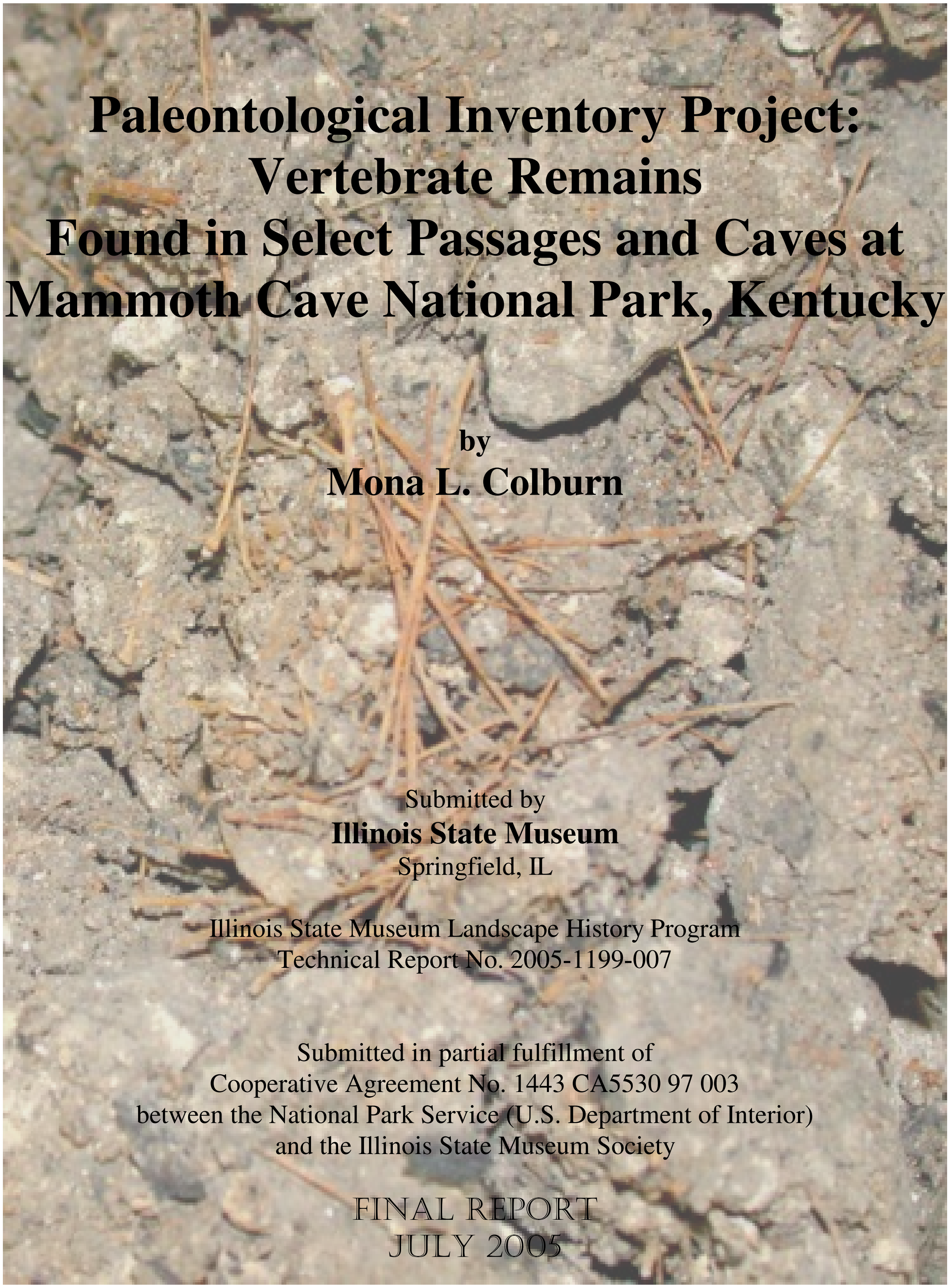

Paleontological Inventory Project: Vertebrate Remains Found in Select Passages and Caves at Mammoth Cave National Park, Kentucky

by

Mona L. Colburn

Submitted by

Illinois State Museum

Springfield, IL

Illinois State Museum Landscape History Program
Technical Report No. 2005-1199-007

