National Park Service
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Natural Resources Stewardship and Science
Geologic Resources Division
Cave and Karst Program

CAVE AND KARST RESOURCES SUMMARY

Mammoth Cave National Park, Kentucky

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Looking out the entrance of Mammoth Cave (NPS Photo by Dale Pate).

LOCATION & AREA

Mammoth Cave National Park (MCNP) is located 90 miles (140 kilometers) south of Louisville, Kentucky and 20 mi (30 km) northeast of Bowling Green, Kentucky. It encompasses 52,830 acres (21,380 hectares) of south-central Kentucky. The park protects portions of the Green River and Nolin River valleys as well as the rolling forested hills of west-central Kentucky within the Interior Low Plateau on the southeastern edge of the Illinois Sedimentary Basin (Meiman 2006; Thornberry-Ehrlich 2006; 2011).

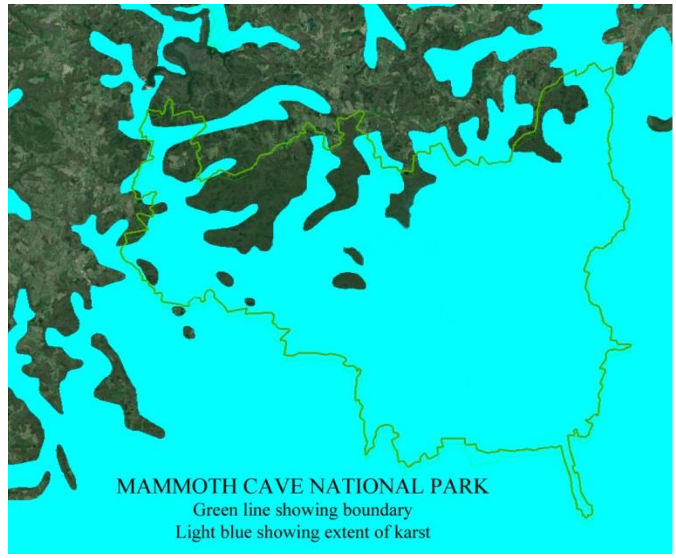
Preserving a portion of a complex and spectacular karst landscape in central Kentucky, the Park is located within a limestone belt that extends from southern Indiana through Kentucky into Tennessee known as the Central Kentucky Karst (White et al. 1970; Thornberry-Ehrlich 2011; NPS 2009). Mammoth Cave National Park was authorized by Congress in 1926 but was not created as a park until 1941. Because of the significance of the caves and karst landscape of the park and the area, MCNP was inscribed as a World Heritage Site in 1981 and became the core area for an International Biosphere Reserve in 1990.

CAVES & KARST

MCNP contains at least 400 caves in addition to significant portions of the Mammoth Cave System which has consisted of connections to the Flint Ridge, Joppa Ridge, Toohey Ridge, and Roppel Cave Systems to form the longest known cave in the world. The Mammoth Cave System is an incredibly complex network of passages that has been documented at over 405 mi (651 km) in length (Gulden 2016) (Thornberry-Ehrlich 2006; 2011). The total thickness of limestone occupied by the Mammoth Cave System is about 393 feet (120 meters) (White et al. 1970).

MCNP is considered to be 84% karst (Land et al. 2013). The Park is part of the Chester Upland, where erosion-resistant, rock-capped ridges overlook the Pennyroyal Plateau, a karst sinkhole plain some 150 to 200 ft (45 to 60 m) below. It is also located within the Interior Low Plateau on the southeastern edge of the Illinois Basin. The park is dissected by the Green River and each half is characteristically different with the nearly flat-topped ridges and intervening broad limestone valleys found on the south side, while the north side consists of rugged hills and ravines (Meiman 2006). The major caves of MCNP have been formed by water that has entered the ground both in the Chester Upland and in the Pennyroyal Plateau. The Green River is the major regional drain for all surface and groundwater and it controls cave development rates and patterns (Palmer 1981).

The sedimentary bedrock units at the park are Mississippian in age, about 330 million years old, to the base of Pennsylvanian aged rocks, 318 million years old. The largest caves at MCNP have formed within three Mississippian-aged limestone formations; the St. Louis Limestone, Ste. Genevieve Formation, and Girkin Formation. These layers are overlain by a resistant cap of sandstone and shale interspersed with relatively minor limestone strata. This



A 2016 Google Earth image of the Mammoth Cave National Park area with a light blue overlay that shows the extent of karst in the general area.

resistant cap allowed preservation of cave passages at many levels. All of these rock layers are tilted very gently to the northwest in the Mammoth Cave area. Because of this tilt, each rock layer lies at progressively higher elevations toward the southeast. Southeast of the park, the insoluble rocks have been removed by erosion. The Pennyroyal Plateau, which lies several hundred feet lower than the area immediately to the northwest, has lost its sandstone caprock to erosion (Palmer 1981).

Beginning about 10 million years ago, groundwater began to interact with the Girkin Limestone (Meiman 2006). Over time, Mammoth Cave developed a number of passage levels. Dating of quartz pebbles using cosmogenic aluminum and beryllium has shown that upper levels of Mammoth Cave had fully developed by 3.2 million years ago. It also indicated that upper portions of the cave filled with sediments as the Green River alluviated (accumulated gravels and other materials) in response to changing flow conditions.

