National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Abraham Lincoln Birthplace National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2010/219

THIS PAGE:
Knob Creek in the Boyhood Home Unit. The bedrock slabs on the left are likely from the Borden Formation. A young Abraham Lincoln fell into this creek and was pulled out by his friend Austen Gollaher.

ON THE COVER:
At the Birthplace Unit, the Memorial Building enshrines an early 19th century Kentucky cabin, symbolizing the one in which Abraham Lincoln was born.

National Park Service photographs.

Abraham Lincoln Birthplace National Historical Park

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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Executive Summary

This report accompanies the digital geologic map for Abraham Lincoln Birthplace National Historical Park in Kentucky, produced by the Geologic Resources Division in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.

Abraham Lincoln Birthplace National Historical Park was among the first units in the National Park System set aside to preserve cultural resources associated with the 16th president of the United States. Today the park consists of the Birthplace Unit containing Sinking Spring and a memorial, and the Boyhood Home Unit several kilometers away at Knob Creek Farm. The park also preserves many natural resources in addition to these cultural features.

Geology is the foundation of the park's ecosystem and was a major control on early settlement patterns in the region. Many geologic factors contributed to the decision by Abraham Lincoln's family to settle here, including the steady supply of water at Sinking Spring and Knob Creek, fertile soils, and gentle topographic expression. Interpreting the geologic resources and natural history of the area will enhance the visitor's experience.

Abraham Lincoln Birthplace National Historical Park sits atop the karst Pennyroyal Plateau. The landscape of the plateau is the result of geologic processes and their interplay with structure and bedrock. The bedrock units of the Pennyroyal Plateau consist of thick, stacked beds of carbonate rocks such as limestone and dolomite, which are interlayered with insoluble sedimentary rocks such as sandstone, siltstone, and shale. The youngest geologic units at the park are unconsolidated deposits associated with local rivers and slope processes. The age gap between the lithified bedrock and the unconsolidated surficial deposits is more than 300 million years.

Karst processes and features dominate the scene and create numerous geologic issues at the park. A karst landscape refers to a terrain produced by the chemical erosion and weathering of limestone and dolomite. This dissolution forms characteristic features such as sinkholes, springs, sinking streams, caves, voids, and conduits, which are interconnected in the karst network.

The Pennyroyal Plateau is significant in being part of the largest continuous region of cavernous rocks in the United States. It contains thousands of shallow sinkholes. The system of underground voids in central Kentucky is an elaborate "plumbing system" through which water flows through discrete conduits. Karst aquifer systems are especially vulnerable to contamination from surficial runoff because any input is quickly transferred through the system with little if any natural filtering. Karst landscapes can also be prone to flooding and subsidence, especially when changes (natural or anthropogenic) occur in the local or regional water table.

The discrete nature of karstic channel networks and the difficulty of direct sampling pose major challenges in characterizing hydrogeologic systems in limestone aquifers. In order for resource management to predict hydrologic response to inputs such as increased runoff and contaminants, methods such as dye-tracer studies, fine-scale topographic measurements, continuous monitoring of discharge, and down-hole video cameras could be applied. There is significant regional expertise in karst hydrology and use of these methods at regional and state universities, as well as the Kentucky Geological Survey (at the University of Kentucky), where local experts could assist the National Park Service in conducting research and monitoring in the park.

At the park, the landscape is a testament to active karst processes of limestone dissolution, underground cavity development, spring activity, sinkhole collapse, and erosion. Most of the subsurface caves and conduits of the area are shallow and clogged with soil, assorted debris, and collapse material. Depressions in which the void is covered by soil or vegetation, called "cover collapse sinkholes," are also common. This, in addition to the karst features' proximity to the water table, makes some of them wet and prone to rapid flooding during high rainfall events. Collapse and subsidence associated with sinkhole development are most frequent during flooding events but can also occur during prolonged droughts. Weathered sinkholes define the rolling hill topography of the area, and a sinkhole provides the catchment for Sinking Spring. The potential for sinkhole collapse exists at both units of the park; careful determination of the nature of the underlying karst features may help resource managers to determine areas particularly at risk.

Although karst dominates, other geologic processes create issues at the park. These include fluvial issues associated with surficial streams at both units, mass wasting associated with slope processes, disturbed lands, and paleontological resources present in the fossiliferous Mississippian-age geologic units.

Refer to the glossary for definitions of geologic terminology utilized in the report.

Acknowledgements

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

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

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Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Abraham Lincoln Birthplace National Historical Park.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The GRI, administered by the Geologic Resources Division of the Natural Resource Program Center, is designed to provide and enhance baseline information available to park managers. The GRI team relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

The goals of the GRI are to increase understanding of the geologic processes at work in parks and to provide sound geologic information for use in park decision making. Sound park stewardship requires an understanding of the natural resources and their role in the ecosystem. Park ecosystems are fundamentally shaped by geology. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

To realize these goals, the GRI team is systematically conducting a scoping meeting for each of the 270 identified natural area parks and providing a park-specific digital geologic map and geologic report. These products support the stewardship of park resources and are designed for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRI mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their Geographic Information Systems (GIS) Data Model. These digital data sets bring an interactive dimension to traditional paper maps. The digital data sets provide geologic data for use in park GIS and facilitate the incorporation of geologic considerations into a wide range of resource management applications. The newest maps contain interactive help files. This geologic report assists park managers in the use of the map and provides an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and current GRI contact information please refer to the Geologic Resources Inventory web site (http://www.nature.nps.gov/geology/inventory/).

Park Setting

Abraham Lincoln Birthplace National Historical Park has had many name designations. It was originally set aside as a memorial commemorating the birthplace of the 16th president of the United States. The original memorial hosted an early 19th century Kentucky cabin, similar to the one in which Lincoln was born on February 12, 1808. "Abraham Lincoln National Park" was established on July 17, 1916, and on August 10, 1933, was transferred from the War Department to the National Park Service and designated a national historical park. The name changed to "national historic site" on September 8, 1959 (73 Stat. 466), and most recently was redesignated as a national historical park on March 30, 2009. The park includes two units: the Birthplace Unit and the Boyhood Home Unit at Knob Creek, which was added in 1998 (fig. 1). The park, though originally set aside for cultural resources, protects 139 ha (345 ac) in Larue County on the karstic Pennyroyal (or Mississippian) Plateau in central Kentucky.

Abraham Lincoln Birthplace National Historical Park is located near the town of Hodgenville, Kentucky, more than 48 km (30 mi) south of Louisville and more than 32 km (20 mi) north of the world's longest cave at Mammoth Cave National Park. This entire region is often referred to as the "Central Kentucky Karst" part of a karstic limestone belt that extends from southern Indiana through Kentucky into Tennessee (White et al. 1970). Nearly horizontal bedrock characterizes the underlying geologic framework of the area. The entire park area is underlain by soluble limestone units (fig. 2; Appendix A). The landscape is characterized by rolling hills (fig. 1), sinking streams, sinkholes, and springs.

In an area dominated by karstic (groundwater) systems, surface water can be scarce on the Pennyroyal Plateau. This factor strongly influenced early settlement patterns. The Lincolns were farmers, and Sinking Spring Farm and the rented Knob Creek Farm were positioned to take full advantage of the available water supply. In addition, local bedrock weathers to a reddish clay-rich soil, the fertility and quality of which was a strong control on agricultural success.

The soluble limestone units of central Kentucky are riddled with caves in the highlands and a series of sinkholes and sinking streams in the lowlands. Ridges where resistant cap rock persists, such as the Chester Upland of the Mammoth Cave area, can support vast cave networks. Areas such as the Pennyroyal Plateau have lost their resistant cap rocks—a necessary ingredient to extensive cave formation—to erosion. As the limestone dissolved below ground, sinkholes developed, which overlapped to form the characteristic rolling landscape of the area.

Glaciers also played a role in landscape development. During the last significant glacial advance, approximately 19,000 to 21,000 years ago, thick ice sheets covered the Great Lakes area and extended south to approximately the position of the present-day Ohio River (the northern boundary of the state). These continental glaciers altered the trends of major waterways, which led to the formation of the Ohio River Valley and its tributary, the Green River. Moreover, during times of continental glaciation, water tables were lower than they are today. Advances and retreats of glacial ice resulted in multiple changes in the water table in the area that is now central Kentucky. This affected the landscape at the park through changes in the depth of caves and conduits, and changes in the slope and erosion rates of the Green River.

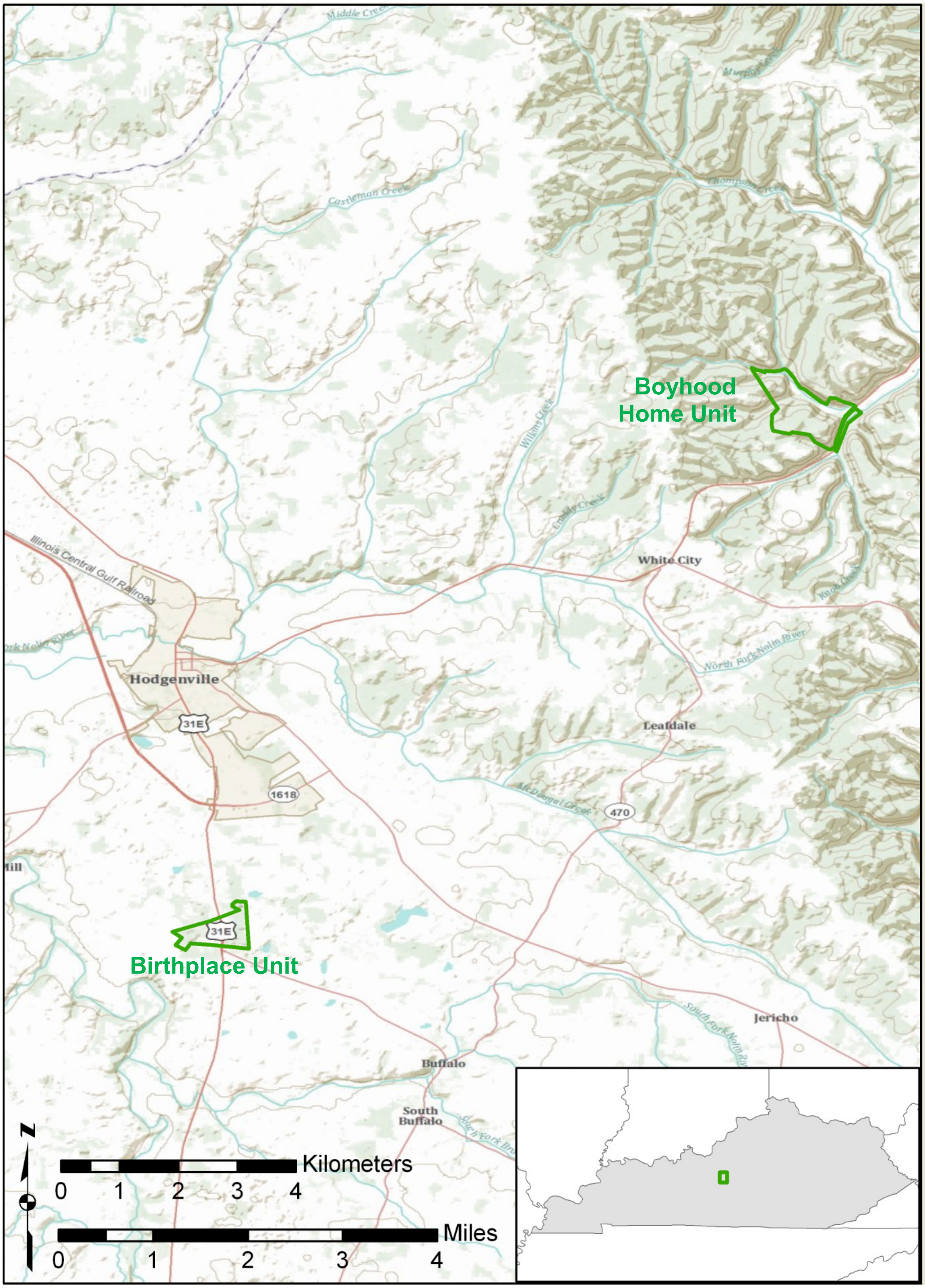

Figure 1. Topographic map showing both units of Abraham Lincoln Birthplace National Historical Park in central Kentucky. Note the differences in landforms between the two units. Compiled by Jason Kenworthy (NPS Geologic Resources Division) from ESRI ArcImage Service; World Topo Map imagery.

