). These can be detected quickly and relatively simply with appropriate equipment and techniques, allowing for prioritized site remediation (Otton and Zielinski 2000).

As technology advances and economic interest increases, exploration for deeper reservoirs and resources may accelerate in the BISO region. Schenk et al. (2006) estimate the volumes of undiscovered oil and gas resources that may underlie BISO at 453 million m³ (16 billion ft³) of gas, 15 thousand barrels of oil, and 232 thousand barrels of natural gas liquids.

Fluvial Issues

Big South Fork and its associated tributaries are the primary natural resources at BISO and are significant because they are among the last free-flowing (undammed) stretches of water in the eastern United States (Thornberry-Ehrlich 2009; National Park Service 2017). The inherent steepness of the river course leads to high-energy water-flow instability along the corridor as well as a series of rapids. Flows can range significantly over the course of a season—between 0.2 and 1,400 m³ per second (10 and 50,000 ft³ per second [cfs]; Thornberry-Ehrlich 2009). Protection of fluvial resources at BISO is a challenge because its protected area is relatively small compared to the whole watershed, and many impacts originate outside park boundaries (Hughes et al. 2018).

The General Management Plan and Environmental Impact Statement for BISO (National Park Service 2005) identified several intended management goals related to fluvial resources:

- Preservation of the natural free-flowing character of the Big South Fork River and its tributaries within BISO.

- Continued existence of natural aquatic, riparian, and wetland environments in which natural physical, chemical, and biological processes function healthfully.
- Maintenance of aquatic systems to support sensitive native indicator species.
- Continuation of natural hydrological processes that shape the landscape of BISO by periodically flooding the bottomlands in a dynamic process of erosion and deposition.
- Maintain the existence of surface waters that provide high-quality fishing and swimming and are consistent with the Clean Water Act and other applicable laws and regulations.

Fluvial issues at BISO include riverbank and head-cutting erosion. Erosion along river channels is a natural process that occurs as rivers adjust to disturbance events and to changes in water and sediment delivery over time (Field et al. 2025). The resulting migration (lateral movement) of river channels is fundamental to building complex, dynamic, and resilient landscapes and dependent habitats. Head-cutting erosion, specifically, is a type of erosion that happens at the origin or head of a stream or gully, causing it to move uphill over time. Natural erosion is crucial for sustaining healthy rivers and should be preserved whenever possible (Field et al. 2025). However, BISO managers may deem protection from bank erosion necessary if bank retreat threatens infrastructure, developed land, or other valuable natural and cultural resources (Field et al. 2025). At the Yamacraw Bridge area, the BISO maintenance staff installed structures to stabilize the shoreline at the canoe launch (Thornberry-Ehrlich 2009). Field et al. (2025) describe various surface treatments and flow deflection treatments to protect designated riverbanks (Figure 11).

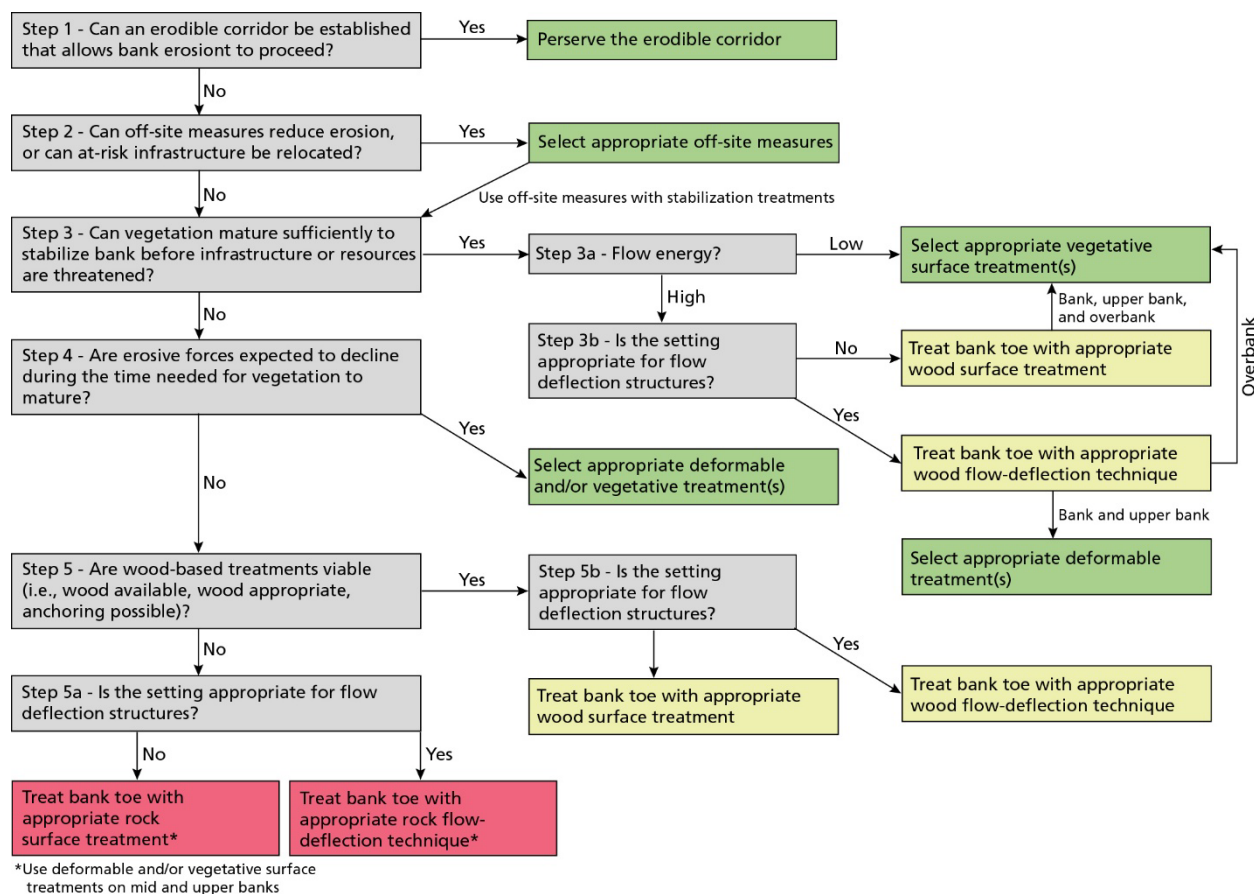


Figure 11. Decision tree to manage riverbank erosion. Step-by-step guidance to determine the best course of action is useful for BISO managers assessing the feasibility of armoring or protecting a riverbank. The colored boxes represent a continuum of bank erosion management strategies going from more natural (green) to less natural (red) aligned with Wild and Scenic River (but also largely applicable to BISO) values and NPS policies. The erodible corridor is a defined area wherein the river can freely migrate. Off-site measures are activities that slow bank erosion without stabilization techniques. Surface treatments are bank stabilization measures that rely on covering the bank with different types of erosion-resistant material: vegetation, wood (logs), deformable treatments (erosion control blankets), and hard armoring (stone or concrete). Flow deflection treatments redirect the flow away from erosion-susceptible areas. Graphic is figure 10 in Field et al. (2025), redrafted by Trista L. Thornberry-Ehrlich (Colorado State University).