Responding to river flow changes connected with climatic shifts (i.e. glaciation periods) around 2 million years ago, the Green River began cutting down into its riverbed. Green River tributaries, including its cave streams, responded by cutting down into their beds. This resulted in the development of the lower levels in the Mammoth Cave System and in other caves in the region (Grainger, et al, 2001). During periods when the river levels stabilized, horizontal cave levels formed.

During periods when the river was downcutting at a faster rate, vertical passages and canyons formed. Occasionally, alluviation filled lower cave levels with sediment. Changes in river erosion rates were connected with climatic shifts causing the river to cut downward and move the active cave development to a lower level. As passage development sought lower levels, complex downcutting superimposed cave passages one above the other (Thornberry-Ehrlich 2006).

GEOLOGY

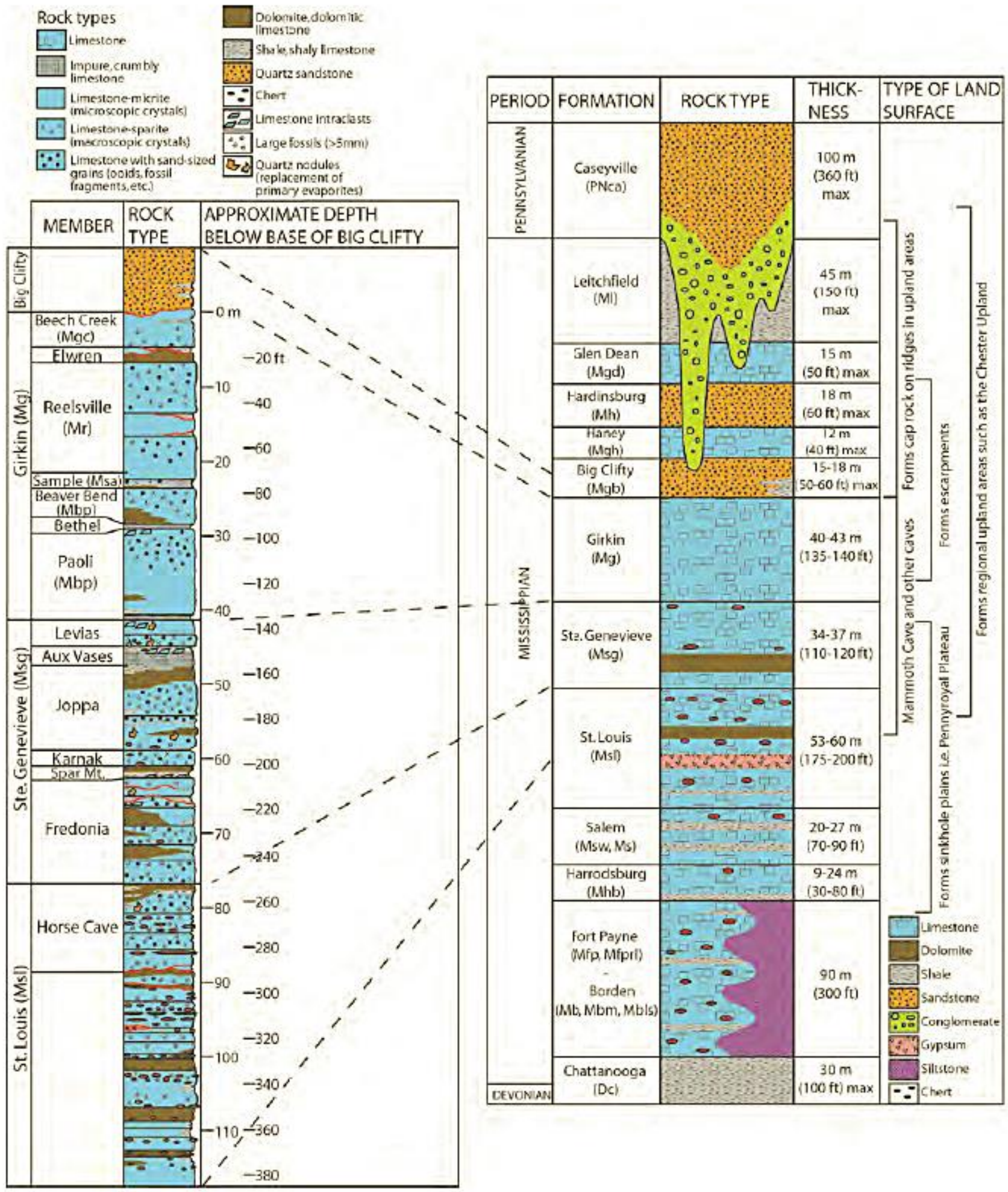
The *St. Louis Limestone* is the oldest and stratigraphically lowest rock formation exposed in MCNP. The formation contains interbedded fine-to medium-grained, thin- to thick-bedded limestone; argillaceous dolomite; sandstone; siltstone; and greenish-gray shale. The formation is characterized by beds and flat nodules of chert that stick out from the cave walls. It is approximately 295 ft (90 m) thick and contains gypsum inclusions that are common at depth in the formation. The *Ste. Genevieve Formation*, which overlies the St. Louis Limestone, ranges between 164 –196 ft (50 to 60 m) thick. It is comprised of very fine-to medium-grained, thick bedded, cross-bedded limestone; and very fine-grained, massive, calcareous dolomite. Different compositions of limestone and dolomite are interlayered. The formation appears gray, tan, and buff in exposures, with more brownish weathering on smooth, rounded surfaces. It does not contain gypsum. The *Girkin Formation* is the uppermost and youngest of the major cave-forming limestones in MCNP. It is approximately 98–196 ft (30 to 60 m) thick and it contains fine- to coarse-grained, crystalline, medium- to thick-bedded, locally cross-bedded limestone. Some shale and sandstone inter-beds are present locally and often separate the limestone into an upper fossiliferous and lower oolitic layers (White et al. 1970; Thornberry-Ehrlich 2011; NPS 2009).