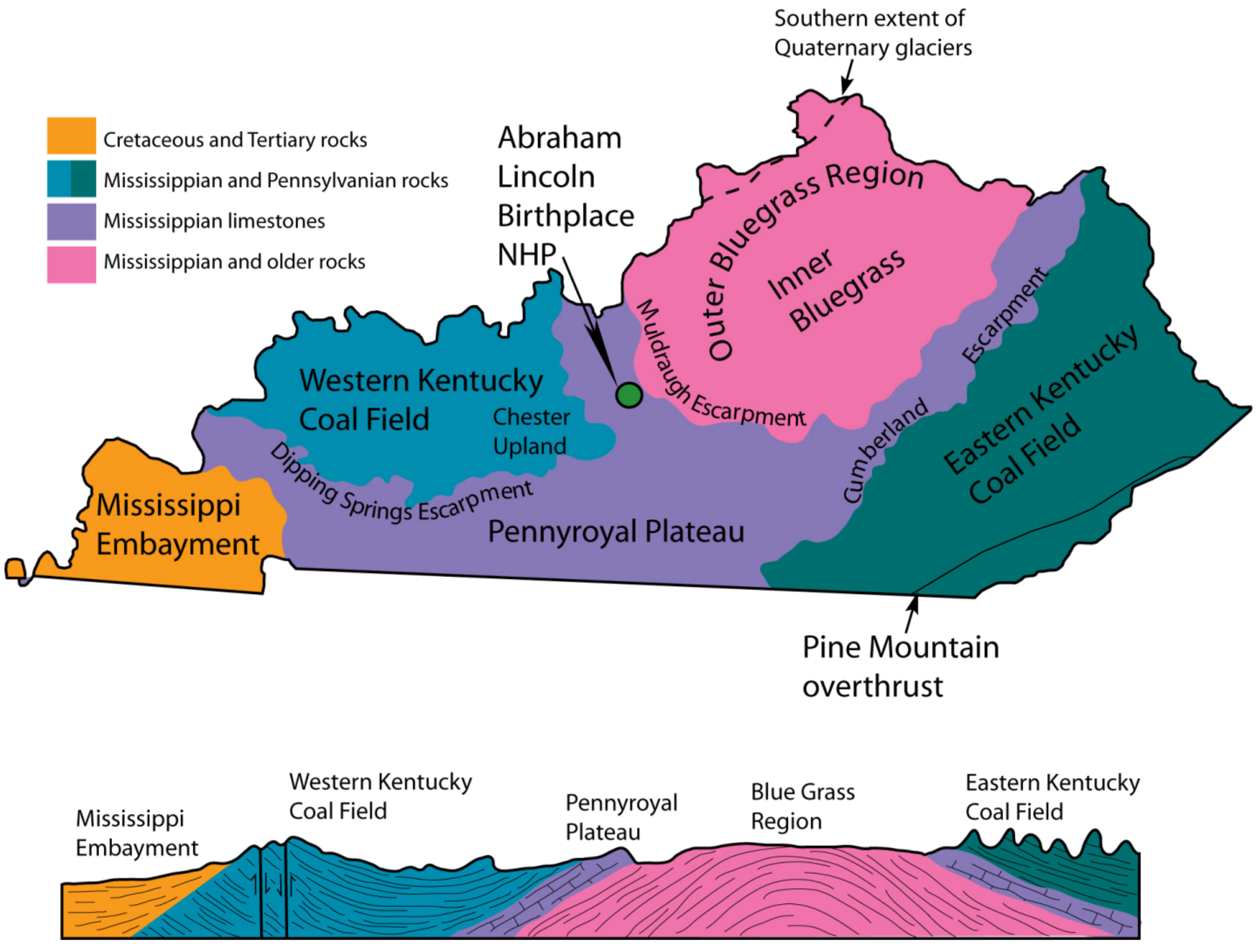

Figure 2. Map and cross section of Kentucky. The figure shows the major physiographic provinces and some large-scale geologic features in Kentucky. The cross-sectional diagram (bottom) illustrates the structural trends in the state. Note the location of Abraham Lincoln Birthplace National Historical Park (green circle) on the map. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after figure 1 in Dougherty (1989).

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping session for Abraham Lincoln Birthplace National Historical Park on June 15, 2006, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers. Contact the Geologic Resources Division for technical assistance.

Introduction

Issues in this section are identified in relative order of resource management significance with the most critical listed first. Potential research projects and topics of resource management interest are presented at the end of each issue.

Caves and Karst

Kentucky karst is among the most well-developed karst landscapes in the world (May et al. 2005). The term "karst" comes from a Slavic word that means "barren, stony ground." The karst landscape of central Kentucky includes the Pennyroyal Plateau with its characteristic sinkhole plains. Karstic features influence groundwater and surface water at Abraham Lincoln Birthplace National Historical Park, and may have been important in the choice of this location as the Lincoln homestead. Sinking Spring, a perennial karst spring at the site, was the primary reason Thomas Lincoln chose to settle here in 1808 (GRI scoping notes 2006). Reliable water sources on the Pennyroyal Plateau are relatively scarce. This spring flows from a small cave and is an important interpretive feature and visitor attraction at the park (figs. 3 and 4) (Seadler et al. 2002). Specific geologic hazards related to karst include sinkholes, cover collapse, and flooding (Ruthven et al. 2003).

Potential for Contamination and Development

Karst aquifer systems are especially vulnerable to nonpoint source contamination (e.g., runoff from agricultural areas) because any surficial input is quickly transferred through the system with little if any natural filtering or sorption (Ryan and Meiman 1996). Agriculture, septic systems, and roadways are the primary sources for groundwater contamination in the park area. Fortunately, dye tests indicated that drainage from Highway 31E does not directly flow to the spring (Seadler et al. 2002).

Despite signage discouraging the practice (fig. 3), Sinking Spring is also a popular coin-toss area for park visitors; pollution of the spring is possible if litter and other inputs are not removed (J. Meiman, National Park Service, written communication, 2010). Park staff members periodically clean out the spring area (National Park Service 2006).

A portion of the basin surrounding Sinking Spring is being developed along the northern boundary of the park. Impacts of this development, including contamination of the spring and alteration or cessation of flow, are resource management concerns (National Park Service 2006). As population growth demands more groundwater resources, the potential for karst collapse is increased as the water table is lowered (Dougherty 1989).

Hydrogeologic Modeling

Resource management would benefit from an understanding of the hydrogeologic system at the park. Knowledge of how water is traveling through the subsurface will assist the selection of future well sites and help predict hydrologic response to inputs such as contaminants and other wastes. The movement of nutrients and contaminants through the hydrogeologic system can be modeled by monitoring the composition of system inputs, such as rainfall, and outputs, such as springs. Other input sources include wind, surface runoff, groundwater transport, sewage outfalls, landfills, and fill dirt. Springs in effect integrate the surface runoff and groundwater flow of their watersheds. Thus, they provide a cumulative measure of the status of the watershed's hydrologic system. Consistent measurement of these water quality parameters establishes baselines for comparison.

The discrete nature of karstic channel networks and the difficulty of downhole sampling (capturing groundwater samples in situ) pose major challenges in characterizing hydrogeologic systems in limestone aquifers (Worthington et al. 1999). Water in an aquifer tends to follow the most favorable flow paths. However, karst flow paths are not necessarily concordant with the direction of bedrock dip (i.e., they may follow fractures instead), and topographic divides do not necessarily correlate with karst basin divides (Wells 1974; Palmer 1990). Most karst networks have high hydraulic conductivity and efficiency given the large apertures of major underground channels. This means they are able to move large flows of groundwater quickly.

Certain types of measurements may aid in the study of the hydrogeologic system at the park. A potentiometric surface results from the intersection of a drilled borehole with a large, subterranean channel. This can be used to evaluate two indicators of the nature of channeling: (1) a decrease in hydraulic gradient in a down-gradient direction, and (2) channels associated with troughs in the potentiometric surface (Worthington et al. 1999).

GIS Karst Mapping

In 1996, the National Park Service commissioned a study to assist park managers in better focusing their efforts on areas of concern that might affect the park's spring. The study incorporated fluorescent dye tracing, a short cave survey, and analysis of unit base-flow discharge to determine the recharge area and flow system. Investigators combined spatial land-use patterns and high-resolution topographic information (a digital elevation model at approximately 0.3 m [1 ft]) to determine flooding mechanisms in the sinkhole surrounding Sinking Spring. Field measurements showed that the spring's catchment area covers approximately 45 ha (110 ac) and is largely contained within the boundaries of the park. Part of the catchment is also located within land used for agriculture nearby (Seadler et al. 2002; National Park Service 2006; Hoffman Institute 2007). Digital themes in the GIS included land use, property lines, streets, soils, caves, geology, and aerial photography. This GIS may offer insight to reduce groundwater problems such as flooding, storm drain blowouts, and water contamination (Hoffman Institute 2007). This report accompanies digital geologic data compiled for Abraham Lincoln Birthplace National Historical Park (Appendix A).

Sinking Spring

The spring, which has produced a moderate flow of water since the 1800s, is actually part of a prominent type of karst window, called a doline, which is fed by a perched aquifer located atop a local shale unit within the Mississippian St. Louis Formation (J. Meiman, National Park Service, personal communication, 2006; National Park Service 2006). Dolines, sinking streams, and springs are useful in characterizing underground channeling in the hydrogeologic system (see "Geologic Features and Processes" section). Dolines are input points to continuous, large-aperture (typically 1 cm to 1 m [0.4 in to 3 ft]) channels that may traverse an entire carbonate aquifer and terminate at springs. Testing discharge from these "terminal" springs enables an estimate of channel hydraulic conductivity (i.e., the ease at which water moves through pore spaces or fractures) (Worthington et al. 1999).

Water from Sinking Spring immediately enters a small cave large enough to fit a person for approximately 24 m (80 ft) and flows below ground before its egress into the South Fork Nolin River, approximately 1.6 km (1 mi) southwest of the spring (National Park Service 2006). This natural and cultural feature is an excellent example of the pervasive karst processes at work on the landscape of the Pennyroyal Plateau. Sinking Spring may actually be part of a cave network (upgradient) and should be managed as such (GRI scoping notes 2006). Sinking Spring may support a variety of sensitive cave-adapted biota, though no official survey has been conducted to determine the extent of this possibility (J. Meiman, National Park Service, written communication, 2010). Water quality at karst springs characteristically undergoes high amplitude, but brief degradation follows runoff influxes. Even brief increases in certain pollutants may have lasting detrimental effects on aquatic cave life and water supply (Ryan and Meiman 1996).

During heavy rains, soil and turf can subside through weak spots in the ceilings of limestone; sedimentation is evident in the spring's flow (National Park Service 2006). These and other sediments in the spring and conduit system serve as storage reservoirs for heavy metals (e.g., chromium, cadmium, nickel, lead, and zinc). Transport and storage of sediment are integrally linked to metal cycling in karst systems. Karst sediment is either sedentary (as deposits) or mobile (as suspended material) with abundant exchange between the two. The testing procedure for heavy metals in sediments separates the metals into exchangeable, carbonate, oxide, organic, and residual fractions, and chemically analyzes and characterizes these materials (Vesper and White 2004).

Karst Feature Potential

Because of the presence of caves, underground voids, and karst networks, the potential for sinkhole development is prevalent across the Pennyroyal Plateau, including Abraham Lincoln Birthplace National Historical Park. Weathered sinkholes define the rolling-hill topography of the area, and a sinkhole provides the catchment for Sinking Spring at the park. A large depression near the northeastern corner of the Birthplace Unit is called Big Sink and once contained a spring that ceased flowing in the 1930s, possibly due to natural diversion into another groundwater flow basin (National Park Service 2006).

The Kentucky Geological Survey (KGS) is using large-scale geologic mapping and a GIS to prepare detailed analyses of the extensive karst terrain in the area. They created an index of relative karst development to compare conditions between regions because data are not uniformly available across all areas. This karst development index (KDI) evaluates the development of karst geomorphic features and bulk porosity. The criteria included in the KDI are epikarst development (depth to bedrock); distribution of sinkholes, caves, and springs; and channel density. Each of the criteria is placed in a weighted scoring matrix to determine a value and then is scaled regionally. A karst potential index (KPI) evaluates the lithologic characteristics inherent in specific geologic units (polygons in GIS) that lead to karst development. Criteria utilized in the determination of the KPI are bedding thickness, overall grain size, percentage of pure calcite in carbonate rock, and the bulk content of insoluble material. Designed and calibrated for specific use in Kentucky, these two indices should be available to resource management at the park for use in the anticipation of karst geologic hazards and the mitigation of human impacts on karst aquifer systems. However, the classification of karst areas, as well as classifications developed for land-use planning and engineering, have always been subjective. Therefore, further onsite measurements would provide specific data for planning purposes at the park (Currens et al. 2005).

Toomey (2009) presents a variety of "vital signs" for monitoring caves and associated landscapes. While many are geared for accessible caves, two vital signs in particular (surface expression and processes, and groundwater levels and quality) may be applicable to Abraham Lincoln Birthplace National Historical Park.

Resource Management Suggestions for Caves and Karst

- Continue dye tracer analysis could be used to determine the underground morphology of the karst network and understand groundwater flow at the park and the immediate surrounding area.
- Use GIS and large-scale geologic mapping to determine cave potential in the area. This same information may be used to evaluate the risk of sinkhole development locally. Consult the KGS karst terrain characterization program.
- KGS staff members suggest preparing a management assistance program for the groundwater springshed with guidance from Eckenfelder, Inc. (1996) and Ginsberg and Palmer (2002).
- Use continuous water quality measuring strategies at Sinking Spring and other springs to fully determine contaminant input before, during, and after influx events (Ryan and Meiman 1996). The Kentucky Geological Survey has maps to show the locations of wells and springs across the state (Ruthven et al. 2003).
- Create hydrogeologic models for the park to better manage the groundwater resource and predict the system's response to contamination.
- Map and quantify subterranean water recharge zones.
- Monitor the concentration of heavy metals in any sediments found within Sinking Spring and other springs at the park (Vesper and White 2004).
- Investigate additional methods to characterize groundwater recharge areas and flow directions.
- Conduct an inventory, including maps, locations, and assessments, of known caves and karst features (National Park Service 2006) and produce associated GIS.
- For additional assistance with water quality issues, contact the NPS Water Resources Division.