Unnaturally increased sediment load (sedimentation) in Big South Fork and its tributaries is a primary threat to fluvial resources. Sediments cloud the water, change natural water levels, and smother the bottom of the channel. These increases stem from past mining and oil and gas activities, roads and trails, forestry, off-road vehicles, and agriculture (Hann et al. 1994; Massey 2008; Hughes et al. 2018; Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025). Sediments are released by ground disturbances, which are passed downslope with runoff to the receiving water body (Massey 2008). In places where mining occurred, the dissolved and suspended solids in the water are twice that of a similar river basin without mining (Hughes et al. 2018). Increased sedimentation occurs in some

streams near high-use areas such as horse or ATV trails. Some trails were developed using a bulldozer that cut a wide swath through the forest, removing stabilizing vegetation and disturbing the soils. Subsequent accelerations in runoff and erosion locally increase sediment load and change channel morphology.

Flooding on the Big South Fork of the Cumberland River poses challenges for resource managers due to its dynamic hydrology, steep topography, and complex watershed interactions. The river and its tributaries are subject to both flash flooding and prolonged inundation events, particularly during periods of intense rainfall common in late winter and early spring. Notable floods occurred in 2020, 2021, and 1957—an event that required evacuations, blocked roads, and contaminated water supplies (National Park Service 2020; National Oceanic and Atmospheric Administration date unknown). These floods can result in severe erosion along streambanks, head-cutting in tributaries, and sediment deposition that alters aquatic habitats and impairs water quality. Infrastructure within the Big South Fork National River and Recreation Area (e.g., trails, bridges, and access roads) often sustains damage, requiring frequent repair and mitigation efforts. Flooding threatens park infrastructure, including a boardwalk and gazebo at BISO (Thornberry-Ehrlich 2009). Furthermore, flooding can degrade cultural sites and dislodge archeological materials, necessitating coordinated monitoring and conservation efforts. However, frequent flooding is necessary to maintain the cobble bar plant communities that harbor rare species (Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025). As climate variability increases, resource managers must consider adaptive strategies, such as riparian buffer restoration, improved hydrologic modeling, and floodplain reconnection, to enhance the watershed's resilience and protect both ecological and recreational values within BISO.

Fluvial processes, including erosion, migration, and sediment transport, are important yet difficult to predict in fluvial environments (Babbitt 2005; Hodges 2015; Thornberry-Ehrlich 2009). More modeling is needed to manage the fluvial resources at BISO. Layering geology, soils, slope, aspect, AML sites, hydrology, and vegetation communities in a GIS would provide a powerful dataset to analyze and identify streams that may need remediation and restoration.

Lake Cumberland (the reservoir behind the Wolf Creek Dam, operated by the USACOE: https://www.lrn-wc.usace.army.mil/basin_project.shtml?p=wol) is located along the northernmost 13 km (8 miles) of Big South Fork at BISO, and it is the largest reservoir in the United States east of the Mississippi River (Thornberry-Ehrlich 2009). The water level fluctuates depending on the management of the dam, but it creates a still-water environment, which destroys/alters flowing-water habitats. The USACOE built the dam on carbonate geologic units prone to dissolution (karstification). At periods in the past (e.g., 2007), the reservoir levels were kept purposefully low to allow the USACOE to install a new apron to the front of the dam and regROUT exposed holes in the dam (Thornberry-Ehrlich 2009). The last dam repair in 2013 kept the water level low for seven years. During the time the reservoir level was lowered, the USACOE discovered that the upper section of the river from Blue Heron downstream for several miles still contained river conditions similar to the upper free-flowing section. Because this section is periodically lowered during any given year, the natural flow is temporarily restored, maintaining river conditions as opposed to still-water conditions

(Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025).

Land Use and Visitor Overuse

Land use within BISO includes recreational activities such as climbing, hiking, horseback riding, and backcountry camping. This use becomes a geologic resource management issue when overuse or inappropriate use degrades the natural environment. Listed in BISO's foundation document (National Park Service 2017) are the following threats related to both geologic resources and recreational use:

- trail damage from overuse and social trails
- vandalism of rock faces (e.g., cliffs, rock shelters)
- erosion at stream crossings
- sedimentation in local streams with adjacent sloped access roads
- camping and fires within archeological sites (alcoves and rock shelters)
- damage from climbing to archeological and cliff line sites that support species of concern

More than 645 km (400 mi) of roads and trails are in use at BISO, plus an additional 160 km (100 mi) of roads related to oil and gas operations that may or may not be in use. Other land-use activities, including ATV use, are of concern to resource managers at BISO. ATV access is not allowed except during hunting season on multi-purpose trails, but illegal use still occurs, particularly in the North White Oak area (Thornberry-Ehrlich 2009). Impacts from illegal ATV use include increased erosion, rutting, compaction, and ecosystem degradation. Early developers did not properly abandon access roads, and some abandoned roads from mining, logging, and oil and gas operations are now used for multi-purpose trails. Resource managers seek to concentrate use at public trailheads. Trail condition studies and climbing use studies are needed to better manage overuse concerns (Thornberry-Ehrlich 2009; Worsham et al. 2013; National Park Service 2017).

Landscape changes, such as negative impacts from adjacent development, population increases, agricultural land uses, habitat fragmentation, and alteration, could harm BISO's natural resources (Worsham et al. 2013). As local populations increase and hydrocarbon demand and technological advances spur renewed interest, BISO managers are concerned about negative impacts on natural resources. Very few regulations exist on urban development in the region around BISO (Thornberry-Ehrlich 2009). As populations increase and development proceeds, stabilizing forests will be logged, viewsheds will be irreparably harmed, and impermeable surfaces such as roads, parking lots, and driveways will increase, causing spikes in unfiltered surface runoff into the Big South Fork watershed (Thornberry-Ehrlich 2009). The BISO foundation document lists potential acquisition of land surrounding BISO as a safeguard to protect it from further development and resource extraction (National Park Service 2017).

Slope Movements

Potential for slope movement exists on all BISO slopes, particularly where the rivers cut steeply through the sedimentary rocks in the gorges. Slope movements are the downslope transfer of material (e.g., soil, regolith, and rock; Figure 12). Slope movements can occur rapidly (e.g., debris flows or rockfalls) or over long periods of time (e.g., slope creep). The magnitude of slope failures depends on slope aspect, soil type, and geology. Big South Fork cuts through steep slopes, terraces, bluffs, and alluvial fans. Gravity, frost and plant root wedging, differential erosion, fluvial undercutting, mining subsidence, and minor karst dissolution are the primary natural causes of slope instability at BISO.