Oolitic limestone – carbonate rock made up of mostly carbonate particles that have concentric rings of calcium carbonate (CaCO3). These formed as grains of sand or shell fragments rolled around on shallow sea floors gathering layer after layer of limestone.

Located above the Girkin Formation, *the Big Clifty Formation* consists of fine-to medium-grained sandstone, dark-gray siltstone, and fissile shale. This formation is the brown resistant rock that stands out in low cliffs along the roads and paths leading to the cave entrances. It is the oldest and lowest of the series of mainly insoluble rocks that form the resistant cap in the ridges of MACA (Palmer 1981; Thornberry-Ehrlich 2011).

Fissile shale – A type of shale rock where a primary property is to split along planes of weakness into thin sheets.

Above the Big Clifty Formation are two thinner Mississippian limestone layers that are also important in the park’s karst landscape. The first is the *Haney Formation* with a maximum thickness of approximately 12 meters (40 ft.). The Haney is generally yellowish-gray or light-olive gray, with local occurrences of shale and chert. It forms an important karst aquifer above the main Mammoth Cave cave-forming limestones. Approximately 50 caves and numerous springs in the park are developed in the Haney (Arpin 2013). Separated above the Haney by the Hardinsburg Sandstone is the *Glen Dean Limestone*. Although some small caves are known from the Glen Dean, this formation has received only cursory study.



Generalized stratigraphic column for Mammoth Cave National Park, including rock units of the Central Kentucky Karst (right column) and a detail of the major cave-forming units (left column) mapped inside caves (unit names are from Sandburg and Bowles [1965]). Note the deep erosional surface between the Pennsylvanian and Mississippian units. Geologic map unit symbols (from the GRI digital geologic map) are included in parentheses where available. Graphic adapted from Palmer (1981, 2007) by Trista L. Thornberry-Ehrlich (Thornberry-Ehrlich 2011).

HYDROLOGY

The Green River flows through the approximate middle of MCNP from East to West. It has been shown to be the low point where all water in the local area on both sides of the river flows to. This includes the many different groundwater basins that feed into the river from springs. The Mammoth Cave karst aquifer is among the best-studied and understood networks in the world (Thornberry-Ehrlich 2011). A number of scientists and cave explorers have worked in the Mammoth Cave area for many decades. In 1973, James Quinlan became Research Geologist for Mammoth Cave National Park. Based on his prior experiences as a member of the Cave Research Foundation and his PhD research on the Central Kentucky Karst, Quinlan began a very successful project of understanding not just the portion of the karst lands within MCNP, but the greater karst fields that lay outside the park boundaries. In all, Quinlan's work delineated 28 distinct groundwater drainage basins and 7 sub-basins south of the Green River. Of these, this research showed that Mammoth Cave System occupies all or a portion of 6 drainage basins. The work of James Quinlan and others was cutting-edge research of very complex underground drainage systems. This long-term study led to significant changes in the local area in an effort to protect groundwater and ultimately, the Green River from major pollutants (Estes et al 1991).

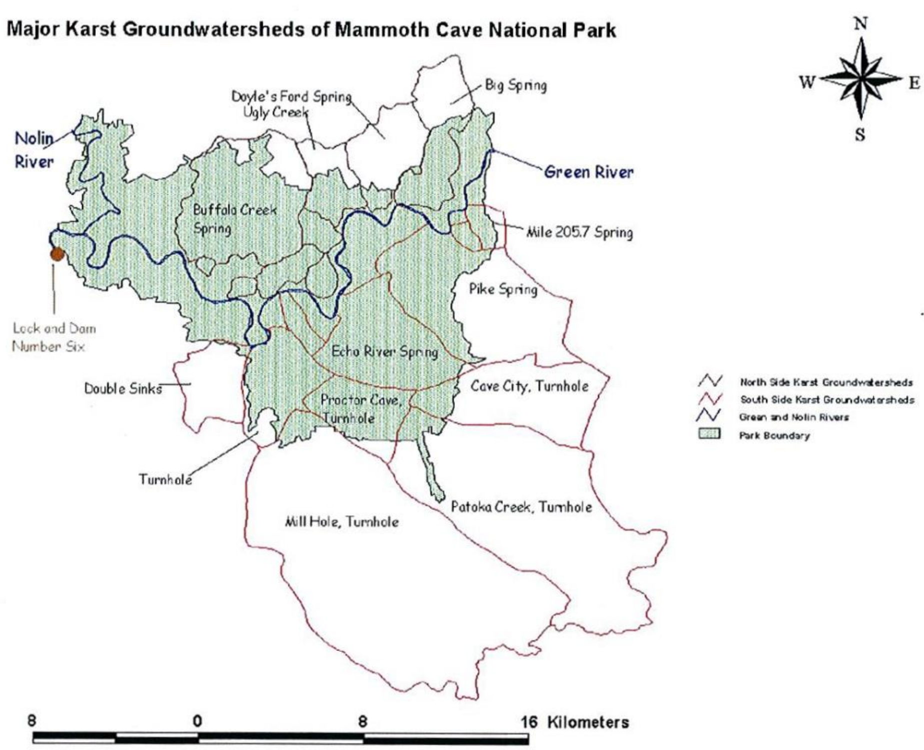
Quinlan's study of this vast aquifer of the Mammoth Cave region from 1973 to 1989 was of great importance. This work by Quinlan along with several other colleagues including cave explorers and surveyors, led to major advancements in the study of karst systems. Accomplishments included the documentation of the first underground distributary system from Hidden River Cave, located within the city of Horse Cave, Kentucky located several miles to the east of MCNP, to the Green River. This particular study was the first to use optical brighteners to hydrologically trace water movement through an aquifer (Estes et al 1991). This work (Quinlan and Rowe 1977, 1978) showed that heavy-metal laden water from a non-functioning water treatment plant was ending up in an active stream within Hidden River Cave, and further downstream these contaminants appeared at 46 different springs in 15 locations along a five-mile reach of the Green River. These studies also showed conclusively that contamination during high-flow events crossed into adjacent ground-water basins.