Fluvial Flooding and Contamination

Water resources in the park area include lakes and ponds, rivers and streams, and springs, including Sportsman and McDougal lakes; the South Fork Nolin River and the North Fork Nolin River; Knob Creek; and Sinking, Howell, Terhune, and Heady springs (National Park Service 2006). The boundaries of the Boyhood Home Unit contain an entire watershed (north branch of Knob Creek). The surrounding areas are largely forested and undeveloped. At the Birthplace Unit, surface water issues include (1) subsurface hydraulic damming (with potential contamination from storm water), and (2) flooding along the South Fork Nolin River and the perennial stream. At the Boyhood Home Unit, flooding occurs along Knob Creek (Seadler et al. 2002). The park contains significant portions of the floodplains of these waterways and park infrastructure and visitor facilities could be threatened if water levels reach the 50-year floodplain mark. Structures at the Boyhood Home Unit are on the edge of the 100-year floodplain (National Park Service 2006).

During flood events, water from broader areas fluxes into free-flow karst aquifers like the one underlying the park. If flow exceeds the capacity of the sinkhole drain, then flooding can result. Flood-event flow may also include nonpoint source and point source contaminants (Reeder and Crawford 1988). Therefore, there is a resource management need for storm event monitoring in the free-flow karst aquifers underlying the park.

Nearby studies have compared observation wells in trunk-cave streams and at nearby farms. These studies indicate that storm water from large cave streams flows (in part) back into karst aquifers. The process may be analogous to riverbank storage in alluvial aquifers. Water samples collected from cave streams and springs during and after storm events also show an increase in point-source contaminants and suspended sediment (Crawford 2005).

Studies begun in 1996 indicate that the water quality for the park is fair for karst flow draining agricultural land. Impacts from nitrates, fecal coliform bacteria, and the broadleaf herbicide Trifluralin are ongoing at the park (Seadler et al. 2002; National Park Service 2006). Subsurface hydraulic damming of the South Fork Nolin River creates storm pulses into the large sink feeding Sinking Spring that may integrate larger concentrations of contaminants collected from a broader drainage area (Seadler et al. 2002).

Lord et al. (2009) suggest "vital signs" for monitoring fluvial systems including: watershed landscape, hydrology, sediment transport, and channel cross section, plan form, and longitudinal profile.

Resource Management Suggestions for Fluvial Flooding and Contamination Issues

- Contact the NPS Water Resources Division for technical assistance.
- Continue to sample spring water quality, especially during storm events at a high frequency level given the rapid response of the karstic system to changes in water input. If degraded water is detected, attempt to locate and mitigate the source (National Park Service 2006).
- Continue to support and cooperate with student research training programs and other agencies to increase understanding of the fluvial system at the park.
- Prepare a quantitative analysis of the Knob Creek floodplain and assess the risk of damaging floods (National Park Service 2006).
- Investigate the potential of a "Wellcam" down-hole video camera to gain a better understanding of the voids associated with the drainage system at the park (Reeder and Crawford 1988).

Mass Wasting

Though the topographic relief in the park area is relatively subdued, there is some potential for slope creep and mass wasting. The Mississippian-age Borden Formation contains abundant clay, glauconite, and shale-rich layers (Johnson 2005) and can pose slope-stability problems when it forms steep slopes or where slopes are undercut. Note the steeper topography at the Boyhood Home Unit compared to the Birthplace Unit (fig. 1 and Appendix A). The newly exposed outcrops of the Borden Formation along the north branch of Knob Creek are likely susceptible to mass wasting. The clays of the Borden Formation are plastic when wet and small landslides are very common, even for moderate to gentle slopes. In layers where clay- rich zones are underlain by relatively impermeable sandstones or shales, a slip surface can develop, increasing the potential for mass wasting (Johnson 2005). Moreover, the shrink-and-swell potential of clays, which causes changes in volume (i.e., swell when water saturated, shrink upon drying), undermines ground stability.

Large rockfall events are not likely at the park; however, when resistant rock units such as sandstone and limestone are located above weaker units, such as shale, rockfall hazards may exist. Any plans for future park infrastructure should carefully consider slope stability and rockfall potential.

Wieczorek and Snyder (2009) suggest monitoring strategies for slope stability. They present five monitoring "vital signs": types of landslides, landslide triggers and causes, geologic materials in landslides, measurement of landslide movement, and assessing hazards and risks.

Resource Management Suggestions for Mass Wasting

- Monitor slope processes at both units of the park.
- Conduct site investigations of clay-rich layers and friable limestones exposed on slopes to determine a vulnerability index to slope failure.
- Determine composition of all clays in surficial deposits. Identify and map the distribution of shrink- and -swell clays for use in identifying potential problem areas.
- Cooperate with GRD Soils Inventory Program to update soil GIS data to include Boyhood Home Unit (National Park Service 2006).

Disturbed Lands

Sinkholes are generally efficient at collecting storm-water runoff and channeling it through the subsurface karst conduit network. However, human practices can disturb the natural drainage, resulting in increased potential for flooding. Infilling sinkholes for construction or mass wasting, can plug the natural karst drainage. Parking lots and roads (as well as other types of construction) tend to decrease infiltration and increase runoff. When storm-water runoff exceeds the capacity of the sinkhole drain to transmit water to the karst network, the result is subsurface flooding (Reeder and Crawford 1988). According to the NPS definition, the area of the basin surrounding Sinking Spring is not a floodplain. However, in flood situations, eruptions or blowouts of the storm drain system occur at the Birthplace Unit (National Park Service 2006).

To avoid this situation, storm-water management strategies include water-catchment basins and drainage wells (Reeder and Crawford 1988). Between 1929 and 1930, the War Department constructed an entrance structure and drain for Sinking Spring to provide access and to alleviate a flood hazard posed by a seasonally ponded sinkhole. This infrastructure consists of a drain system of pipes and culverts, some of which are 1 m (3.3 ft) in diameter and are buried 3–4 m (10–13 ft) below ground. Limestone steps with flagstone landings and walls lead to the spring. A spring pool is visible through a circular hole in flagstone paving, which is sheltered by a natural rock ledge (fig. 3)(National Park Service 2006). This system was intended to coalesce and funnel runoff towards the natural spring, but the structure was a failure and did not change the flood hazard at the site. Resource managers might consider removing the structure and installing drainage wells, but need to investigate any potential effects (GRI scoping notes 2006).

Resource Management Suggestions for Disturbed Lands

- Cooperate with the Kentucky Geological Survey to obtain land-use planning maps (derivatives from the digital geologic map).
- Investigate potential effects to the watershed, Sinking Spring, and surrounding landscape of removing the 1920s era infrastructure designed to alleviate flood hazard at the Birthplace Unit.
- Incorporate human impacts, historical land use evolution, and the influences of geologic resources on the park's history into interpretive programs.

Paleontological Resources

Hunt-Foster et al. (2009) completed a literature-based paleontological resource summary for the Cumberland Piedmont Network, including Abraham Lincoln Birthplace National Historical Park. Fossils add to the understanding of geologic history, help correlate units across time and space, and provide clues to the original depositional environment of the bedrock in which they occur. Some fossils can also provide information about post-burial geochemical changes, deformation, and changes in bedding orientation.

Although not formally documented, fossils are known from bedrock within the park, including crinoids and other Mississippian-age fossils in the Borden Formation. Some crinoids may be partly intact and show some color-banding preservation (or it may just be normal quartz banding seen in many silicified fossils) (J. Meiman, National Park Service, personal communication, 2006; S. Greb, Kentucky Geological Survey, written communication, 2010). Brachiopods, bryozoans, and corals are relatively common in the Borden Formation and might occur in the park. The Borden Formation crops out in broad areas throughout the region and generally does not contain rare fossils. However unauthorized collection or fossil theft is possible. Fossils exposed by erosion on slopes can concentrate in alluvium and colluvium derived from bedrock geologic units. Knowledge of the extent of the paleontological resources in the area may also influence future expansion directions for the park.

Fossil resources require science-based resource management as directed by the 2009 Paleontological Resources Preservation Act (Public Law 111-11). The National Park Service is currently developing regulations associated with the Act (J. Brunner, Geologic Resources Division, personal communication, May 2010). Santucci et al. (2009) suggest strategies for monitoring in situ paleontological resources utilizing five "vital signs." The paleontological resource monitoring vital signs include: natural erosion (geologic variables; e.g. rock type, degree of slope, bedding), natural erosion (climatic variables; e.g. precipitation, temperature, freeze/thaw cycles), catastrophic geologic processes (geohazards; e.g. landslides), hydrology and bathymetry (e.g. shoreline processes and water level fluctuation), and human impacts (e.g. unintentional impacts and intentional theft/vandalism).

Resource Management Suggestions for Paleontological Resources

- Perform a comprehensive field-based inventory and documentation of fossil resources in the geologic units exposed at the park.
- Monitor paleontological resources as they are exposed in the cutbanks and slopes at the park (National Park Service 2006).
- Develop an interpretive program that incorporates the fossil story along with the geologic history of the area. Interpretation should also include a resource stewardship message.

Figure 3. Sinking Spring. Thomas Lincoln established "Sinking Spring Farm" to take advantage of this perennial water source. National Park Service photograph by Brenda Wells (Mammoth Cave National Park).

Figure 4. Sinking Spring is a primary geologic feature in the park. The above image is a scan of a historic photograph of the spring. The lower image shows the modern path and access to the spring. National Park Service photographs available online: http://www.nps.gov/abli/photosmultimedia/photogallery.htm (accessed June 22, 2010).

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Abraham Lincoln Birthplace National Historical Park.

Geology and History Connections

Geology has a strong influence on the development of any landscape. In central Kentucky, where the limestone units have dissolved into a karstic underground drainage network, surface water can be scarce. Lakes and other large bodies of water are virtually nonexistent and most of the streams and surface runoff disappear rapidly underground. Thus, the presence of a consistent, reliable water source was a valuable asset to a family looking to settle in the area. The site chosen by Thomas Lincoln, near Hodgenville, Kentucky, in 1808, had a perennial spring, flowing from a small cave called Sinking Spring (Seadler et al. 2002).

Thomas Lincoln paid $200 cash and assumed a small debt of the previous owner to obtain Sinking Spring Farm in December 1808. His son, Abraham, was born on February 12, 1809, in a small (3.6 × 5 m [12 × 17 ft]), chinked, log cabin. Due to an ongoing legal struggle regarding prior land claims asserted on the farm, the Lincoln family relocated to Knob Creek Farm where they leased 12 ha (30 ac) from George Lindsey's 93-ha (230-ac) farm for six years before moving to Indiana (National Park Service 2006). The future president's earliest memories would be of the Knob Creek Farm. He wrote of his experiences in 1860, recalling planting pumpkin seeds in the garden while others planted corn. The following day a large rainstorm caused local flooding of Knob Creek (inside front cover) that eroded away the newly planted garden (National Park Service 2009).

Early settlement of the area was mainly due to agricultural endeavors. Then as now, farmers were attracted to a steady supply of water and thick, fertile soil. Patterns of population followed suit. Today, the sparsely populated, rugged Chester Upland south and west of the park, with its thin, rocky soil and rapid surface drainage stands in stark contrast to the Pennyroyal Plateau (fig. 2). The plateau contains nearly all the cities and larger towns of central Kentucky, as well as the state's extensive and fertile farms (tobacco being a dominant crop). The extreme weathering of the limestone underlying the plateau has left a residue of thick, sticky reddish soil (Palmer 1981). As limestone dissolves, calcium carbonate is removed, and other elements and trace materials in the rocks are left as residue, including quartz sands and iron-rich clays that combine with organic material to create soil.

Before European settlers came to Kentucky, American Indians used local caves as shelter and the natural resources of the area for tools, food, and clothing. American Indian remains and artifacts are located in nearby caves including Mammoth Cave about 55 km (35 mi) southwest of Hodgenville, Kentucky (Palmer 1981). Evidence suggests people have inhabited the Pennyroyal Plateau region since at least 11,000 Before Common Era (BCE; preferred to "BC"). At the Boyhood Home Unit, a recent archaeological survey of the developed area and fields uncovered a possible large prehistoric site including stone tools and flakes. Shovel testing identified a large chert procurement and initial flaking site. Chert (microcrystalline quartz) is common in the area's limestone units and commonly weathers from the limestone. Because chert is hard and tends to break along sharp, conchoidal fractures, prehistoric peoples commonly used it to make stone tools. They may have collected chert from the Knob Creek area for tool making. Some evidence indicates that a prehistoric domestic camp may have been located in the developed portion of the park property (National Park Service 2006).

The area's fertile soil promoted maize agriculture, which supported human occupation through the prehistoric period—1000 to 1650 Common Era (CE; preferred to "AD"). An area called the barrens, burned off by native people to attract buffalo, was located near the Birthplace Unit. Historical evidence shows the Cherokee, Chickasaw, Shawnee, and Iroquois all used the region for hunting and fishing (National Park Service 2006).