Submitted in partial fulfillment of
Cooperative Agreement No. 1443 CA5530 97 003
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JULY 2005

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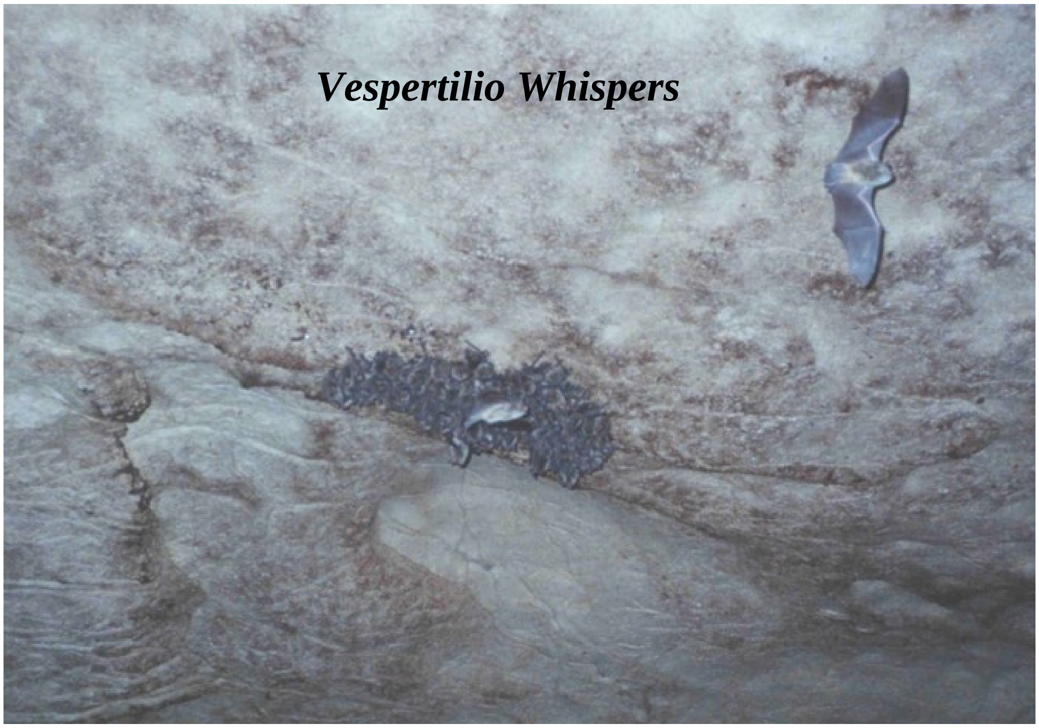

Bats in Dixon Cave, KY m. colburn

Leathered limbs winging,
Crepuscule insecticide
devouring echoes

Biocide echoes
Vespertilio whispers,
Silencing night song

mona colburn, oct. 2002

Paleontological Inventory Project: Vertebrate Remains Found in Select Passages and Caves at Mammoth Cave National Park, Kentucky

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Paleontological Inventory Project: Vertebrate Remains Found in Select Passages and Caves at Mammoth Cave National Park, Kentucky

ACKNOWLEDGMENTS

Without the contributions of many people, this project might be residing in a bottomless pit. My apologies to any individual who is not singled out and felt that he/she should have been -- blame it on too many unplanned cranial contacts with cave structures.

Dr. Rickard Toomey and Rickard Olson (Park Ecologist at Mammoth Cave) wrote the proposal for the Paleontological Inventory Project. Toomey initiated the Paleontological Inventory Project when he was at the Illinois State Museum. Before fieldwork was completed, he moved on to the challenges of Kartchner Caverns in the hotter ("yeah, but it's a dry heat") climate of Arizona. The Paleo Project was handed off to Mona Colburn, who completed the fieldwork and analyzed all of the collected samples (except those from Bat Cave) at the Illinois State Museum's Research and Collections Center. While employed on the project, Blaine Schubert assisted with part of the data collecting in Historic Mammoth Cave and Proctor Cave, scanned Historic Section maps provided by the Cave Research Foundation (CRF) and transferred the locations of flagged data points from field maps to electronic maps. He also processed Bat Cave samples and compiled a laundry list of bone identifications and measurements from that site.