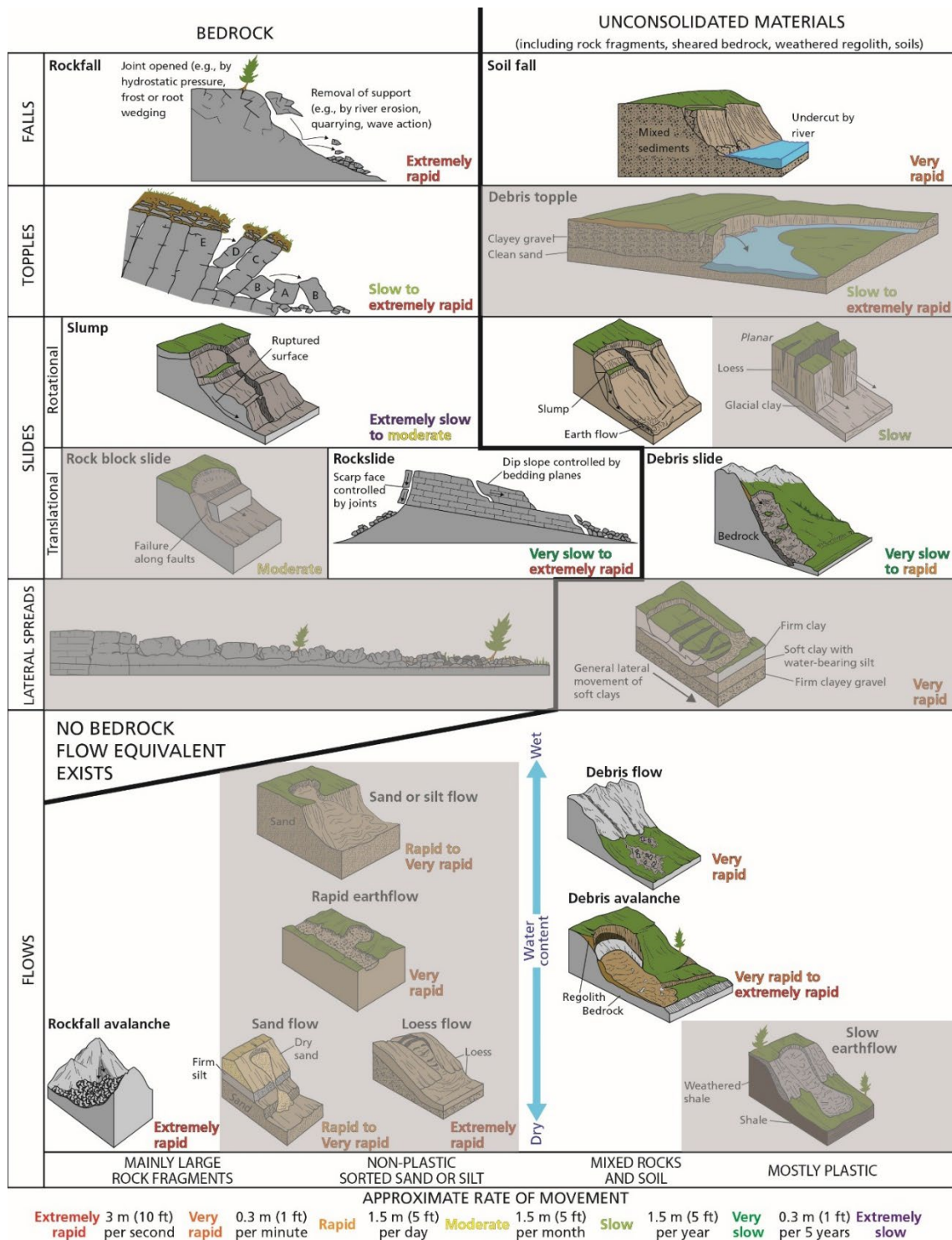


Figure 12. Illustrations of slope movements. Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at BISO. The abundant vegetation in the park stabilizes some slopes, but slope issues could be exacerbated by factors such as natural or anthropogenic removal of vegetation, upstream development, and weather patterns. Graphic by Trista Thornberry-Ehrlich (Colorado State University), redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

Anthropogenic land disturbances contribute heavily to instability and slope movements. Anthropogenic changes to the hill slopes, such as road and trail construction, mining, undercutting, and deforestation, are the most common triggers of active sliding. Engineering structures designed to redirect water and stabilize riverbanks often lead to instability and reactivation of old landslides. Geologic units containing significant shale layers act as regional slip surfaces and are often present at the toe (base) of slides.

Evidence of former slope movements is everywhere at BISO. Colluvial fans, which are composed of loose and incoherent deposits transported by gravity, occur at the base of many slopes and bluffs along Big South Fork and its tributaries. Ancient rockfalls, slides, and debris flows left scars along the slopes of the river valleys, and large blocks of Pennsylvanian sandstone are ubiquitous within the valley floors (Thornberry-Ehrlich 2009; Phillips et al. 2010). In Kentucky, slope movements are mapped, including active or recently active landslides, old landslides, mosaics of recent and older landslides, colluvial slopes susceptible to mass movements, areas susceptible to debris flows and avalanches, and areas susceptible to rockfall (Taylor and Thomas 1982; Phillips et al. 2010).

Any steep slope at BISO poses a landslide hazard, and rockfall is a threat along long stretches of the rivers. Visitors need to be aware of rockfall potential and warned about active slide and rockfall areas. If an area is identified as a threat, signage and warnings are developed and issued to the public (Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025). The roadway down into the gorge at the Blue Heron mining camp is prone to landslides, especially in the shale layers associated with the contact between Mississippian and Pennsylvanian rock layers. Sprayed concrete and drain structures have been used in this area to try to mitigate the slide hazard (Thornberry-Ehrlich 2009). Sections of concern are being monitored along the road and adjoining slopes. Future projects will develop as needed to stabilize or repair road or slope issues (Tom Blount, chief of resource management, Big South Fork National River and Recreation Area, written communication, 27 May 2025).

Seismicity

Seismicity refers to the ground shaking that occurs during earthquakes. Though not traditionally considered a seismically active area, BISO is north of the Southern Appalachian seismic zone—an active earthquake zone that runs just northeast of Knoxville, Tennessee (Figure 13). Nearly 100 small earthquakes (too minor to be felt at the surface) occur every year along this diffuse zone (Thornberry-Ehrlich 2009). The potential for seismicity is present (moderate risk) at BISO and may trigger landslides, rockfall, and damage infrastructure (Thornberry-Ehrlich 2009). The USGS and the Center for Earthquake Research and Information at the University of Memphis monitor seismic activity throughout the region.