Maintaining historic features may entail resisting natural geologic processes, which presents several management challenges. Geologic slope processes such as landsliding, slumping, chemical weathering, block sliding, and slope creep are constantly changing the landscape at the park. Runoff erodes sediments from open areas and carries them down streams and gullies. Erosion naturally diminishes higher areas and fills in the lower areas to distort the historical landscape conditions. Issues can arise from different objectives between cultural and natural resource management. For example, a proposal for maintenance of a historic building, field, or grove of trees may consist of removing surrounding natural resources or installing stabilization structures. These efforts can alter natural geologic processes.

The fundamental resources at the Birthplace Unit include the historic memorial and cultural landscape, Sinking Spring, old-growth forest, and the historic Boundary Oak site (Lawliss and Hitchcock 2004). At the Boyhood Home Unit, resources include a 3-ha (7-ac) field, rural 19th century landscape, Knob Creek and its tributaries, rare limestone glades (occurring on limestone outcroppings on south- or west-facing slopes characterized by shallow rocky soils and unique flora that have adapted to the harsh dry conditions), unusually diverse and abundant flora, boundary oak, fossil-bearing Mississippian limestone, and possibly a section of the original Louisville-Nashville Turnpike (Cumberland Road) (National Park Service 2006).

Karst Topography and the Pennyroyal Plateau

A karst landscape refers to a characteristic terrain produced by the dominant geomorphic processes of chemical erosion and weathering of carbonate rocks (i.e., limestone and dolomite) (Palmer 1984). Dissolution occurs when acidic water reacts with carbonate rock surfaces along cracks and fractures. Most meteoric water is of relatively low pH ("acidic") due to the reaction between atmospheric carbon dioxide (CO_2) and water (H_2O). The product of this reaction is carbonic acid (H_2CO_3). Groundwater may become even more acidic as it flows through decaying plant debris and soils (Florida Geological Survey 2005). The acid reacts with calcium carbonate ($CaCO_3$) in the rocks to produce soluble calcium (Ca^{2+}) and bicarbonate (HCO_3^-); that is, "rocks in solution" or "dissolved rocks." In addition, most of the carbonaceous limestone and dolomite in central Kentucky are inherently porous, which facilitates dissolution. Over hundreds of thousands of years, dissolution has occurred between the intergranular pores and along fractures, creating larger and larger voids.

Many of the larger surface karst features formed by mechanical processes such as collapse were triggered by subsurface dissolution. There is a strong correlation between underground conduits, geologic structure, and surficial karst features that evolved with groundwater recharge (figs. 5, 6, and 7). If the recharge influx is concentrated at discrete points, such as dolines, a dendritic flow pattern and cave system is the dominant form of karst drainage. Recharge dominated by one or a few sinking streams typically result in a single major conduit with minimal tributaries, whereas if the recharge is diffuse from many smaller sources, a network maze of intersecting fissure passages commonly develops (Palmer 1984).

The system of underground voids in west-central Kentucky is extensive and varied with respect to network patterns. It can be viewed as an elaborate plumbing system through which water flows through discrete conduits (Palmer 1990). The Pennyroyal Plateau is significant in being the largest continuous region of cavernous rocks in the United States (Palmer 1981). It contains thousands of shallow sinkholes, occasional blind valleys, some karst pavement, and numerous karst windows (Mylroie and Dyas 1985). The Mammoth–Flint Ridge–Tooney Ridge cave network, located in the Chester Upland 64 km (40 mi) south of the park, is the longest known system of connected passages in the world. In areas where there are cavernous rocks, collapse of overlying rock and soil into underground voids (e.g., conduits and caves) can produce sinkholes. If the sinkhole occurs in a streambed, it may capture the water flow, creating a disappearing stream.

At Abraham Lincoln Birthplace National Historical Park, the landscape is a testament to active karst processes of limestone dissolution, underground cavity development, spring activity, sinkhole collapse, and erosion (fig. 8). The dominant surficial geologic units include the St. Louis Limestone, the Harrodsburg Limestone, the Salem Limestone, and the Borden Formation. All but some members of the Borden Formation contain thick deposits of soluble limestone and dolomite, which typically dip less than 1°—or 5 to 10 m/km (22 to 46 ft/mi)—to the northwest, though local undulations are common (Mylroie and Dyas 1985; Palmer 1985). The four bedrock units record a longstanding marine basin—the Illinois basin (see "Geologic History" section)—during the Mississippian Period. Insoluble rocks such as shales and sandstones anchor dissected plateaus towards the center of the Illinois basin. Around the edges of the basin, these clastic cap rocks have been removed by erosion, exposing underlying limestone at the surface, which forms a broad, low-relief karst plain (the Pennyroyal Plateau) with characteristic sinkholes, small caves, springs, sinkhole ponds, and sinking streams (Palmer 1985).

Southeast of the park area lies the borderland called the Chester Upland. The boundary between the Chester Upland and Pennyroyal Plateau is a sharp, irregular 60 m (197 ft) slope locally called the Chester Escarpment. Limestone ridges, riddled with caves and capped by insoluble rocks, characterize parts of the Chester Upland. The upland and plateau together form a crescent-shaped band of karst landforms that wraps around the southern and eastern edges of the Illinois basin from southern Indiana, through western Kentucky, and into southern Illinois. The configuration of the basin controls the morphology and evolution of the broad karst area (Palmer 1985). The Pennyroyal Plateau formed during the late Tertiary (Neogene) Period under conditions of very slow fluvial erosion (dominated by the Green River) alternating with periods of aggradation. The altitude of the plain correlates with wide, well-developed upper cave levels in nearby Mammoth Cave (Palmer 1984).

The Pennyroyal Plateau contains large karst basins that drain into the area's largest rivers, the Green and Barren rivers, primarily through the subsurface. Most of the subsurface caves and conduits of the Pennyroyal Plateau are shallow and clogged with soil, assorted debris, and collapse material. This in addition to their proximity to the water table makes them wet and prone to rapid flooding. These are dangerous places to explore and thus the number of explored caves in the area is relatively low (Palmer 1985).

Caves in the park area likely formed by both vadose (above the water table) and phreatic (at or below the water table) solution. In the Pennyroyal Plateau karst system , nascent passages conduct water through the vadose zone to the phreatic zone, and solutional enlargement of conduits occurs in both zones simultaneously. In these systems, the nature of the water table is highly irregular and discontinuous. The position of the water table can vary greatly on a short-term basis because it is partly controlled by the amount of groundwater flow. The distinction between phreatic and vadose karst features in a cave such as that of Sinking Spring is an essential component to the interpretation of the regional landscape evolution (Palmer 1984). Palmer (1984, 1990) described characteristic features in a conduit formed by vadose and phreatic solution; such descriptions are valuable to researchers and park mangers attempting to interpret cave features at Abraham Lincoln Birthplace National Historical Park.

Spring Development and Sinking Spring

Generally, springs develop where the ground surface intercepts the water table. In karst systems, almost all groundwater emerges at discrete springs in entrenched river valleys or karst windows (Palmer 1990). However, features of karst networks such as nonuniform porosity, irregular and discontinuous water table, and large areal variations in permeability make hydrologic characterization and predicting groundwater behavior difficult (Scanlon and Thrailkill 1987; Palmer 1990).

The formation of springs requires the dissolution of discrete bedrock units. Additionally, through-flow of water is needed to carry away dissolved material, which depends on a preexisting interconnected network of openings not formed by solution (Palmer 1990). Upon the establishment of a hydrogeologic gradient across a carbonate (limestone) aquifer, a narrow enlargement of a bedding plane or joint extends toward the low surface-flowing stream. Where this opening reaches the surface or the stream channel, a seep may form. Upon enlargement of this initial narrow conduit into a larger conduit (a diameter of a dime is sufficient), the flow conditions change and a spring develops (S. Greb, Kentucky Geological Survey, written communication, 2010). Springs may also develop in karst systems on slopes that intersect relatively impermeable layers such as shale or sandstone that form small, locally perched aquifers. In central Kentucky, dye-tracing studies have identified two physically distinct spring types: (1) local high-level springs discharging from shallow flow paths, and (2) major low-level springs incorporating discharge from a deep integrated much longer conduit system (fig. 9). Both types tend to show chemical similarities with respect to calcium, magnesium, bicarbonate, and hardness (Scanlon and Thrailkill 1987).

Based on the relatively small size of the catchment basin at Sinking Spring (approximately 45 ha [110 ac]), the feature is likely a high-level spring type. The shallow flow paths inherent in this spring type are highly connected with surface runoff and thus have rapid responses to changes in precipitation and any contamination. Furthermore, there is little mitigating effect by long-term percolation. A shallow zone of interconnecting solutional openings is common in the upper few meters of limestone bedrock on the Pennyroyal Plateau, and relatively few individual openings receive enough water to enlarge into large conduits. At the inputs of larger conduits, sinkholes may develop in the landsurface because of the concentrated dissolution, collapse, and transport of “clogging” underburden by groundwater flow through the conduit. The sinkhole then acts as the primary influx point. The development of the Sinking Spring sinkhole depended on the presence of an underlying conduit (Palmer 1990).

Much evidence indicates that Sinking Spring is a high-level spring, but it is also associated with a type of karst window, called a doline, which forms by dissolution and gentle subsidence, and discharges near a major surface stream (the South Fork Nolin River)—both of which are characteristics of a major (low-level) spring type (Scanlon and Thrailkill 1987; GRI scoping notes 2006). Hence, further research into the development and evolution of Sinking Spring is needed to better understand its hydrogeologic character.

Sinkhole Collapse

The Pennyroyal Plateau is a rolling landscape defined by thousands of rounded depressions. Nearly all karst depressions originate at least in part by collapse or slow subsidence of dissolved bedrock fragments into a preexisting underground conduit or void. On the surface, the expression of an old, weathered depression can look the same whether the feature formed by sinkhole collapse or solution (Palmer 1990).

Most subsurface streams throughout the area are roofed by bedrock. When shallow underground stream conduits are roofed by thin layers of overlying rock, an eventual collapse produces a steep-walled sinkhole whose resultant debris is removed mechanically and by dissolution from below. This may form a karst window that allows direct access to the conduit. For about 10% of sinkholes, the debris produced as collapse takes up more volume than it did as solid bedrock thus self-limiting the process of sinkhole formation (Palmer 1990; J. Currens, Kentucky Geological Survey, written communication, 2010). Collapse and subsidence associated with sinkhole development are perhaps most frequent during flooding events, but the process can be continuous. Most dolines form by dissolution and the removal of solids and gradual subsidence (S. Greb, Kentucky Geological Survey, written communication, 2010). By contrast, rapid collapse can occur within a few hours of erosion. Collapses are limited to the depth of the active conduit passage below; however, lateral development can occur (fig. 10). The areas that are most susceptible to collapse are shallow conduits at or just beneath the water table (Palmer 1990). The potential for sinkhole collapse exists at both units of the park and careful determination of the nature of the underlying karst features may help resource management to determine areas particularly at risk.

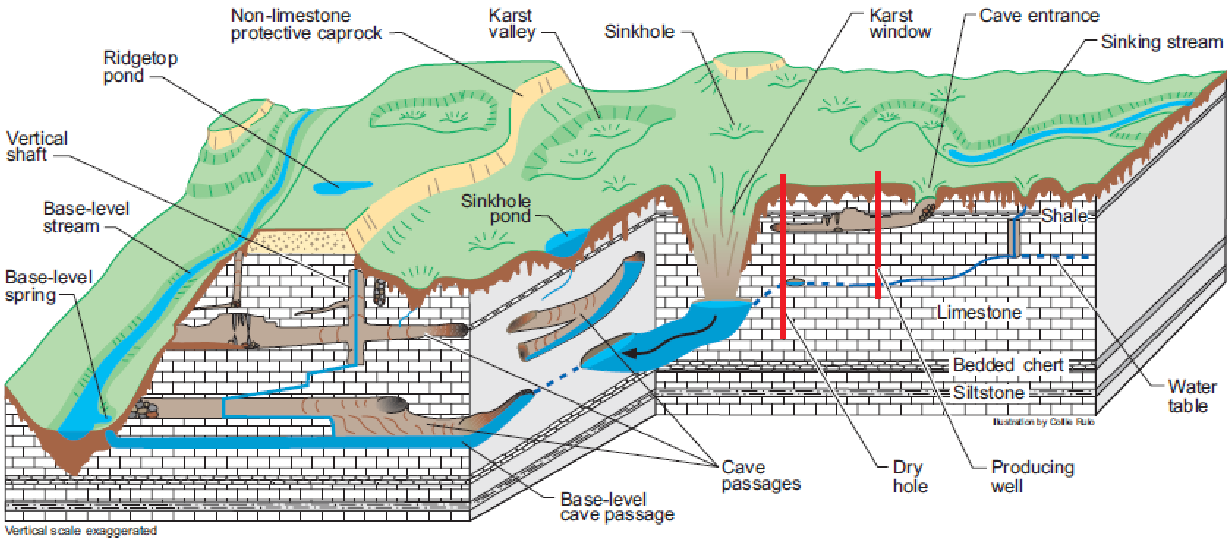

Figure 5 Generalized block diagram of karst features occurring in the western Pennyroyal karst. Kentucky Geological Survey graphic from Currens (2001b).