Further work revealed that agricultural and industrial contaminants were entering the Mammoth Cave System from various places outside the national park (Quinlan et al. 1983; Quinlan 1989; Kambesis 2007). Quinlan was able to determine that effluent from Cave City, Kentucky (located several miles to the south of the park) flowed through a major drainage trunk into portions of Mammoth Cave within the park. In 1977 and based on these ongoing studies, the Environmental Protection Agency (EPA) initiated an Environmental Impact Statement (EIS) in the Mammoth Cave area of Kentucky to address wastewater management practices in Cave City, Horse Cave, Munfordville and Park City, Kentucky. The existing wastewater management practices of wastewater treatment plants discharging to sinkholes and the use of septic systems were impacting area cave streams and systems and posed a threat to MCNP (Mikulak 1988).

In 1981, the EPA's EIS was completed and recommended a regional wastewater management system to replace the sinkhole discharges in Horse Cave and Cave City with a surface water discharge to the Green River. In addition, the recommendation was to also upgrade and replace the septic systems in Park City, with a centralized collection system connected to the Horse Cave/Cave City system (Mikulak 1988). As a result of this, the Caveland Sanitation Authority (CSA) was created and a regional sewage system was completed to protect and conserve the groundwater of the park (Meiman 2006).

To help prevent the introduction of hazardous materials into the Mammoth Cave karst system from an accident along main travel corridors in place above the Pennyroyal Plateau, in 1995 the *Groundwater Hazard Map of the Turnhole Spring Karst Groundwater Basin* was published outlining the potential hydrological hazards along the major travel corridors within the Mammoth Cave watershed in the event of a serious hazardous spill. This area includes twelve miles of Interstate 65 and the CSX Railroad, and five miles of the Cumberland Parkway. These travelways have thousands of semi-trailer trucks and railroad cars and tankers that haul many different substances including very hazardous chemicals on a daily basis. Serious accidents have occurred in the past along these routes and there is high potential that they will occur again.

Contaminants can easily flow into the Mammoth Cave karst aquifer along with stormwater runoff, sinking directly into caves without any filtration through soil. Once contaminants reach underground streams, they may be carried for miles through the aquifer in a matter of hours or a few days (Kuehn et al. 1994; May et al. 2005). Understanding how and where groundwater is flowing from the surface through aquifers and cave conduits to the Green River is vital in predicting hydrologic system response to contaminants and other impacts from outside development (Thornberry-Ehrlich 2006). There have been numerous dye-tracing studies within the Mammoth Cave System since 1989. Most of these have helped to more precisely locate groundwater-basin divides and to understand their increasingly apparent complexities. There is a need to continue dye-tracing and other specific groundwater work and to continue with more accurate mapping of cave passages (Meiman and Groves, 1999; Thornberry-Ehrlich 2011).



Map showing the major karst groundwatersheds of Mammoth Cave National Park. (From Meiman 2006)

In 2002, the Cumberland Piedmont Network Inventory and Monitoring Program began long-term water-quality monitoring at MCNP including small near-pristine springs, large cave streams, and in the Green River. High bacteria values have been found at every site except in the Nolin River and all were associated with high flow events following runoff-producing rainfall. Nitrate levels within developed watersheds of Mammoth Cave are elevated. The highest nitrate values are found in the Turnhole Spring watershed, at Turnhole Spring and its cave stream tributaries of Logdson River and Hawkings River (CUPN 2012).

Joe Meiman completed a comprehensive summary of water-related resource management concerns in a *Water Resources Management Plan for MCNP* in 2006. The report identified the refinement of karst watershed maps as a strategy to improve the hydrologic integrity of park waters and support natural aquifer system processes and native life. Based on Quinlan's initial work, subsequent refinement summarized in this document show that there are 11 karst watersheds that drain into the park from the south side of the Green River.