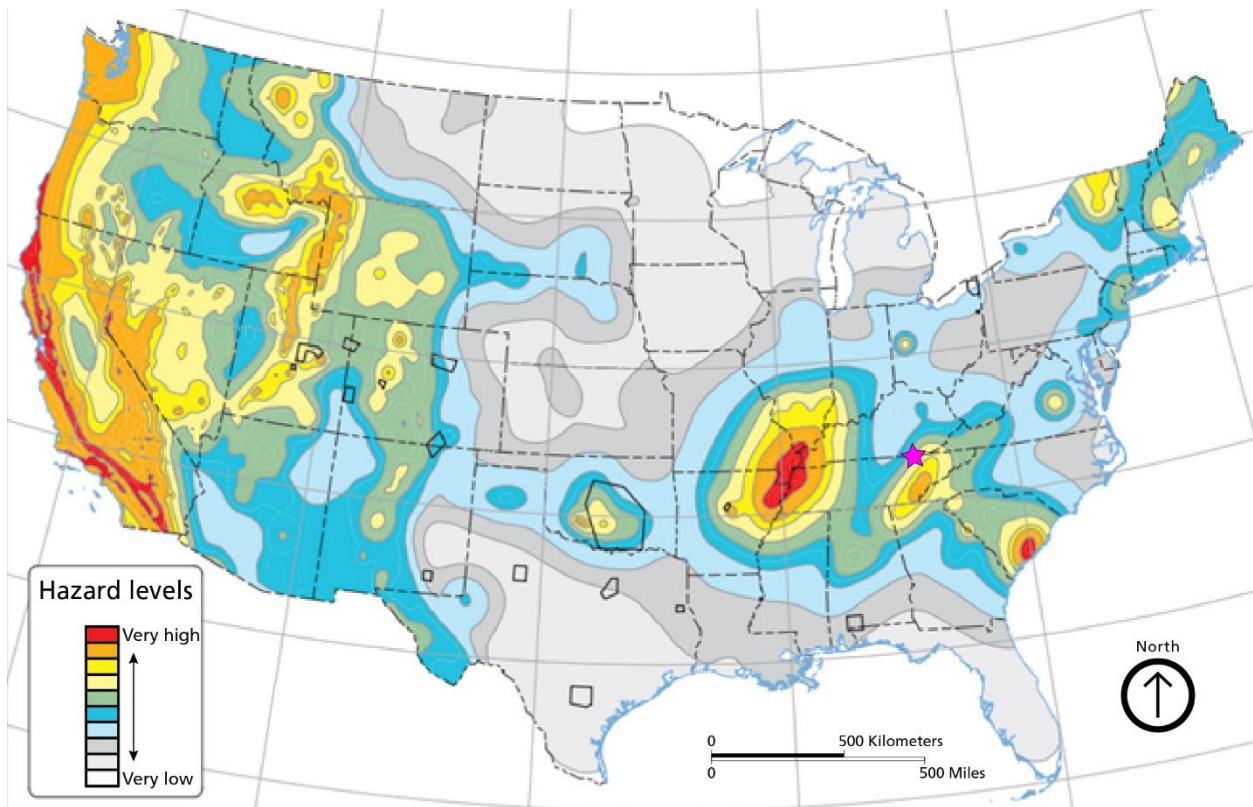


Figure 13. National seismic hazard map. The map shows the relative hazard associated with potential earthquakes in different areas. The map is based on USGS models that calculate the probability of an earthquake within 50 years for a firm rock site based on seismicity, fault-slip rates, and the frequency of earthquakes of various magnitudes. Locally, the hazard may be greater than shown because site geology may amplify ground motions. The BISO location is at the pink star, near the northwestern edge of the Southern Appalachian seismic zone, and of moderate hazard risk. Public domain graphic courtesy of the US Geological Survey; available at <https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map>.

Inventory Needs

The following table (Table 2) presents several geologic and soil resources inventory needs that were identified during the 2007 scoping meeting, in NPS planning documents, and through literature review.

Table 2. List of identified geologic and soil resource inventory needs for BISO.

Subject	Inventory Need	Reference(s)
Abandoned Mineral Lands and CMD	Organize coal mine maps and drill hole information from state surveys into the BISO GIS data Digitize mine maps Identify which coal beds contain significant sulfur Spoil area mapping Acid mine drainage mapping for aquatic species restoration Identify all AML sites Inventory all CMD sites to mitigate Update AML inventory (Burghardt [2014]) tables B-1 and C)	Thornberry-Ehrlich (2009)
Geohazards	Landslide area mapping Slope movement potential mapping (slope analysis with geology correlation)	Thornberry-Ehrlich (2009); Phillips et al. (2010)
Geoscience Research	Geoheritage inventory Ecological flow study (medium priority)	National Park Service and American Geosciences Institute (2015); National Park Service (2017)
Geological infrastructure materials	Map locations of clinker (brittle, pH-neutral material formed above burning coal seams) for trail base Building stone/dimension stone quarry location inventory	Thornberry-Ehrlich (2009)
Cave and Karst	Cave and karst feature identification and mapping Identify talus cave areas	Thornberry-Ehrlich (2009); National Park Service (2017)
Mapping	Cave and karst mapping Landscape evolution mapping Land-use planning mapping Encourage consistent stratigraphic nomenclature across state boundaries of Kentucky and Tennessee Carbonate-bearing rock mapping for use in acid mine drainage buffering	Thornberry-Ehrlich (2009); Santucci et al. (2008); National Park Service (2017)
Paleontology	Field inventories, formal site documentation, and condition assessment of fossil resources Develop a monitoring plan Fossil recovery from private collections (low priority)	Thornberry-Ehrlich (2009); Santucci et al. (2008); National Park Service (2017)
Stratotypes	Investigate initiating a formal stratotype designation for Burnt Mill Shale exposures at BISO, which should then be protected and monitored Increase awareness and understanding about the geoheritage of geologic stratotypes	Henderson et al. (2021)
Hydrogeology	Groundwater flow mapping Watershed map coverage Streambed mapping to determine aquatic habitat potential Develop basin-wide hydrogeologic model	Leary (1991); Thornberry-Ehrlich (2009); Worsham et al. (2013)
Cliff management (e.g., climbing access)	Survey cliff areas for biodiversity and prioritize lower diversity areas for climbing access Climbing use study (high priority) Visitor use management plan (medium priority)	Bogges et al. (2017); National Park Service (2017)

Legislatively Required Geologic Inventories

Some laws, regulations, and policies specifically apply to geologic and soil resources or processes. These include legislatively required inventories. The NPS GRD has an article series (<https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0>) that summarizes these laws, regulations, and policies. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or anthropogenic activity.

Caves and Karst

Karst is a landscape that forms through the dissolution of soluble rocks, commonly carbonate rocks such as limestone or dolomite (Toomey 2009). Dissolution occurs when acidic water reacts with carbonate rock surfaces along cracks and fractures.

Caves are naturally occurring underground voids such as solutional caves (commonly associated with karst), lava tubes (tunnel-like caves in a lava flow after lava has stopped flowing), sea caves (clefs or cavities in a sea cliff), talus caves (a void among collapsed boulders), regolith caves (formed by soil piping), and glacier caves (ice-walled caves) (Toomey 2009). All cave features are nonrenewable resources. The Federal Cave Resources Protection Act of 1988 stipulates that all “significant caves” in NPS areas will be identified, regulation or restriction of use will be employed as needed to protect cave resources, and significant caves will be included in land management planning. The act also imposes penalties for causing harm to a cave or cave resources and exempts park staff from releasing specific location information for significant caves in response to a Freedom of Information Act request.