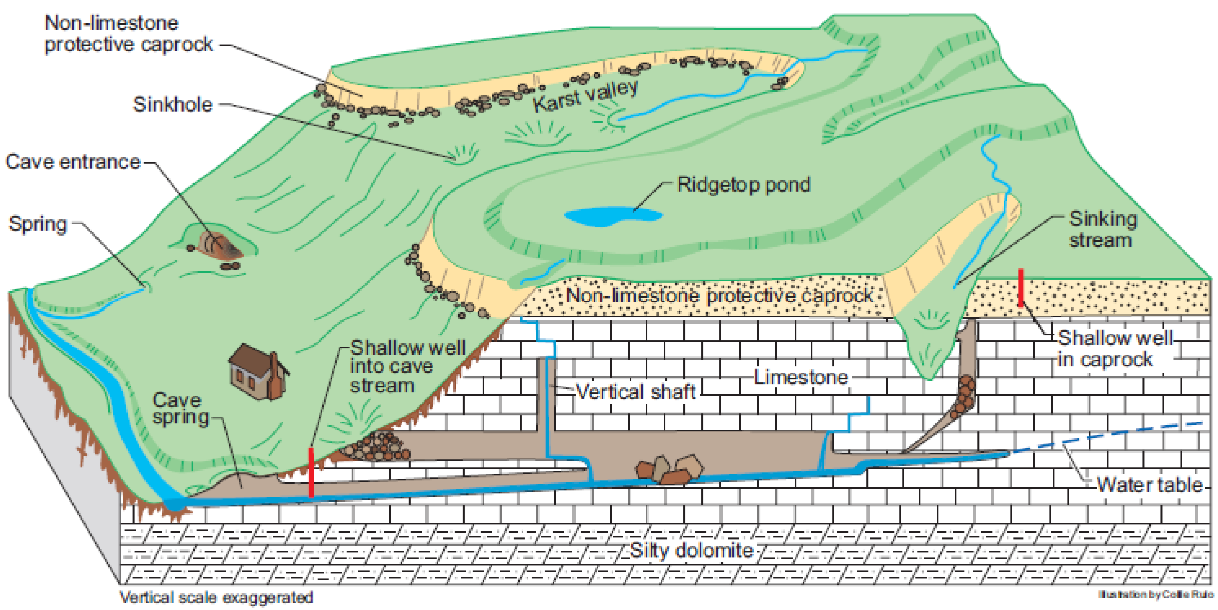

Figure 6. Generalized block diagram of karst features occurring in the eastern Pennyroyal karst. Kentucky Geological Survey graphic from Currens (2001a).

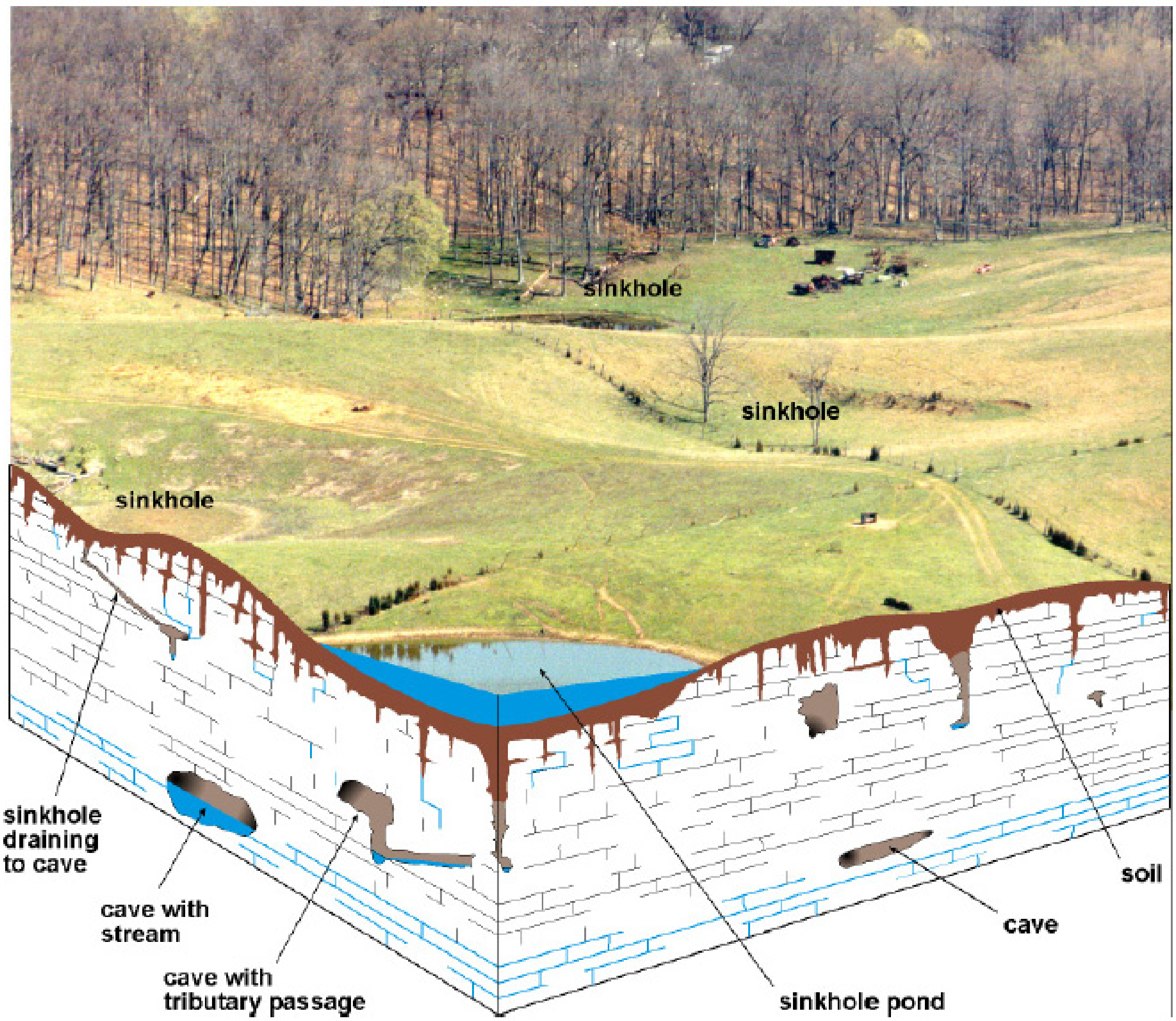

Figure 7. Generalized block diagram of karst features within Larue County. The figure shows landscape features typical of Abraham Lincoln Birthplace National Historical Park. Kentucky Geological Survey graphic from Davidson et al. (2006).

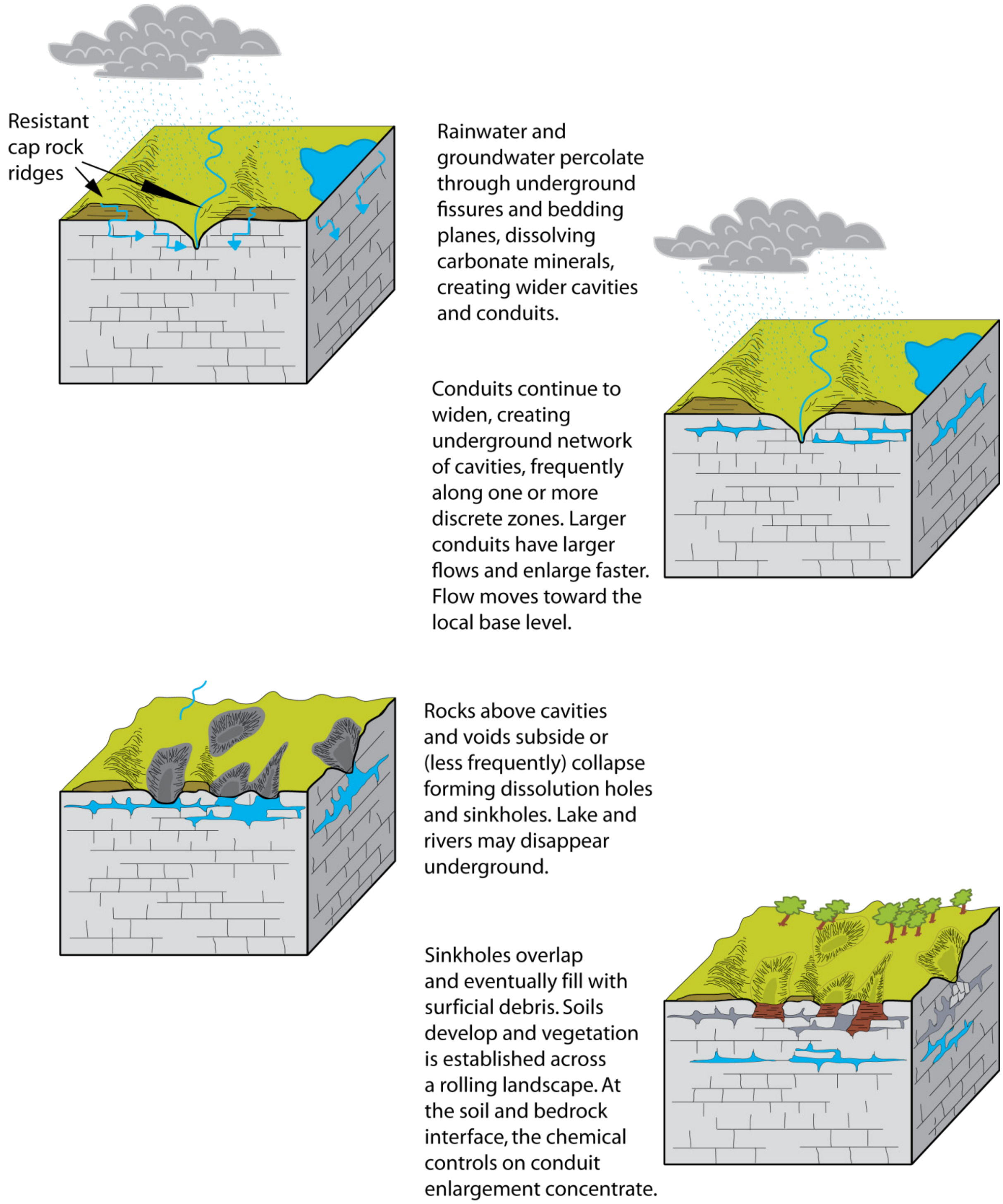

Figure 8. Generalized cross-sectional view of the development of a karstic landscape analogous to the Pennyroyal Plateau. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

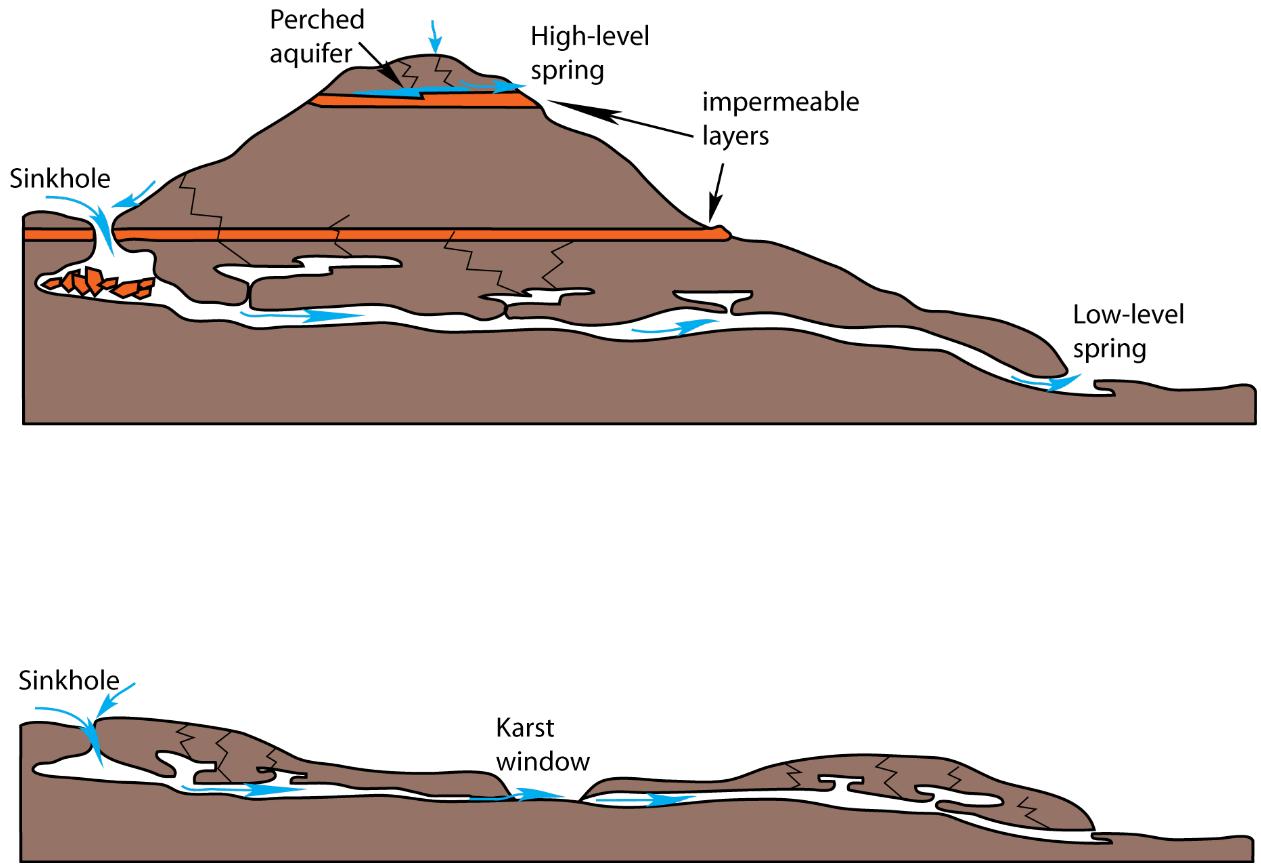

Figure 9. Cross-sectional diagrams of springs in a karst landscape. High-level springs discharge from shallow flow paths. Low-level springs incorporate discharge from long, deep conduits. Sinking Spring (lower diagram) combines features of both spring types. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from figure 14 of Scanlon and Thrailkill (1987).