Alterations to areas of the park have created numerous stressors that have altered the aquatic ecosystem. Each land use, from the chronic inputs of non-point source contaminants (nutrients, pesticides, and sediment) to acute sources such as toxic spills have the potential to affect the waters and wildlife of the park. Physical changes in the park's hydrology have severely altered flow regimes and aquatic habitat (Meiman, 2006).

MCNP has also undertaken a number of projects to help keep the Mammoth Cave System from being contaminated from park infrastructure. A good example of this is the filtering system placed on all drainage from the Maintenance Yard. This filtering system captures all water runoff from the park's maintenance yard and

The park's maintenance yard showing the linear drain system that funnels runoff through a filtering system (NPS Photo by Dale Pate).

funnels the water through a robust filtering system releasing clean water into the surrounding karst.

One of the issues affecting the hydrology of the lower portions of the Mammoth Cave System is Lock and Dam #6 located in the Green River just downstream from the park. It was built in 1904 – 1905, and used until 1950 to allow for the navigation of barges carrying natural asphalt from the mines near Nolin River. This structure causes increased sedimentation by backing up water into the lower portions of Mammoth Cave, degrading habitats for the endangered Kentucky shrimp. In a 1995 disposition study that included Lock and Dam #6, the U.S. Army Corp of Engineers noted that the removal of the dam would restore the cave aquatic and Green River ecosystems by returning free-flowing conditions as well as it would enhance recreation opportunities for the area (Thornberry-Ehrlich 2011). While not decided upon by the time of this report, it does look good for the eventual removal of this lock and dam structure.

BIOLOGY

Animals - Studied since the mid- to late-1800s, the cave biota of MCNP is among the most diverse in the world. There are at least 130 animal species that regularly occur in caves of the park roughly divided among troglobites, troglophiles, and trogloxenes. Of these, 41 species are troglobitic organisms adapted to living in the extreme environments of caves and underground environments (Culver and Sket, 2000). Research of the biota has included taxonomic studies of specific organisms, ecological studies of terrestrial and aquatic systems, and evolutionary studies of the adaptation of cave animals. Poulson (1992) maintains that Mammoth Cave is the best studied and best understood cave ecosystem in the world.

Troglobite – these animals spend their entire life cycles inside a cave or smaller openings in rock. They are specially adapted to survive in these extreme environments. Most of these animals lack color pigment and have small or no eyes.

Troglophiles – these animals have some adaptation to caves, but generally must leave the cave regularly for food.

Trogloxenes – these animals occasionally visit caves but are not adapted to living in them. Sometimes these would be called accidentals because they don't plan on entering a cave, but just end up there.

The large diversity of cave biota found in the Mammoth Cave area is a direct result of the vast array of habitats, both aquatic and terrestrial and the long amount of time it has taken to form the cave systems we see today. Habitats include the numerous types of aquatic areas that exist ranging from small pools, to shallow streams, to larger base-level streams. Habitats also include the terrestrial zones that have been left high and dry from streams seeking lower levels when conditions were conducive for downcutting. Food sources for these habitats include leaf litter and debris around entrance areas, flood debris that carries organic loads into large areas of the caves, and various animals that provide organic input such as cave crickets, woodrats, bats, and raccoons (Olson 2003).

These habitats and food sources support an amazing range of animals that includes some vertebrates, but mostly invertebrates. Vertebrates include several fish (troglobitic and troglophilic) and a troglophilic cave salamander. Too numerous to list here, invertebrates includes the endangered troglobitic Mammoth Cave Shrimp (*Palaemonias ganteri*) and a host of troglobitic or troglophilic planaria, amphipods, isopods, snail, cave crayfish, beetles, harvestman, spiders, pseudo-scorpions, millipedes, and bristletails. nematodes, copepods, tardigrades, oligochaete worms, springtails, collembolans, mites and cave crickets (Olson 2003).

Bats **-** There are at least nine species of cave-dwelling bats at MCNP including the federally endangered Indiana bat (*Myotis sodalis*) and Gray bat (*Myotis grisescens*) as well as Little Brown bats (*Myotis lucifugus*), Big Brown bats (*Estesicus fuscus*), Tricolored bats (*Perimyotis subflavus*), and Rafinesque Big-eared bats (*Corynorhinus rafinesquii*). In addition, there are four species of tree-dwelling bats in the park.

White-Nose Syndrome **-** With the discovery of a disease in 2006 that appeared to be killing thousands of bats in hibernation in the Northeast, MCNP and other NPS staff began systematic monitoring of hibernating park bats for White-Nose Syndrome (WNS) and developed protocols to help prevent the human spread of this deadly disease by park visitors and staff. Though the spread of this deadly disease has been accomplished by bat to bat contact, decontamination procedures were put into place to help ensure that humans do not accidently spread WNS (Mammoth Cave National Park, 2011).

White-nose syndrome is caused by *Pseudogymnoascus destructans*, a cold-loving species of fungus. This fungus invades a bats' skin where it is not covered by fur, such as the muzzle, wings and ears. The fungus forms white patches on these areas, giving rise to the name. The fungus attacks bats while they are hibernating. It disrupts their hibernation and may cause starvation or dehydration. Scientists are actively studying the fungus to determine how it kills the bats. (Park Website, Feb. 2016)

In January of 2013, White-Nose Syndrome (WNS) was detected in a Northern long-eared bat in a cave within the park (NPS 2013a). The disease has since spread to several species of bats and is found within numerous caves including the Mammoth Cave System.