At BISO, karst dissolution occurs in every unit composed of carbonate or carbonate cements, primarily Mississippian limestones. However, unlike other areas of Kentucky (e.g., Mammoth Cave) and Tennessee, karst features at BISO have not developed into an extensive network because the Mississippian limestone units are only exposed in the deepest part of the gorges. At BISO, karst features include limited small caves, conduits, pits, alcoves, and springs (Thornberry-Ehrlich 2009). Dissolution caves include True Cave at Oil Well Branch and small openings along the Angel Falls trail. There may be more karst development in the western areas of the BISO watershed (Highland Rim) near Wilder and Jamestown. Further karst and cave feature identification, mapping, and digitization are significant resource management needs at BISO (National Park Service 2017). All caves are at risk of vandalism, archeological looting, and speleothem (e.g., stalagmites and stalactites) theft (Thornberry-Ehrlich 2009). Other caves, such as talus caves, are very likely formed in the blocks of Pennsylvanian sandstone littering the base of slopes at BISO. These provide vital habitat for bats and other creatures.

Geothermal Features and Springs

Geothermal refers to heat or energy produced in Earth’s interior. Geothermal features may include geysers, fumaroles, hot springs, and bubbling mud pits. The Geothermal Steam Act of 1970, amended in 1988, prohibits geothermal leasing in parks and authorizes the Secretary of the Interior to

mitigate or not issue geothermal leases outside parks that would have a significant adverse impact on significant thermal features in the 16 park units listed in the act. Geothermal features are not known within BISO, though many regular springs exist throughout the area.

Paleontological Resources Inventory and Protection

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism's activity such as nests, burrows, tracks, or feces). Fossils may occur in rocks or unconsolidated deposits, in museum collections, or in cultural contexts, such as building stone. All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act (PRPA). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources.

Fossils are present in nearly all of the flat-lying, sedimentary rocks at BISO; the northern third of BISO has more significant fossil localities than the southern two-thirds (Santucci et al. 2008). Paleontological resources from these units, both within and beyond BISO boundaries, are as follows:

- Mississippian rocks exposed at Leavenworth Ford—horn corals, bivalves, blastoids (sea buds), and brachiopods (Thornberry-Ehrlich 2009)
- Monteagle Formation—crinoids (sea lilies)
- Pennington Formation—fossil wood debris, burrows, horn corals, bivalves, brachiopods, blastoids
- Fentress Formation—marine trace fossils, *Skolithos* (primitive worm) burrows
- Breathitt Group—fossil plants (rare stigmarian leaf stem axes and calamitean stem fragments), *Lepidodendron* fragments
- Rockcastle Sandstone—tetrapod trackways (early reptile)
- Potential for Pleistocene animal remains (e.g., cave bears, mastodons, mammoths) in many rock shelters, notches, and small caves

BISO has 44 cataloged paleontological specimens in its museum collection. These include various Pennsylvanian fossil plants, including lycopsid seed ferns such as *Lepidodendron* and *Sigillaria*. Specifically, the collection includes bark, branches, and leaf fossils of these primitive plants. The collection also contains specimens of scouring rush plants such as *Calamites*. Additionally, the park collection includes some unidentified species of Mississippian brachiopods, crinoid stems, and a blastoid. There are also worm trails or traces in the collection from a locality in Fentress County, Tennessee (Santucci et al. 2008).

Many BISO fossils occur in friable (easily split or broken apart) shales and at the tops of coal beds, which flex and swell with humidity and are not viable for long-term preservation. These resources should be inventoried (field-based) and monitored.

Summary of Geologic and Soil Hazards

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

According to PM 15-01, managers should apply the handbook guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (Table 3) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board (AIRB) submittal process at the Investment Concept (IC) stage. Table 3 is a screening tool to be used at the IC stage to help teams determine potential climate change effects and natural hazards to a proposed facility investment. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis. Ground-disturbing activities should neither be approved nor denied based upon the information here. Table 3 includes selected geologic and soil hazards listed in Part 1 of the handbook (National Park Service 2023). The GSRI team has added additional hazards where appropriate for BISO. If needed, Part 2 of the handbook could inform completion of the checklist, such as whether a hazard is applicable. Contact the NPS GRD with any questions.

Table 3. Geologic and soil hazards checklist. This checklist includes selected hazards listed in Part 1 of National Park Service (2023).

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment (SHIRA hazard level where given)	Source(s) of Information (some links require DOI network access)
Sea Level Change	Inundation. Shoreline erosion. Destruction of infrastructure (e.g., through saturation). Water quality effects. Water supply diminished.	Not applicable	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) .
Coastal Storm Surge	Wind driven rising water (e.g., hurricane, nor'easter).	Not applicable	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Flash Flood	Sudden rising water (e.g., in a dry wash or canyon). Loss of life due to unexpected flooding. Destruction of infrastructure (e.g., through impact or saturation). Reduced or precluded visitation. Power failure due to areawide power outages.	Known hazard	GRI Scoping Summary (Thornberry-Ehrlich 2009) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) FEMA: NFHL https://www.fema.gov/flood-maps/national-flood-hazard-layer
Riverine Flood	Inundation. Destruction of infrastructure (e.g., through impact or saturation). Stream channel migration and streambank erosion. Water quality effects. Water supply diminished. Reduced or precluded visitation.	Known hazard (high to extreme)	GRI Scoping Summary (Thornberry-Ehrlich 2009) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) FEMA: NFHL https://www.fema.gov/flood-maps/national-flood-hazard-layer