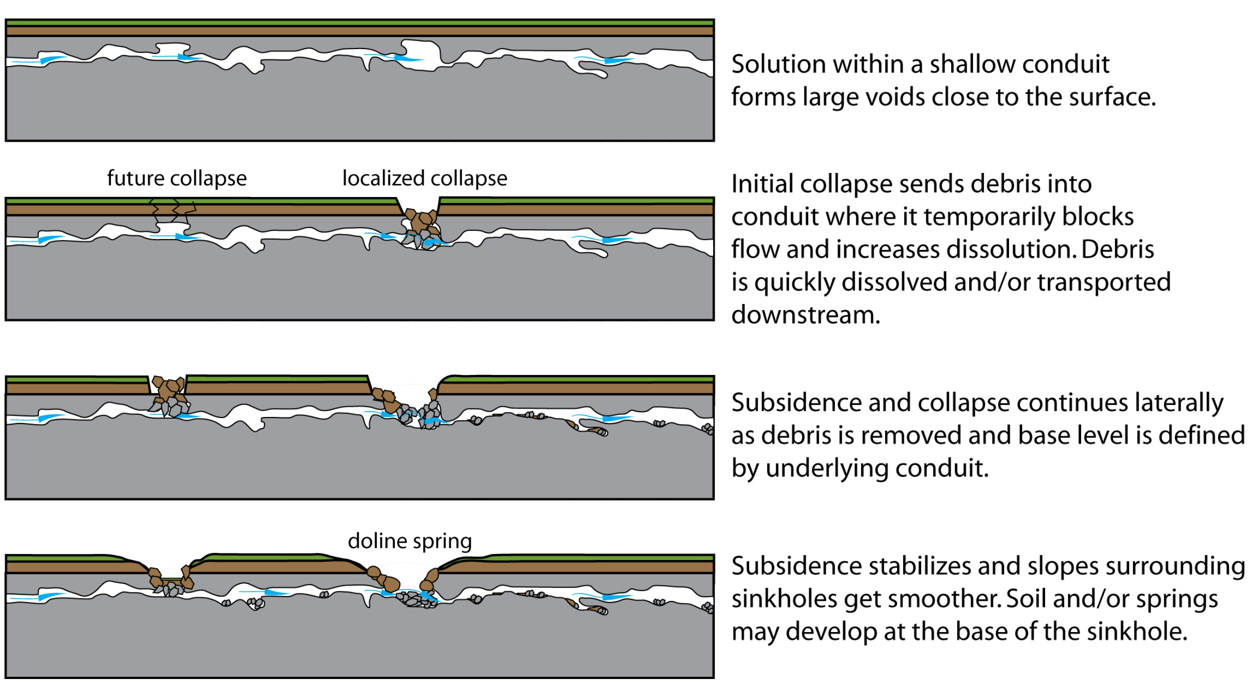

Figure 10. Cross-sectional view of the development of sinkholes on a landscape analogous to the Pennyroyal Plateau and the formation of a doline spring analogous to Sinking Spring. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Abraham Lincoln Birthplace National Historical Park. The accompanying table is highly generalized and for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Abraham Lincoln Birthplace National Historical Park provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report. Geologic maps are two-dimensional representations of complex three-dimensional relationships; their color coding illustrates the distribution of rocks and unconsolidated deposits. Bold lines that cross or separate the color patterns mark structures such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mines, wells, and cave openings.

Incorporation of geologic data into a Geographic Information System (GIS) increases the usefulness of geologic maps by revealing the spatial relationships among geologic features, other natural resources, and anthropogenic features. Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps are not soil maps, and do not show soil types, but they do show parent material—a key factor in soil formation. Furthermore, resource managers have used geologic maps to make connections between geology and biology; for instance, geologic maps have served as tools for locating sensitive, threatened, and endangered plant species, which may prefer a particular rock unit.

Although geologic maps do not show where earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Similarly, map units show areas that have been susceptible to hazards such as landslides, rockfalls, and volcanic eruptions. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by depicted geomorphic features. For example, alluvial terraces may have been preferred use areas and formerly inhabited alcoves may occur at the contact between two rock units.

The geologic units listed in the following table correspond to the accompanying digital geologic data. Map units are listed in the table from youngest to oldest. Please refer to the geologic timescale (fig. 11) for the age associated with each time period. The table highlights characteristics of map units such as susceptibility to erosion and hazards; the occurrence of paleontological resources (fossils), cultural resources, mineral resources, and caves or karst; and suitability as habitat or for recreational use. Some information on the table is conjectural and meant to serve as suggestions for further investigation.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following references are the sources for the GRI digital geologic data for Abraham Lincoln Birthplace National Historical Park:

Johnson, T. L. 2005. Spatial database of the Hodgenville quadrangle, Larue and Nelson counties, Kentucky (scale 1:24,000). Digitally Vectorized Geologic Quadrangle Data DVGQ-749_12, Series 12. Kentucky Geological Survey, Lexington, Kentucky.

Moore, F. B. 1968. Geologic map of the Hodgenville quadrangle, Larue and Nelson counties, Kentucky (scale 1:24,000). Geologic Quadrangle Map GQ-749. U.S. Geological Survey, Reston, Virginia.

Kentucky Geological Survey. 2005. Kentucky oil and gas well data, NAD 83, version 10 (kyog83v10). Kentucky Geological Survey, Lexington, Kentucky.

Paylor, R. L., L. Florea, M. Caudill, and J. C. Currens. 2003. A GIS sinkhole coverage for the karst areas of Kentucky. Unpublished data. Kentucky Geological Survey, Lexington, Kentucky

The GRI team implements a geology-GIS data model that standardizes map deliverables. This data model dictates GIS data structure including data layer architecture, feature attribution, and data relationships within ESRI ArcGIS software, and increases the overall utility of the data. GRI digital geologic map products include data in ESRI personal geodatabase, shapefile, and coverage GIS formats, layer files with feature symbology, Federal Geographic Data Committee (FGDC)–compliant metadata, a Windows help file that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map. GRI digital geologic data are included on the attached CD and are available through the NPS Data Store at http://science.nature.nps.gov/nrdata/ (accessed May 21, 2010).

Abraham Lincoln Birthplace National Historical Park Map Units

The geologic bedrock units at Abraham Lincoln Birthplace National Historical Park are the Borden Formation, Harrodsburg Limestone, Salem Limestone, and St. Louis Limestone. The Mississippian Borden Formation contains seven distinct members in ascending order: New Providence Shale, Nancy, Cowbell, Halls Gap, Wildie, Nada, and Muldraugh members. The Muldraugh Member and a crinoidal limestone member are present in the park area (Johnson 2005). In the mapped area, The Muldraugh Member is largely undifferentiated as interbedded shales, siltstones, and limestones (Moore 1968). The Muldraugh formed in prodeltaic environments on an abandoned delta front (the Borden delta complex). Deeper water was to the west and south.

The Harrodsburg Limestone is characterized by coarse-grained limestones and some silty dolomitic limestone interlayers. This unit contains abundant marine invertebrate fossils including crinoids. The limestone records the development of a carbonate platform on the underlying deltaic deposits. The carbonates accumulated in incredibly prolific crinoids-rich seas of the Mississippian Period (Johnson 2005).

The Salem Limestone contains abundant coarse-grained limestone, dolomite, shale, and siltstone. This unit is also fossiliferous recording a nearshore marine depositional environment (Moore 1968; Johnson 2005).

The St. Louis Limestone is primarily limestone, dolomite, and limy shale with silty, carbonaceous, siliceous, and cherty zones present. The relatively pure limestone layers of the St. Louis Limestone were once quarried locally. The unit supports vast cave networks nearby.

Quaternary alluvium and colluvium overlie the Mississippian bedrock. These unconsolidated deposits consist of clay, silt, sand, pebbles, organic material, and gravel in channels, floodplains, and small alluvial fans (Moore 1968; Johnson 2005).

The following page presents a tabular view of the stratigraphic column and an itemized list of features for each map unit. This sheet includes several properties specific to each unit present in the stratigraphic column including name and map symbol; description; resistance to erosion; suitability for development; hazards; potential paleontologic, cultural, and mineral resources; recreational use potential, and global significance. For more information on understanding how to use geologic maps for managing geologic issues specific to Kentucky, please see Ruthven et al. (2003). Similarly, Davidson et al. (2006) prepared a geologic map specifically for land-use planning in Larue County, Kentucky. This map displays features including mapped sinkholes, flood zones, wetland areas, gas fields, and watershed boundaries that would be useful for resource managers at Abraham Lincoln Birthplace National Historical Park.

Geologic History

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

Abraham Lincoln Birthplace National Historical Park sits on a Mississippian-age limestone karst plain—the Pennyroyal Plateau of central Kentucky. This area is part of the ancient Illinois basin. The park and surrounding area host physiographic features associated with the geologic history of this long-standing feature on the western edge of the Appalachian Mountains, as well as the evolution of the North American continent (fig. 11). A regional perspective is presented here to connect the landscape and geology of the park to its surroundings.

Precambrian (prior to 542 million years ago)

Deep below the sediments of the Illinois basin, coarse-grained, pink granitic rocks, dated at 1.2–1.4 billion years old, record a deeply buried and overprinted mountain-building event—the Grenville Orogeny (Swann 2007). During this mid-Proterozoic orogeny, a supercontinent had formed that was made of most of the continental crust in existence at that time. This included the crust of North America and Africa (Harris et al. 1997). The continents had been squeezed together forming mountains; however, during the late Proterozoic, roughly 800–600 million years ago, crustal extension rifted the supercontinent apart. A rift basin formed along the eastern margin of North America that eventually became the Iapetus Ocean (a precursor to the Atlantic Ocean). During this time, the central Kentucky area was subjected to more than three quarters of a billion years of erosion that beveled the mountains, stripped away overlying rocks, and exposed the granitic rocks of the orogenic roots (Swann 2007). In the southern reaches of the Kentucky area, layered volcanic and sedimentary rock formed during extensional events. The eroded surface of the Grenville rocks was to become the foundation of the Illinois basin.

Paleozoic Era (542 to 251 million years ago)

From Early Cambrian through Early Ordovician time, orogenic activity along the eastern margin of the continent culminated in the Taconic Orogeny (approximately 440 to 420 million years ago in the central Appalachians). Oceanic crust and the volcanic arc from the Iapetus Ocean basin were thrust westward onto the eastern edge of the North American continent. The crust bowed downwards in response to the weight of the overriding plate, creating deep basins farther west that filled with mud and sand eroded from the highlands to the east (Harris et al. 1997). The Illinois basin is separated from the Appalachian basin to the east by the Cincinnati arch (Swann 2007).

Illinois Basin

The Illinois basin is a spoon-shaped, asymmetrical depression that trends northwest-southeast through Kentucky, Indian, and Illinois (fig. 12). At its deepest, the basin is filled with more than 4,300 m (14,000 ft) of predominantly shallow marine Paleozoic sediments (Maverick Energy, Inc. 2002; Swann 2007). The basin is surrounded by arches and domes. To the north lies the Wisconsin arch, to the east is the Cincinnati arch, to the southwest is the Ozark dome, to the southeast is the Nashville dome, and to the northwest is the Mississippi River arch. Depositional and erosional thinning of strata occurs from the basin center towards the basin flanks. The park is on the eastern flank of the basin. For most of the Paleozoic (especially in western Kentucky), the Rough Creek graben was the center of deposition (depocenter), and strata thickened into it (S. Greb, Kentucky Geological Survey, written communication, 2010).

Since early in its history, the Illinois basin has been subjected to repeated uplifts, downwarpings, folding, and faulting of the depositional strata. Some of the largest structures within the basin including the Rough Creek fault system have all had a significant influence on the accumulation of hydrocarbons in the basin and attest to numerous deformational (uplift) events. During the Paleozoic, the basin was open to the south as recorded by finer, deep-water sediments (Maverick Energy, Inc. 2002; Swann 2007). Deposition in the Illinois basin was mixed with erosional episodes as the basin was emergent at least 50 times and marginal areas exposed approximately 100 times during the Paleozoic (Swann 2007).