Cave microorganisms – Studies on the various roles that cave microorganisms play have only begun fairly recently. On-going cooperative research with the USGS and university researchers is focusing on some of the roles that micro-organisms play in the cave ecosystem and how they react to changes in water quality and chemistry. Microorganisms may play an important role in the development of speleothems and other karst features. In addition, researchers are using Mammoth Cave to study pathogenic fungi, including both the causative agent of WNS and a fungus that affects cave crickets.

Invasive algae, cyanobacteria, moss diatom, and fern species ("lampen flora") are present in the lighted cave areas and are a critical concern for park management. The presence of lampen flora is being managed with the use of extinguishable light stations along tour routes to avoid continuous light exposure. LED bulbs are being tested and used, in order to reduce exotic plant growth in the cave. In addition, LED lights of different colors are also being tested, to determine if a specific color might reduce the effects of invasive microorganisms in the cave. Currently, the lights appear to have reduced the growth of the lampen flora and achieved a shift in taxa. Furthermore, the use of LEDs has increased the efficiency of the system, reduced the frequency of replacement or service, and allowed an increase in total illumination (Toomey et al. 2009).

PALEONTOLOGY

Within Mammoth Cave National Park, abundant fossils have been documented from within the Mississippian- to Pennsylvanian-aged bedrock units in which the caves are formed and also from bone deposits from within the numerous caves.

A summary completed by Hunt-Foster et al (2009) show that the St. Louis Limestone contains fossil marine invertebrates such as corals, bryozoan, bivalves, brachiopods, gastropods, and crinoids, as well as shark and plant remains. The Ste. Genevieve Formation contains pencil-like coral, bryozoans, brachiopods, echinoderms, crinoids, conodonts, and isolated teeth, fin spires, and calcified cartilage from sharks. The Girkin Formation contains brachiopods, crinoids, corals, gastropods, echinoids, crinoid columnals and calyxes, horn corals, spiriferid and productid brachiopods.

An inventory found fossil vertebrate remains in four contexts in Mammoth Cave: 1) older deposits hundreds of thousands to millions of years old associated with water-lain sediments representing cave streams that flowed in now abandoned levels, 2) surficial and shallowly buried deposits associated with past cave use as well as materials from cave streams eroded out of such deposits, 3) relictual deposits on the cave surface prior to human utilization, and 4) recent surficial remains often less than 4,000 years old (Hunt-Foster et al. 2009) .

A focus on historic bat use of the cave was a priority where large quantities of raccoon scat containing a high percentage of bat bones were documented, mostly from the Historic Entrance area. The most common bat species using this entrance area were the little brown bat (*Myotis. Lucifugus)* and the Indiana bat (*Myotis sodalist*). (Toomey et al. 1998; Hunt-Foster et al. 2009). Less common bat genera found near the Historic Entrance area included *Eptesicus fuscus* (big brown bat), *Pipistrellus subflavus* (eastern pipistrelle), *Lasiurus borealis* (red bat), and *Corynorhinus* (big-eared bat). Bat bones, bat guano, and raccoon scat were radiocarbon dated with ages ranging from 8,700 years old to just 100 years old. Most of the material yielded dates to less than 1,000 years old (Toomey et al. 1998; Hunt-Foster et al. 2009).

From various studies, remains of animals found include frogs, salamanders, turtles, snakes, lizards, birds, and a number of mammals. These mammals include tapir, short-faced bear, a mammoth or mastodon, peccary, armadillo, raccoon, rodents, deer, and bats. (Hunt-Foster et al. 2009)

The oldest vertebrate remains have been found in dry upper-level laminated flood sediments and could be 1 to 2.5 million years old. These include remains of a hellbender (salamander), a vampire bat, and other bat bones (Hunt-Foster et al. 2009.

ARCHEOLOGY/CULTURAL

***Prehistoric* -** Humans moved into the area of MCNP starting about 11,000 year ago. Beginning as early as 5,000 years ago, American Indians began exploration of park caves. Over 20 km (13 miles) of passages within Mammoth Cave were explored between 5,000 and 1,000 years ago. Evidence of human presence in and use of the cave includes petroglyphs and rock art, torch material, food, clothing material, 2,200 to 2,400 year old mummified remains, and mineral-extraction tools and baskets along with scraped wall in numerous locations (Watson 1974; Thornberry-Ehrlich 2011). American Indians entered the cave to mine sulfate minerals such as gypsum, epsomite, and mirabilite (Watson, 1974; Palmer

Remnants of a ladder used by Native Americans to access mineral areas about 4,000 years ago in Mammoth Cave. (NPS Photo by Dale Pate)

1981; Kuehn et al. 1994).

***Historic* –** The modern day history of Mammoth Cave begins in the 1790's. The cave was probably well known by locals during this time, but it is said that a hunter named *Houchins* discovered (or rediscovered) the cave while chasing a bear. Owned by Valentine Simmons, the first registered survey of 200 acres included "*two saltpetre caves*" in 1799. The mining of saltpeter from Mammoth Cave probably began in the early 1800's and continued through the War of 1812 and ended in 1813-14. Mammoth Cave was mined using mostly slave labor for the production of saltpeter (Duncan 1997; Thornberry-Ehrlich 2011). Of interest, the New Madrid Earthquakes of 1811-12 damaged some of the saltpeter structures in Mammoth Cave causing a slow-down of production. Remains of the mining operation, including leaching vats and parts of a wooden piping system, are still in place in the cave.