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment (SHIRA hazard level where given)	Source(s) of Information (some links require DOI network access)
Lake and Reservoir Level Change or dam failure	Water supply diminished. Flooding and erosion impacts to infrastructure. Diminished or lost recreational opportunities. Release of sediments. Streambank erosion. Reduced or precluded visitation.	Known hazard; however, all dams have been evaluated and not considered significant threats (Tom Blount, BISO, written communication 27 May 2025)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) USGS: Lakes and reservoirs dataset https://waterdata.usgs.gov/nwis/current/?type=lake&group_key=state_cd US Bureau of Reclamation Water Operations https://www.usbr.gov/main/water/#GP
Precipitation: Increased Extreme Events	Surface erosion. Floods. Water damage to structures from driven rain. Unstable saturated soils. Reduced or precluded visitation. Power failure due to areawide power outages.	Potential hazard (very low)	NPS: National Park historical and projected climate change trends https://irma.nps.gov/DataStore/Reference/Profile/2266988 NASA: DAYMet gridded climate data https://daymet.ornl.gov/ DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Precipitation: Altered Patterns and Changing Humidity	Local flooding. Mold growth. Wood decay. Drought. Fire. Water supply change.	Potential hazard (very low)	NPS: National Park historical and projected climate change trends https://irma.nps.gov/DataStore/Reference/Profile/2266988 Climate Toolbox: Climate Mapper (for Western US) https://marine.usgs.gov/coastalchangehazardsportal/ NASA: DAYMet gridded climate data https://daymet.ornl.gov/
Drought: Increased Frequency, Intensity, Magnitude, and Duration	Limited water supply for visitor, staff, and operational needs (e.g., potable and fire suppression water). Increased competition for available water and water supply impacts (e.g., water supply curtailment by state agencies). Crack/heave damage in drier soils. Increased vulnerability to wildfire.	Potential hazard (very low)	FEMA: Drought risk https://hazards.fema.gov/nri/drought University of Nebraska-Lincoln: Drought Monitor https://droughtmonitor.unl.edu/ DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment (SHIRA hazard level where given)	Source(s) of Information (some links require DOI network access)
Permafrost Dynamics	Thawing. Surface collapse. Increased landslide susceptibility. Road/service disruption. Frost heave.	Not applicable	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Landslide	Rockfall. Mud or debris slides or flows onto or from under structures. Reduced or precluded visitation. Avalanche.	Known hazard (very high)	GRI Scoping Summary (Thornberry-Ehrlich 2009) Kentucky Geological Survey (hazards tab): https://www.uky.edu/KGS/ Tennessee Geological Survey: https://www.tn.gov/environment/program-areas/tennessee-geological-survey.html FHWA Unstable Slope Management Program (USMP): Geologic and Geotechnical Services FHWA (dot.gov) . FEMA: Landslide risk https://hazards.fema.gov/nri/landslide USGS: Emergency Assessment of Post-Fire Debris-Flow Hazards https://landslides.usgs.gov/hazards/postfire_debrisflow/ DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Earthquake	Falling objects. Collapsing structures. Inoperability of major building systems (e.g., power, sewer, water). Liquefaction - loss of strength to foundations, silt deposition, standing water. Trigger to other hazards (e.g., landslides, debris flows).	Known hazard (moderate)	GRI Scoping Summary (Thornberry-Ehrlich 2009) Kentucky Geological Survey (hazards tab): https://www.uky.edu/KGS/ Tennessee Geological Survey: https://www.tn.gov/environment/program-areas/tennessee-geological-survey.html USGS: Earthquake Probability Mapping https://www.usgs.gov/natural-hazards/earthquake-hazards/hazards FEMA: Earthquake risk https://hazards.fema.gov/nri/earthquake DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Tsunami	Coastal area inundation.	Not applicable	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Shrink/Swell Soils	Damage to structure. "Heaving" of ground beneath structure. Increased landslide susceptibility.	Potential hazard	Kentucky Geological Survey (hazards tab): https://www.uky.edu/KGS/ NPS: https://irma.nps.gov/DataStore/Reference/Profile/1048823 USDA: Web Soil Survey https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/ (look for "linear extensibility" data).

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment (SHIRA hazard level where given)	Source(s) of Information (some links require DOI network access)
Volcanic Eruption	Lava flows. Fire. Seismicity. Tsunamis. Toxic gas releases. Ash and air quality degradation. Reduced or precluded visitation.	Not applicable	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Hydrothermal Activity (e.g., geysers)	Toxic gas release. Explosion. Boiling water. Steam. Surface collapse into void.	Not applicable	NREL: Geothermal resource data, tools, and maps https://www.nrel.gov/gis/geothermal.html USGS: Geothermal resources https://www.usgs.gov/programs/energy-resources-program/science/science-topics/geothermal
Subsurface Hazards: Abandoned Mineral Lands Oil and Gas Infrastructure Cave/Karst (sinkholes)	Mine shaft access hazards. Surface subsidence. Surface collapse. Contaminated soils and mine drainage. Flammable or toxic sites. Surface water pollutant discharge.	Known hazard (moderate to high) (Etta Spradlin, BISO, written communication, 21 May 2025)	Kentucky Geological Survey (energy or hazards tab): https://www.uky.edu/KGS/ Tennessee Geological Survey, Mineral Industry: https://www.tn.gov/environment/program-areas/tennessee-geological-survey/geology-redirect/tennessee-s-mineral-industry.html USGS: Karst in the United States: A Digital Map Compilation and Database (Weary and Doctor 2014) Thornberry-Ehrlich (2009) Evaluation of cave and karst programs and issues at US national parks (Land et al. 2013) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Toxicological Soil	Unhealthy levels of <i>Bacillus anthracis</i> , asbestos or erionite, arsenic, cadmium, lead, selenium, or valley fever fungus.	Known hazard (very low to high)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Toxicological Geology	Elevated radon levels.	Known hazard (moderate)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

Acknowledgments

The GSRI team thanks the participants of the 2007 scoping meeting for their assistance in this summary. The lists (below) reflect the names and affiliations of these participants at the time of the meeting. Because the GSRI team does not conduct original geologic mapping, we are particularly thankful for the US Geological Survey, Tennessee Division of Geology, and Kentucky Geological Survey for their maps of the area. This summary report and accompanying geologic index maps data could not have been completed without them.

Scoping Participants

Steve Bakaletz (NPS BISO)
Tom Blount (NPS BISO)
Philip Campbell (NPS Obed Wild and Scenic River)
Tim Connors (NPS GRD)
Ron Cornelius (NPS BISO)
Matt Crawford (Kentucky Geological Survey)
Reed Detring (NPS BISO)
Robert Emmott (NPS Appalachian Highlands Network)
Elaine Foust (Tennessee Division of Geology)
Stephen Greb (Kentucky Geological Survey)
Albert Horton (Tennessee Division of Geology)
Mike Hoyal (Tennessee Division of Geology)
Barry Miller (Tennessee Division of Geology)
Nora Murdock (NPS Appalachian Highlands Network)
Lisa Norby (NPS GRD)
Bethany Overfield (Kentucky Geological Survey)
Rebecca Schapansky (NPS Obed Wild and Scenic River)
Etta Spradlin (NPS BISO)
Trista Thornberry-Ehrlich (Colorado State University)
Larry West (NPS Southeast Region)

Summary Review

Victoria Crystal (Colorado State University)
Tom Blount (NPS BISO)
Etta Spradlin (NPS BISO)
Brian Barbaris (NPS BISO)

Summary Editing

Suzanne McKetta (Colorado State University)

GRI GIS Data Production

Chase Winters (Colorado State University)

Georgia Hybels (Colorado State University)

James Winter (Colorado State University)

Stephanie O'Meara (Colorado State University)