Shallow marine to fluvial sedimentation continued intermittently in these basins for a period of about 250 million years during the Paleozoic. The Illinois basin sank and trapped sediment. The overall rate of subsidence was low, averaging only a few centimeters per thousand years (Swann 2007). However, this resulted in a thick sedimentary section. East of the park, older Ordovician through Devonian rocks crop out at the surface, but these are deep beneath the surface at the park itself.

Local sea level was not constant in the Illinois basin throughout the Paleozoic as major unconformities and erosional surfaces attest. The major regional unconformities include the profound unconformities at the top and bottom of the entire Paleozoic stack, Middle Ordovician, Middle Devonian, and pre-Pennsylvanian surfaces. These unconformities mark changes in the pattern of basin architecture, record episodes of uplift and erosion, and define major rock units named the Sauk, Tippecanoe, Kaskaskia, and Absaroka sequences (Swann 2007).

Appalachian Mountain Building

Although focused north of the latitude of central Kentucky, the Acadian Orogeny (approximately 360 million years ago) continued the mountain building of the Taconic Orogeny as the African continent drifted towards North America (Harris et al. 1997). The Acadian event involved land-mass collision, mountain building, and regional metamorphism (Means 1995). The Acadian event caused further uplift of Taconic highlands east of central Kentucky. Erosion of these highlands provided more sediment to the Illinois basin. In the Middle Devonian through Mississippian, deposition of the Kaskaskia sequence began with reworked sands filling erosional valleys and joints (Swann 2007).

The Kaskaskia sequence contains vast limestone and dolomite deposits interlayered with thin sandstone, siltstone, shale, and chert beds. This sequence dominates the rock units found on the Pennyroyal Plateau and includes the Lower to Middle Mississippian Borden Formation, Harrodsburg Limestone, Salem Limestone, and St. Louis Limestone, which are exposed at Abraham Lincoln Birthplace National Historical Park (Moore 1968; Johnson 2005; S. Greb, Kentucky Geological Survey, written communication, 2010). The Kaskaskia sequence records a long-standing, prolific marine basin marked with periodic influxes of alluvial sediments present in the Borden Formation carried south from Canada by the ancient Michigan River. When the sediments that became the bedrock at the park were deposited, a shallow sea covered what is now Kentucky, which was south of the equator (fig. 12). Sediment eroding from the Taconic highlands (proto-Appalachian Mountains) to the east was carried by rivers westward into the shallow seas (S. Greb, Kentucky Geological Survey, written communication, 2010). The Borden Formation, which is the oldest, lowermost bedrock at the park, was deposited in a deltaic environment (Borden delta front) in this shallow sea. Deeper water was to the west and south in the basin. Many of the shaly and silty members of the Borden Formation (e.g., Muldraugh Member) exposed in the park record the infilling of the shallow sea in front of the main wedge of deltaic sediments (S. Greb, Kentucky Geological Survey, written communication, 2010).

When deltaic sedimentation ceased, ending the influx of clastic material, a series of carbonate units precipitated on top of the deltaic deposits, creating a broad carbonate platform (S. Greb, Kentucky Geological Survey, written communication, 2010). Low-energy shallow marine environments dominated the formation of the fossiliferous, relatively pure limestone units including the Harrodsburg, Salem, and St. Louis limestones, which all record widespread carbonate sedimentation in shallow, tropical seas (S. Greb, Kentucky Geological Survey, written communication, 2010). Toward the end of the Mississippian Period, the shallow seas withdrew from the region, and erosion created the next regional unconformity (Maverick Energy, Inc. 2002; Swann 2007).

In the Upper Mississippian (known locally as the Chester series), sea-level fluctuations and renewed tectonism (mountain-building orogeny, see below) on the eastern margin of North America led to the deposition of alternating coastal and deltaic deposits (sandstones and shales), and shallow marine carbonates. These are the units that form much of the Chester Upland, located south of the park. Though still enigmatic, sea-level fluctuations during this part of the Mississippian may have been caused by continental glacier development in the southern hemisphere at this time (S. Greb, Kentucky Geological Survey, written communication, 2010).

Sandstones of the Upper Mississippian and Lower Pennsylvanian form impermeable cap rock atop the limestones of the Mississippian to the west and south of the park. In areas such as the Chester Upland, these cap rocks cover vast cave networks such as the Flint–Mammoth Cave system (Palmer 1981). Younger Upper Mississippian and Pennsylvanian strata crop out to the west, but these have eroded from the surface at the park. Rocks in the western Kentucky coal field, approximately 50 km (30 mi) west of the park, were deposited in the Pennsylvanian Period. The Lower Pennsylvanian began with downcutting and formation of deep erosional valleys, which filled with river channel and floodplain deposits of sandstone, shale, and conglomerate. As sea level rose, the river valleys were converted to estuaries. During the Middle Pennsylvanian, sea level fluctuated many times. The area that is now Kentucky (and the Illinois basin) was located in a rainy climate belt near the equator. Vast marshy peatlands, which upon burial eventually became the coal that is mined to the west of the park, were deposited during this time (S. Greb, Kentucky Geological Survey, written communication, 2010).

During the Pennsylvanian through Permian the proto-Atlantic (Iapetus) Ocean closed as the North American continent collided with the African continent. This mountain-building episode is called the Alleghanian Orogeny (approximately 325 to 265 million years ago), the last major orogeny of the Appalachians (Means 1995). This orogeny was one of several around the world at the time. By the end of the Permian, most of the world's continents had collided together and formed the supercontinent Pangaea.

Rocks younger than the Permian are not preserved in most of Kentucky (except in the Jackson Purchase area of far western Kentucky). Throughout most of the time since the late Paleozoic, Kentucky was above sea level and exposed to erosion and weathering. If any additional sediments were deposited in parts of Kentucky, they eroded away long ago (S. Greb, Kentucky Geological Survey, written communication, 2010).

Mesozoic Era to Present Day (the past 251 million years)

Following the Alleghenian Orogeny during the Upper Triassic (approximately 230 to 200 million years ago), a period of rifting began as the deformed rocks of the joined continents began to break apart. Pangaea was segmented into roughly the continents that persist today. This episode of rifting initiated the formation of the current Atlantic Ocean and caused many block-fault basins to develop on the eastern margin of the continent with accompanying volcanism (Harris et al. 1997; Southworth et al. 2001). At some time in the Mesozoic Era, the Illinois basin became structurally closed to the south as the Pascal (Pascola) arch uplifted (Maverick Energy, Inc. 2002; Swann 2007). Any Mesozoic and Cenozoic rocks that may have been deposited in the Illinois basin area have been lost due to the predominantly terrestrial (above sea level) system prevalent since the end of the Paleozoic.

The North American plate has continued to drift toward the west since the breakup of Pangaea and the uplift of the Appalachian Mountains. Isostatic adjustments uplifted the continent and exposed the Illinois basin to erosion after the Alleghanian Orogeny continued at a lesser rate throughout the Cenozoic Period (Harris et al. 1997). The landscape and geomorphology of the Pennyroyal Plateau area of central Kentucky are the result of steady-state uplift and erosion in addition to relatively minor deposition along the area's rivers from the Mesozoic Period to the present (Palmer 1985). Shifting rivers changed gradient and base level (S. Greb, Kentucky Geological Survey, written communication, 2010). Much of the karst development is correlative with changing base level and river orientation, especially during glacial (ice age) events.

The locus of karst development is migrating with time toward the northwest in the bedrock dip direction. In uplifted areas still capped by insoluble rocks, cave development is greatest (e.g., Chester Upland). The Pennsylvanian cap rocks to the west have already been eroded from the Pennyroyal Plateau. During the late Tertiary (Neogene) and earliest Quaternary, cyclic climatic changes caused alternating periods of slow erosion and deposition, forming a low-relief landscape. At this time, the uppermost levels of the Flint–Mammoth Cave system formed, and surface drainage was still prevalent on the proto-Pennyroyal Plateau (Palmer 1981; Palmer 1985).

During the last million years, Pleistocene (ice age) glaciers advanced and retreated. The southernmost extent of the ice sheets was approximately the present-day course of the Ohio River. The river valley formed when the last ice melted. Although the continental glaciations did not reach into Kentucky, glaciation played a significant role in the formation of the modern landscape at Abraham Lincoln Birthplace National Historical Park. The region likely experienced periglacial conditions (possibly discontinuous permafrost, tundra-like vegetation, and freeze-thaw cycles) because of its proximity to the glaciers. Freeze-thaw cycles may have led to frost wedging in bedrock fractures. This process still happens during the winter, but may have been accentuated during the colder climates of the Pleistocene (Means 1995).

Although changing climatic conditions likely influenced karst development, perhaps the most important influences were reorganization of the surface drainage system (S. Greb, Kentucky Geological Survey, written communication, 2010). Prior to the ice-age events, the Monongahela River of southwestern Pennsylvania flowed north towards an ancestral basin that was to become Lake Erie. It was the dominant drainage in western Pennsylvania (Harper 1997; Marine and Donahue 2000). However, advancing glacial fronts dammed the north flowing rivers in northern Ohio, Pennsylvania, and New York, forming large ponded areas and flooded river valleys. The glacial damming and lake development occurred several times during the Pleistocene coincident with four major glacial advances. These lakes eventually overflowed drainage divides, reversing the ancient drainages of the Monongahela and Allegheny rivers to their modern southerly courses (Harper 1997).

The last ice advance and retreat changed the course of the major river at the time, from a northerly position in Ohio to the present position of the Ohio River. This change in drainages significantly changed base-level gradients in the region. The major rearrangements of the Ohio River drainage caused tributaries such as the White River in Indiana and the Green River to accelerate their rate of erosion and downcutting (Palmer 1984; Swann 2007). This event had a marked effect on local cave formation as downcutting abandoned long-standing, well-developed upper cave passages and broad erosional surfaces (the Pennyroyal Plateau) and focused active erosion at lower elevations (Palmer 1984; Palmer 1985). During rapid erosion, major rivers became entrenched, and minor tributaries, left hanging, were diverted underground, developing karst drainage, caves, sinkholes, and karst valleys between capped ridges (Palmer 1985). Karst topography continues to develop on the Pennyroyal Plateau; as erosion and limestone dissolution are the prevalent geologic processes of the region today.

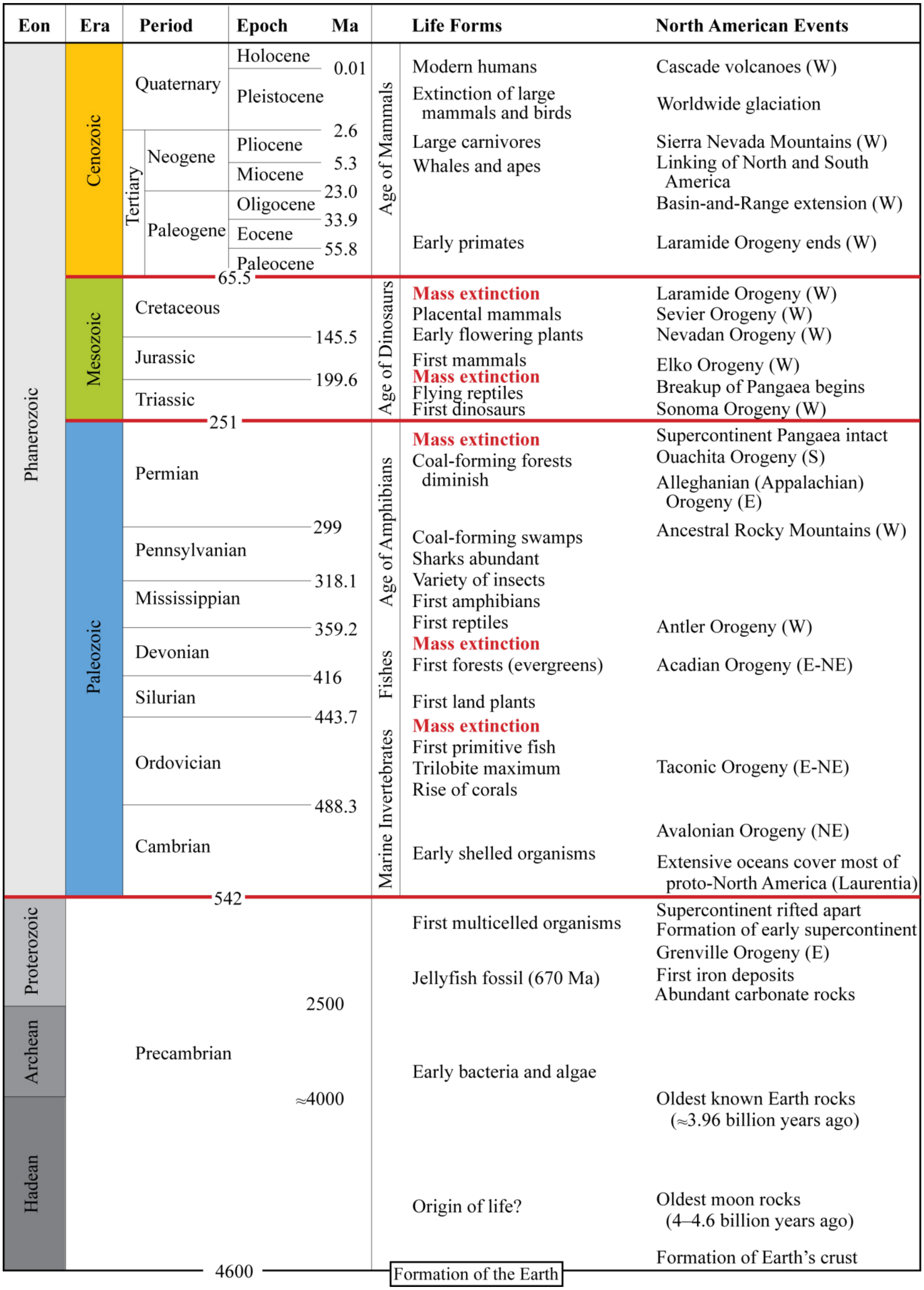

Figure 11. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Isotopic ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/; accessed May 21, 2010) with additional information from the International Commission on Stratigraphy (http://www.geomorph.org/sp/arch/ISChart2009.pdf; accessed May 21, 2010).