Mammoth Cave became a "show cave" in 1816 and operated as a private commercial operation until 1941 when Mammoth Cave National Park was established. The park was established to preserve the cave system, including Mammoth Cave, the scenic river valleys of the Green and Nolin rivers, and a section of south central Kentucky's hill country.

By 1920 an economic cave war had broken out in the area between the Mammoth Cave Estate and other cave owners in the local area. One tragic event during this time became national headlines when Floyd Collins became trapped and died in Sand Cave while searching for a cave to commercialize.

Floyd Collins gravesite at the Mammoth Cave Cemetery (NPS Photo by Dale Pate).

Understanding of the vastness and complexities of the caves and karst of the Mammoth Cave area has been greatly aided by a cadre of cave surveyors beginning with the guide and slave, Stephen Bishop in the 1840's. A 1909 map of the cave made by Max Kämper also stands out for its accuracy. In the 1950's, documentation of Mammoth Cave and the numerous others caves in the park began as the Cave Research Foundation (CRF) developed a long-term partnership with MCNP. With the aid of accurate mapping, CRF members made incredible discoveries including the connection between Mammoth Cave and the Flint Ridge Cave System in 1972 to create the longest known cave in the world. With many other discoveries and connections, the cave now stands at 405 miles (651 kilometers) in length and its survey by CRF members has provided the baseline for most other research projects. Knowledge from these surveys and various research projects has helped the NPS to better understand and protect this tremendous resource.

With over 200 years of human use in the caves of the park, many areas have seen lots of wear and tear. Partnerships with organizations like the Cave Research Foundation and the National Speleological Society have provided a large and eager workforce of volunteers that have restored numerous cave areas to more natural conditions.

REFERENCES

Arpin, S. M., 2013, "Karst Hydrogeology of the Haney Limestone, South-Central Kentucky" Western Kentucky University, Masters Theses & Specialist Projects. Paper 1253.

Duncan, M. S. 1997. Examining early nineteenth century saltpeter caves: an archaeological perspective. Journal of Cave and Karst Studies 59(2):91–94.

Estes, Elizabeth K. and E. Calvin Alexander, Jr. 1991. *Karst Hydrogeologic Research at Mammoth Cave National Park.* Department of Geology & Geophysics. University of Minnesota. 49 pgs.

George, Angelo and Gary O'Dell. 1992. The New Madrid Earthquake at Mammoth Cave (1811-1812). George Publishing Company. Louisville, Kentucky. 27 pages.

Gulden, Bob. 2016. *"World's longest caves"*. Geo2 Committee on Long and Deep Caves. *National Speleological Society* (NSS). *Retrieved January 10, 2016*.

Granger, D.E., Fabel, D. & Palmer, A.N. 2001. Pliocene-Pleistocene incision of the Green River, Kentucky, determined from radioactive decay of 26Al and 10Be in Mammoth Cave sediments. Geological Society of America Bulletin, 113(7): 825-836.

Hunt-Foster, R., J. P. Kenworthy, V. L. Santucci, T. Connors, and T. L. Thornberry-Ehrlich. 2009. Paleontological resource inventory and monitoring—Cumberland Piedmont Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/235. National Park Service, Fort Collins, Colorado.

Jegla, T. C. and J. S. Hall. 1962. A Pleistocene deposit of the free-tailed bat in Mammoth Cave, Kentucky. Journal of Mammalogy 43:481-477.

Kambesis, P. 2007. The Importance of Cave Exploration to Scientific Research. Journal of Cave and Karst Studies, v. 69, no. 1, p. 46-58.

Kuehn, K. W., C. G. Groves, N. C. Crawford, and J. Meiman. 1994. Geomorphology and environmental problems of the Central Kentucky Karst. Annual Field Conference of the Geological Society of Kentucky, October 14-15, 1994. Geological Society of Kentucky, Bowling Green, Kentucky, USA.

Land, Lewis, George Veni, and Dianne Joop. 2013. *Evaluation of Cave and Karst Programs and Issues at US National Parks.* National Cave and Karst Research Institute Report of Investigations 4, Carlsbad, New Mexico.

Mammoth Cave Area International Biosphere Reserve. 1996. Groundwater Hazard Map of the Turnhole Spring Karst Groundwater Basin. National Park Service, the Kentucky Division of Water, the Barren River Area Development District, the U.S. Environmental Protection Agency.

Mammoth Cave National Park. 2011. White-Nose Syndrome Response Plan Mammoth Cave National Park. National Park Service. Mammoth Cave, KY. 49 p.

May, M. T., K. W. Kuehn, C. G. Groves, and J. Meiman. 2005. Karst geomorphology and environmental concerns of the Mammoth Cave Region, Kentucky. Kentucky Section of the American Institute of Professional Geologists, Lexington, Kentucky, USA.

Meiman, J. 2006. Mammoth Cave National Park, Kentucky, Water Resources Management Plan. Technical Report. National Park Service, Mammoth Cave, Kentucky, USA.