Literature Cited

- AMEC Earth & Environmental, Inc. 2001. Environmental assessment, implementation or remediation activities for selected contaminated mine drainage (CMD) sites at the Big South Fork National River and Recreation Area. Preliminary draft prepared for the National Park Service. AMEC Earth & Environmental, Inc., Knoxville, Tennessee.
<https://irma.nps.gov/DataStore/Reference/Profile/659997>
- Anderson, M. 2017. National Parks Index: 2012–2016. Official index of the National Park Service. National Park Service, Washington, DC. <https://www.nps.gov/aboutus/publications.htm>
- Anthony, D. M., and D. E. Granger. 2007. A new chronology for the age of Appalachian erosional surfaces determined by cosmogenic nuclides in cave sediments. *Earth Surface Processes and Landforms* 32:874–887.
- Babbitt, G. S. 2005. Bankfull hydraulic geometry of streams draining the southwestern Appalachians of Tennessee. Thesis. University of Tennessee, Knoxville, Tennessee.
https://trace.tennessee.edu/utk_gradthes/1611/
- Barclay, L. A., and D. R. Parsons. 1983. An endangered species survey of abandoned mine shafts in the Big South Fork National River and Recreation Area, KY and TN. US Fish and Wildlife Service, Ecological Services Office, Cookeville, Tennessee.
- Blair, R. H. 2010. Classification and fertility of soils in the Big South Fork National River and Recreation Area based on landscape position and geology. Thesis. University of Tennessee, Knoxville, Tennessee. https://trace.tennessee.edu/utk_gradthes/605/
- Bogges, L. M., G. L. Walker, and M. D. Madritch. 2017. Cliff flora of the Big South Fork National River and Recreation Area. *Natural Areas Journal* 37(2):200–211.
- Burghardt, J. E., E. S. Norby, and H. S. Pranger, II. 2014. Abandoned mineral lands in the National Park System: comprehensive inventory and assessment. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2014/906. National Park Service, Fort Collins, Colorado.
http://go.nps.gov/aml_publications
- Cruden, D. M., and Varnes, D. L. 1996. Landslide types and processes. Pages 36–75 (chapter 3) in A. K. Turner and R. L. Schuster, editors. *Landslides: investigation and mitigation*. Special Report 247. Transportation Research Board, National Research Council, Washington, DC.
- Fenneman, N. M. 1938. *Physiography of the eastern United States*. McGraw Hill, New York, New York.

- Ferguson, T. A. 1988. Lithic analysis and the discovery of prehistoric man-land relationships in the uplands of the Big South Fork of the Tennessee Cumberland Plateau. PhD Dissertation. University of Tennessee, Knoxville, Tennessee. https://trace.tennessee.edu/utk_graddiss/4065/
- Field, J. J., C. M. Leonard, D. M. Schook, J. M. MacCartney, and S. O. Erwin. 2025. Best practices for managing bank erosion within the National Park Service and National Wild and Scenic River System. Science Report NPS/SR—2025/234. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2306106>
- Filson, J. 1784. This map of Kentucke, drawn from actual observations, is inscribed with the most perfect respect, to the Honorable the Congress of the United States of America; and to his excellency. George Washington, late commander in chief of their army (scale ca 1:633,600). H.D. Pursell, Philadelphia, Pennsylvania. <https://www.loc.gov/item/2001623605/>
- Gordon, H. 2025. Classification of rapids, water levels, and canoeists. Paddling.com. <https://paddling.com/learn/classification-of-rapids-water-level-and-canoeists> (accessed 28 January 2025)
- Hann, C. T., B. J. Barfield, and J. C. Hayes. 1994. Design hydrology and sedimentology for small catchments. Academic Press, Inc., San Diego, California.
- Henderson, T., V. L. Santucci, T. Connors, and J. S. Tweet. 2021. National Park Service geologic type section inventory: Appalachian Highlands Inventory & Monitoring Network. Natural Resource Report NPS/APHN/NRR—2021/2278. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2286699>
- Hodges, R. L. 2015. Bankfull geomorphic relationships and HECRAS assessment in small catchments of the Cumberland Plateau ecoregion. Thesis. University of Tennessee, Knoxville, Tennessee. https://trace.tennessee.edu/utk_gradthes/3584/
- Hughes J., R. Emmot, N. Murdock, P. Flaherty, and E. Raskin. 2018. Protocol narrative: long-term continuous water-quality monitoring at Big South Fork National River and Recreation Area and Obed Wild and Scenic River. Natural Resource Report. NPS/APHN/NRR—2018/1722. National Park Service. Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2255929>
- Humbert, S. E. 2001. Subaerial paleokarst in the upper Pennington Formation (Upper Mississippian) limestones at Leatherwood Ford, Big South Fork, Tennessee. Thesis. University of Tennessee, Knoxville, Tennessee. https://trace.tennessee.edu/utk_gradthes/4210/
- International Commission on Stratigraphy. 2023. International chronostratigraphic chart (v2023/09). Drafted by K. M. Cohen, D. A. T. Harper, P. L. Gibbard, and N. Car. International Union of Geological Sciences (IUGS), International Commission on Stratigraphy (ICS), Durham, England [address of current ICS chair]. <https://stratigraphy.org/chart> (accessed 21 January 2025)

- Jarvis, J. E. 2015. Addressing climate change and natural hazards for facilities. Policy Memorandum 15-01 to All Employees (National Park Service), 20 January 2015. Washington DC Support Office, Washington DC. <https://www.nps.gov/subjects/policy/policy-memos.htm>
- Jillson, W. R. 1952. The first oil well in Kentucky; notes on the history, geology, production and present status of the Beatty oil well, drilled in Wayne, now McCreary County, Kentucky, in the year 1818. Roberts Print. Co., Frankfort, Kentucky.
- Kite, S. J. 2016. Surficial geologic map of the Gauley River National Recreation Area, West Virginia (scale 1:12,000). Open-File Report OF-1601. West Virginia Geological and Economic Survey, Morgantown, West Virginia.
- Land, L., G. Veni, and D. Joop. 2013. Evaluation of cave and karst programs and issues at US national parks. Report of Investigations 4. National Cave and Karst Research Institute, Carlsbad, New Mexico. <https://www.nps.gov/subjects/caves/technical-publications.htm>.
- Leary, M. C. 1991. The effects of abandoned coal mines on stream water chemistry in the Big South Fork National River and Recreation Area, Tennessee and Kentucky. Thesis. University of Tennessee, Knoxville, Tennessee.
- Maner, J. 2010. Controls on whitewater rapid formation Big South Fork, TN. Tennessee Technological University, Cookeville, Tennessee. <https://irma.nps.gov/DataStore/Reference/Profile/2253066>
- Massey, M. P. 2008. Use of the AnnAGNPS pollutant loading model for prediction of sediment yields in a mountainous Cumberland Plateau region: correlations with the stream bed sediment characteristics. University of Tennessee, Knoxville, Tennessee. https://trace.tennessee.edu/utk_gradthes/404/
- Milici, R. C., G. Briggs, L. M. Knox, P. O. Sitterly, and A. T. Statler. 1979. Tennessee. Pages G1–G38 in *The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States*. Professional Paper 1110, G. US Geological Survey, Reston, Virginia. <https://pubs.usgs.gov/publication/pp1110AL>
- Minear, R. A., and B. A. Tschantz. 1976. The effect of coal surface mining on the water quality of mountain drainage basin streams. *Journal (Water Pollution Control Federation)* 48(11):2549–2569.
- National Oceanic and Atmospheric Administration. Date unknown. Remembering the flood of '57. Weather.gov. <https://www.weather.gov/jkl/1957flood> (accessed 28 April 2025).
- National Park Service. 2005. Big South Fork general management plan and environmental impact statement. Oneida, Tennessee.