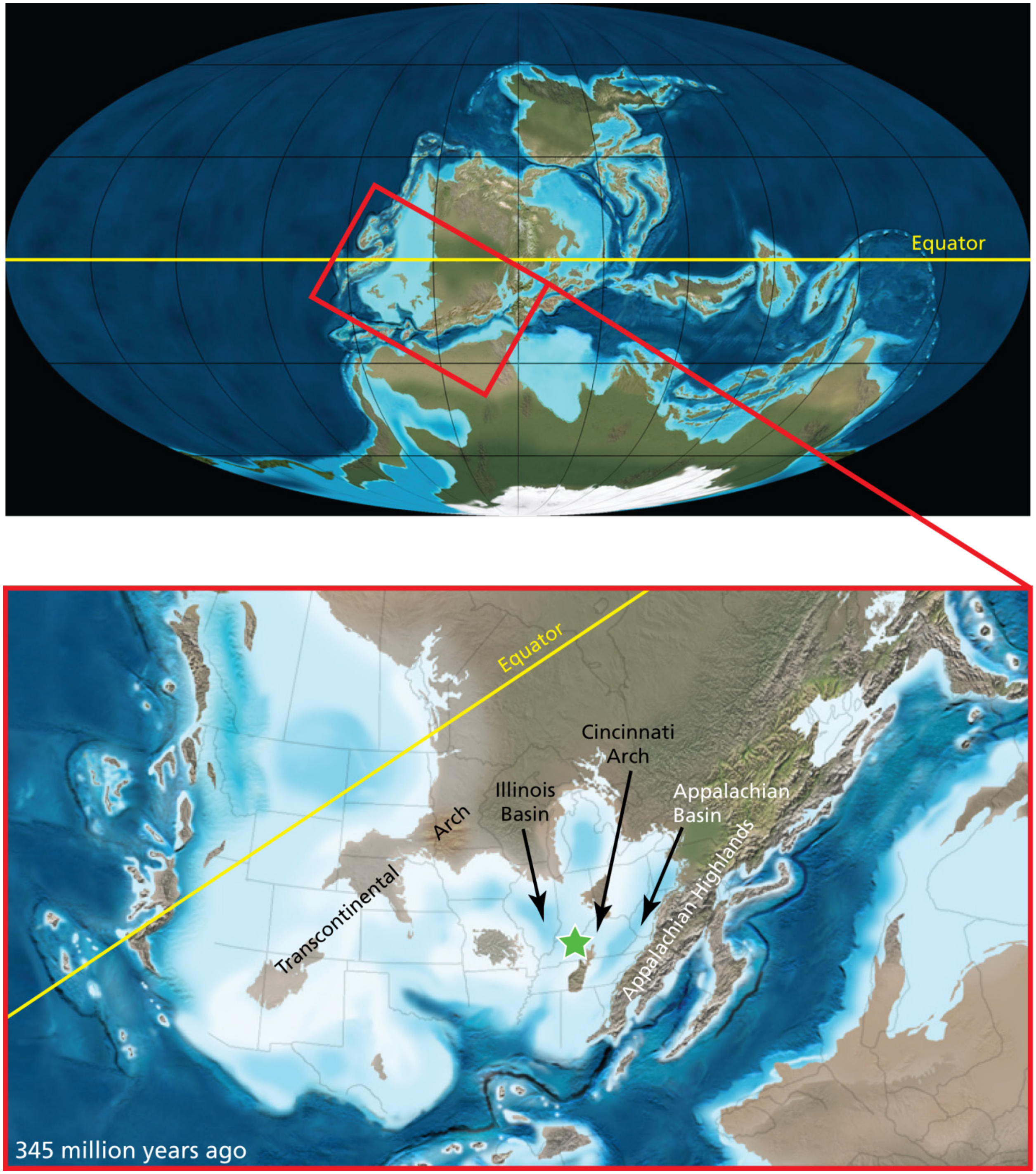

Figure 12. Paleogeographic map showing the regional setting of the Illinois basin during the Mississippian Period. Base map by Ron Blakey (Northern Arizona University Department of Geology) modified by Jason Kenworthy (NPS Geologic Resources Division) after figure 1A from Smith and Read (2001). Paleogeographic maps available for download at: http://jan.ucc.nau.edu/~rcb7/index.html (accessed May 21, 2010).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html. Definitions are based on those in the American Geological Institute Glossary of Geology (fifth edition; 2005).

active margin. A tectonically active margin where lithospheric plates come together (convergent boundary), pull apart (divergent boundary) or slide past one another (transform boundary). Typically associated with earthquakes and, in the case of convergent and divergent boundaries, volcanism. Compare to "passive margin."

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

alluvium. Stream-deposited sediment.

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

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

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

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

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

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

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

bedding. Depositional layering or stratification of sediments.

bedrock. A general term for the rock that underlies soil or other unconsolidated, surficial material.

block (fault). A crustal unit bounded by faults, either completely or in part.

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

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

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

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

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

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

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

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

chert. A extremely hard sedimentary rock with conchoidal (smooth curved surface) fracturing. It consists chiefly of interlocking crystals of quartz. Also called "flint."

clast. An individual grain or rock fragment in a sedimentary rock, produced by the physical disintegration of a larger rock mass.

clastic. Describes rock or sediment made of fragments of pre-existing rocks (clasts).

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

concordant. Strata with contacts parallel to the orientation of adjacent strata.

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

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

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

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

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

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

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

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

crust. Earth's outermost compositional shell, 10 to 40 km (6 to 25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

cutbank. A steep, bare slope formed by lateral erosion of a stream.

debris flow. A moving mass of rock fragments, soil, and mud, in which more than half the particles of which are larger than sand size.

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

delta. A sediment wedge deposited where a stream flows into a lake or sea.

depocenter. An area or site of maximum deposition; the thickest part of any specified stratigraphic unit in a depositional basin.

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

dip-slip fault. A fault with measurable offset where the relative movement is parallel to the dip of the fault.

disconformity. An unconformity where the bedding of the strata above and below are parallel.

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

doline. A type of sinkhole, or a karst collapse feature.

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

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

downcutting. Stream erosion process in which the cutting is directed in primarily downward, as opposed to lateral erosion.

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

dripstone. A general term for a mineral deposit formed in caves by dripping water.

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

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

facies (sedimentary). The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.

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

fanglomerate. A sedimentary rock of heterogeneous materials that were originally deposited in an alluvial fan and have since been cemented into solid rock.

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

floodplain. The surface or strip of relatively smooth land adjacent to a river channel and formed by the river. Covered with water when the river overflows its banks.

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

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

footwall. The mass of rock beneath a fault surface (also see "hanging wall").

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

fracture. Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, or fault).

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

geology. The study of Earth including its origin, history, physical processes, components, and morphology.

hanging wall. The mass of rock above a fault surface (also see "footwall").

intrusion. A body of igneous rock that invades (pushes into) older rock. The invading rock may be a plastic solid or magma.

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

isostacy. The condition of equilibrium, comparable to floating, of the units of the lithosphere above the asthenosphere. Crustal loading (commonly by large ice sheets) leads to isostatic depression or downwarping; removal of the load leads to isostatic uplift or upwarping.

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

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

karst valley. A closed depression formed by the coalescence of several sinkholes.

karst window. A collapse sinkhole opening into a cave.

lamination. Very thin, parallel layers.

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

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

lithification. The conversion of sediment into solid rock.

lithify. To change to stone or to petrify; especially to consolidate from a loose sediment to a solid rock through compaction and cementation.

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

matrix. The fine grained material between coarse (larger) grains in igneous rocks or poorly sorted clastic sediments or rocks. Also refers to rock or sediment in which a fossil is embedded.

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

member. A lithostratigraphic unit with definable contacts; a member subdivides a formation.

metamorphic. Describes the process of metamorphism or its results. One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

metamorphism. Literally, a change in form. Metamorphism occurs in rocks through mineral alteration, formation, and/or recrystallization from increased heat and/or pressure.

meteoric water. Pertaining to water of recent atmospheric origin.

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

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

nonconformity. An erosional surface preserved in strata in which crystalline igneous or metamorphic rocks underlie sedimentary rocks.

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

obduction. The process by which the crust is thickened by thrust faulting at a convergent margin.

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

orogeny. A mountain-building event.

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

outwash. Glacial sediment transported and deposited by meltwater streams.

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

parent rock. The original rock from which a metamorphic rock was formed. Can also refer to the rock from which a soil was formed.

passive margin. A margin where no plate-scale tectonism is taking place; plates are not converging, diverging, or sliding past one another. An example is the east coast of North America (compare to "active margin").

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

peneplain. A geomorphic term for a broad area of low topographic relief resulting from long-term, extensive erosion.

perched aquifer. An aquifer containing unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

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

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

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

pluton (plutonic). A body of intrusive igneous rock that crystallized at some depth beneath Earth's surface.

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

potentiometric surface. A surface representing the total head of groundwater and defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface.

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

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

protolith. The parent or unweathered and/or unmetamorphosed rock from which regolith or metamorphosed rock is formed.

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

radioactivity. The spontaneous decay or breakdown of unstable atomic nuclei.

radiometric age. An age expressed in years and calculated from the quantitative determination of radioactive elements and their decay products.

recharge. Infiltration processes that replenish groundwater.

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

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

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

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

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

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

sequence. A major informal rock-stratigraphic unit that is traceable over large areas and defined by a sediments associated with a major sea level transgression-regression.

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

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

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

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

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

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

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

speleothem. Any secondary mineral deposit that forms in a cave.

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

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

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

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

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

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

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

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

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault. Said to be "sinistral" (left-lateral) if relative motion of the block opposite the observer appears to be to the left. "Dextral" (right-lateral) describes relative motion to the right.

structural geology. The branch of geology that deals with the description, representation, and analysis of structures, chiefly on a moderate to small scale. The subject is similar to tectonics, but the latter is generally used for the broader regional or historical phases.

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

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

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

system (stratigraphy). The group of rocks formed during a period of geologic time.

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

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

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

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

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

unconformity. An erosional or non-depositional surface bounded on one or both sides by sedimentary strata that marks a period of missing time.

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

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

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

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Additional References

This section lists additional references, resources, and web sites that may be of use to resource managers.

Kentucky Karst Resources

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General Geology and Paleontology

Paleobiology Database: http://paleodb.org/cgi-bin/bridge.pl

Ron Blakey (Northern Arizona University) paleogeographic reconstructions: http://jan.ucc.nau.edu/~rcb7/index.html

Geology of National Park Service Areas

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

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

U.S. Geological Survey Geology of National Parks (includes 3D photographs): http://3dparks.wr.usgs.gov/

Harris, A. G., E. Tuttle, and S. D. Tuttle. 2003. Geology of national parks. Sixth edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

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

Resource Management/Legislation Documents

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

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

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

Geologic Monitoring Manual
R. Young, R., and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. [Website under development]. Contact the Geologic Resources Division to obtain a copy.

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

Geological Survey Websites

Kentucky Geological Survey (University of Kentucky): http://www.uky.edu/KGS/

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

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

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

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

Other Geology/Resource Management Tools

Neuendorf, K. K. E., J. P. Mehl Jr., and J. A. Jackson. 2005. Glossary of geology. Fifth edition. American Geological Institute, Alexandria, Virginia.

Bates, R. L., and J. A. Jackson, editors. Dictionary of geological terms. Third edition. Bantam Doubleday Dell Publishing Group, New York, New York.

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

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

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

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

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

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

Appendix A: Overview of Digital Geologic Data

The following page is an overview of the digital geologic data for Abraham Lincoln Birthplace National Historical Park. For a poster-size PDF of this overview and complete digital data, please see the included CD or visit the Geologic Resources Inventory publications web site (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Appendix B: Scoping Session Participants

The following is a list of participants from the GRI scoping session for Abraham Lincoln Birthplace National Historical Park, held on June 15, 2006. The contact information and email addresses in this appendix may be outdated; please contact the Geologic Resources Division for current information. The scoping meeting summary was used as the foundation for this GRI report. The original scoping summary document is available on the GRI web site: http://www.nature.nps.gov/geology/inventory/gre_publications.cfm.

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