Meiman, J., and C. Groves. 1999. Delineation of karst groundwater divides by in-cave dye tracing, Mammoth Cave Karst Aquifer, Kentucky. National Cave and Karst Management Symposium 1999:122.

Mikulak, R.J. 1988. Wastewater Management in Cave Country; An Unlikely Success Story. *In:* Proceedings of the Conference on Environmental Problems in Karst Terranes and their Solutions 1988: 2, pp. 315-331.

National Park Service. 2011. Mammoth Cave National Park, Mammoth Cave Fact Sheet Q&A.http://www.nps.gov/maca/planyourvisit/upload/Q-A_Fact_Sheet_2011-web.pdf (accessed 10 July 2013).

National Park Service. 2013a. Mammoth Cave National Park, Kentucky. News Release: White-Nose Syndrome Confirmed in Park Bats. January 16, 2013. http://www.nps.gov/maca/parknews/nr-wnsinparkbats.htm (accessed 3 July 2013).

National Park Service. 2013b. Mammoth Cave National Park, Kentucky. News Release: Mammoth Cave hits 400 miles. February 15, 2013. http://www.nps.gov/maca/parknews/mammoth-cave-400-miles.htm (accessed 3 July 2013).

Olson, R., 2004. Mammoth Cave, United States: Biospeleology. In: Encyclopedia of Caves and Karst Science, edited by John Gunn, Taylor and Francis 29 West 35th street, New York, NY 10001, p. 499 – 501.

Olson, R 2005. The Ecological Effects of Lock and Dam No. 6 in Mammoth Cave National Park. Harmon, David, ed. People, Places and Parks: Proceedings of the 2005 George Wright Society Conference on Parks, Protected Areas, and Cultural Sites. Hancock, Michigan, p. 294 – 299.

Palmer, A. N. 1981. A geological guide to Mammoth Cave National Park. 2002 edition. Zephyrus Press, Teaneck, New Jersey, USA.

Palmer, A.N. 2009. The Mammoth Cave Region, Kentucky. pp. 108-113. in A.N., Palmer and Palmer, M.V. editors. Caves and Karst of the USA. National Speleological Society, Inc., Huntsville, Alabama.

Poulson, T., 1992, The Mammoth Cave ecosystem. Pages 564–611 in A. A. Camancho, editor. The natural history of biospeleology. Monographs of the National Museum of Natural Sciences, Madrid, Spain.

Quinlan, J.F., Ewers, R.O., Ray, J.A., Power, R.L., and Krothe, Noel C.,1983, Hydrology and geomorphology of the Mammoth Cave Region, Kentucky, and of the Mitchell Plain, Indiana, in Shaver, R.H., and Sunderman, J.A., eds., Field Trips in Midwestern Geology: Bloomington, Indiana, Geological Society of America and Indiana Geological Survey, v. 2, p. 1–85.

Santucci, V. L., J. P. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. Technical Report NPS/NRGRD/GRDTR-01/02. Geological Resources Division, National Park Service, Lakewood, Colorado, USA.

Toomey, R., R. Olson, S. Kovar, M. Adams, and R. Ward. 2009. Relighting Mammoth Cave's new entrance: improving visitor experience, reducing exotic plant growth, and easing maintenance. Pages 1223–1228 in V. White, editor. Proceedings 15th International Congress of Speleology 2(2). Kerrville, Texas, USA.

Thornberry-Ehrlich, T. L. 2006. Geologic resource evaluation [inventory] scoping summary, Mammoth Cave National Park. National Park Service, Geologic Resources Division, Denver, Colorado, USA. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/MACA_scoping_summary_2006-0815.pdf. (accessed 26 June 2013).

Thornberry-Ehrlich, T. 2011. Mammoth Cave National Park: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/448. National Park Service, Fort Collins, Colorado.

U.S. Fish & Wildlife Service. 2012. White-nose syndrome. The devastating disease of hibernating bats in North America. August 2012. http://whitenosesyndrome.org/sites/default/files/resource/white-nose_fact_sheet_9-2012.pdf (accessed 10 July 2013).

Weary, D.J., and Doctor, D.H., 2014, Karst in the United States: A digital map compilation and database: U.S. Geological Survey Open-File Report 2014–1156, 23 p., Doctor and Weary - Karst in the United States

White, W.B., Watson, R.A., Pohl, E.R. and Brucker, R. 1970. The Central Kentucky Karst. Geographical Review, Vol. 60, No. 1, pp. 88-115.

Wilson, R. C. 1981. First extinct vertebrates from Mammoth Cave, Kentucky. Page 339 in Proceedings of the Eighth International Congress of Speleology. International Union of Speleology.

Wilson, R. C. 1985. Vertebrate remains in Kentucky caves. Pages 175-168 in Caves and Karst of Kentucky. Kentucky Geological Survey, Lexington, Kentucky.

ADDITIONAL RESOURCES

Cave Research Foundation
Cave Research Foundation

Karst Field Studies
Karst Field Studies

Mammoth Cave International Center for Science and Learning
Mammoth Cave International Center for Science and Learning

Mammoth Cave National Park
Mammoth Cave National Park

NPS Cave & Karst Program
NPS Cave & Karst Program

National Speleological Society
National Speleological Society