- National Park Service. 2015a. The legend of Devil's Jump. Big South Fork National River and Recreation Area, Oneida, Tennessee.
<https://www.nps.gov/biso/learn/historyculture/devilsjump.htm> (accessed 21 January 2025)
- National Park Service. 2015b. Addressing climate change and natural hazards: Facility planning and design considerations. Level 3 Handbook. National Park Service, Park Planning Facilities and Lands, Construction Program Management Division, Denver, Colorado.
- National Park Service. 2017. Foundation document: Big South Fork National River and Recreation Area. BISO 645/134962. National Park Service, Fort Collins, Colorado.
- National Park Service. 2020. Big South Fork recording a 2020 rain event to remember with stream gauges. News release. Big South Fork National River and Recreation Area, Oneida, Tennessee.
<https://www.nps.gov/biso/learn/news/big-south-fork-recording-a-2020-rain-event-to-remember-with-stream-gauges.htm> (accessed 28 April 2025).
- National Park Service. 2023. Addressing climate change and natural hazards handbook: checklist for assessment of environmental change and effects on National Park Service facilities, version 2, April 2023. NPS Park Planning, Facilities, and Lands Directorate. Washington, DC.
- National Park Service and American Geosciences Institute. 2015. America's geologic heritage: An invitation to leadership. NPS 999/129325. National Park Service, Denver, Colorado.
<https://www.earthsciweek.org/content/our-shared-geoheritage>
- Natural Resources Conservation Service. 2013. Soil Survey of the Big South Fork National River and Recreation Area, Kentucky and Tennessee. NPS TIC # BISO 645 110346. United States Department of Agriculture, Washington, DC.
- Neff, S. E. 1981. The Big South Fork experience. *Water Spectrum* 13(1)1–7.
- Nordman, Carl W. 2011. Vascular plant inventory and plant community classification for Big South Fork National River and Recreation Area. Final Report submitted to the National Park Service, Appalachian Highlands Inventory and Monitoring Network. NatureServe, Durham, North Carolina.
- Nuttall, B. C. 2014. Of Kentucky, salt, and oil: a history of early petroleum finds along the Cumberland River. *Oil-Industry History* 15(1):67–80.
<https://archives.datapages.com/data/phi/v15-2014/nuttall.htm>
- Ottom, J. K., and R. A. Zielinski. 2000. Simple techniques for assessing impacts of oil and gas operation on federal lands—a field evaluation at Big South Fork National River and Recreation Area, Scott County, Tennessee. Open-File Report 00-499. US Geological Survey, Lakewood, Colorado. <https://pubs.usgs.gov/publication/ofr2000499>

- Perrone, S. 2023. Report: State of soils information at the National Park Service, WASO level. National Park Service. <https://irma.nps.gov/DataStore/Reference/Profile/2307328>
- Phillips, J. D., S. McCormack, J. Duan, J. P. Russo, A. M. Schumacher, G. N. Tripathi, R. B. Brockman, A. B. Mays, and S. Pulugurtha. 2010. Origin and interpretation of knickpoints in the Big South Fork River basin, Kentucky-Tennessee. *Geomorphology* 114:188–198. <https://irma.nps.gov/DataStore/Reference/Profile/2253211>
- Pollio, C. A. 1991. Reclamation of abandoned mines at New River Gorge, Gauley River, and Bluestone. *Park Science* 11(2):8–10.
- Rice, C. L., E. G. Sable, G. R. Dever Jr., and T. M. Kehn. 1979. Kentucky. Pages F1–F3.2 in *The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States*. Professional Paper 1110, F. US Geological Survey, Reston, Virginia. <https://pubs.usgs.gov/publication/pp1110AL>
- Santucci, V. L., R. T. P. McKenna, J. P. Kenworthy, and T. Connors. 2008. Paleontological resource inventory and monitoring—Appalachian Highlands Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/080. National Park Service, Fort Collins, Colorado.
- Schenk, C. J., T. R. Klett, R. R. Charpentier, T. A. Cook, and R. M. Pollastro. 2006. An allocation of undiscovered oil and gas resources to Big South Fork National Recreation Area and Obed Wild and Scenic River, Kentucky and Tennessee. Open-File Report 2006-1048. US Geological Survey, Reston, Virginia.
- Shepherd, R. G. 1988. America's first commercial oil well. *Earth Sciences History* 7(2):134–139.
- The Nature Conservancy. 2003. The Cumberlands and Southern Ridge & Valley ecoregion: a plan for biodiversity conservation. The Nature Conservancy, Arlington, Virginia.
- Thompson, J. A., S. Kienast-Brown, T. D’Avello, J. Philippe, and C. Brungard. 2020. Soils2026 and digital soil mapping – a foundation for the future of soils information in the United States. *Geoderma Regional*. 22. E00294. <https://doi.org/10.1016/j.geodrs.2020.e00294>
- Toomey, R. S., III. 2009. Geological monitoring of caves and associated landscapes. Pages 27–46 in R. Young and L. Norby, editors. *Geological monitoring*. Geological Society of America, Boulder, Colorado. <http://go.nps.gov/geomonitoring>.
- US. Congress. 1974. An act to establish the Big South Fork National River and Recreation Area in the states of Kentucky and Tennessee. Pub. L. No. 93–251, 88 Stat. 49:43. Washington, DC.
- Varnes, D. J. 1978. Slope movement types and processes. Pages 11–33 in R. L. Schuster and R. J. Krizek, editors. *Landslides: analysis and control*. Special Report 176. Transportation and Road Research Board, National Academy of Science, Washington, DC.

- Weary, D. J., and D. H. Doctor. 2014. Karst in the United States: a digital map compilation and database. US Geological Survey Open-File Report 2014–1156.
<https://dx.doi.org/10.3133/ofr20141156>
- Wilson, C. W., Jr., J. W. Jewell, and E. T. Luther. 1956. Pennsylvanian geology of the Cumberland Plateau. Geologic Folio. Tennessee Division of Geology, Nashville, Tennessee.
- Worsham, L., G. Sundin, N. Nibbelink, G. Grossman, and M. Mengak. 2013. Natural resource condition assessment for Big South Fork National River and Recreation Area. Natural Resource Report NPS/BISO/NRR—2013/619. National Park Service, Fort Collins, Colorado.
- Yates, M. K., and Kite, S. J. 2014. Surficial geologic map of the Bluestone National Scenic River area, West Virginia (scale 1:12,000). Open-File Report 1401. West Virginia Geological and Economic Survey, Morgantown, West Virginia and West Virginia University, Morgantown, West Virginia.
- Yates, M. K., and Kite, S. J. 2015. Surficial geologic map of the New River Gorge National River, West Virginia (scale 1:48,000). Open-File Report OF-1501. West Virginia Geological and Economic Survey, Morgantown, West Virginia and West Virginia University, Morgantown, West Virginia.