The National Park Service supported the Paleo Project monetarily and logistically. Many park employees provided enthusiastic support, suggestions, observations, and conversation; and, Chuck DeCroix, Brice Leech, and Colleen O'Connor Olson volunteered time in the field. Mammoth Cave Park Ecologist, Rick Olson, worked closely with the project -- from conception of an idea, to development and proposal writing, to assisting with fieldwork.

The support of the Cave Research Foundation is acknowledged. Doug Baker, Scott House, Bob Osburn, Mick Sutton, and Dave West allowed us to use copies of their maps and surveyed unmapped areas in short order. Pat Kambesis (past CRF president), Bob Osburn (Eastern Operations, Chief Cartographer) and Dave West (Eastern Operations Manager) provided a wide variety of support. When requested, Eastern Operations Expedition Leaders supplied enthusiastic field parties and knowledgeable guides for the paleontologists during CRF trips. Numerous Joint Venturers lent their hands, knees, and eyes in the search for paleontological remains during CRF expeditions. CRF members Eric Sikora and Patty Daw volunteered their own time, apart from an expedition.

The Illinois State Museum provided supplemental funding and facility support. I would like to thank several volunteers who came via the Illinois State Museum. I especially thank David Schroder, a retired college biology professor and a long-time volunteer of the Illinois State Museum, who was willingly recruited in my hour of need. He has spent many hours helping with fieldwork at Mammoth Cave and with lab work at the Illinois State Museum (sample processing, data entry, and digitizing data point locations onto maps). Lisa Winhold and Pat Kollen assisted in Dixon Cave. John a.k.a. Jack White volunteered in Main Mammoth Cave. Jennifer Ellington helped in the lab. Leslie Cline helped edit portions of the database.

Several paleontologists outside of the Illinois State Museum provided a variety of assistance. Dr. Dan Fisher (University of Michigan, Ann Arbor) met with me and examined proboscidean remains from Proctor Cave. Frederick Grady (Supervisory Museum Specialist/Vertebrate Paleontology Preparator, National Museum of Natural History, Smithsonian Institution, Washington D.C.) took time to verify several identifications for me. Amy Henrici (Scientific Preparator, Carnegie Museum of Natural History, Pittsburgh) allowed access to bones collected circa 25 years ago by Ron Wilson that are curated in the Carnegie Museum's collections.

Other paleontologists aided me in my identification of an intriguing bone from Proctor Cave. Crawling like a caver through this report will bring the reader to the answer to the mystery. Bill Simpson (Collections Manager of Fossil Vertebrates, Department of Geology, Field Museum of Natural History, Chicago) allowed access to Field Museum collections. Dr. Jessica Theodor (Geology Department Curator, Illinois

State Museum) transported a specimen to California (so that it would not be irradiated in the mail) where Dr. Blair Van Valkenburgh (University of California at Los Angeles) and Shelley Cox (Collections, George C. Page Museum, Los Angeles) looked at it.

Dr. Bonnie Styles (Illinois State Museum Interim Director, and Head of the Science Section), Karli White (Research Associate in Education), and Rick Olson (Mammoth Cave) offered editorial comments on this report. Portions of this report were prepared as part of a Master's Thesis for the Environmental Studies Department at the University of Illinois, Springfield. I thank my graduate committee, Drs. Tih-Fen Ting, Sharron LaFollette, Lynn Fisher, and Calvin Mouw, for their comments.

Dr. Donald A. McFarlane (The Claremont Colleges, California) provided a dead vampire bat for the Illinois State Museum's comparative collection. Craig Ludwig provided a printout of Mammoth Cave specimens curated in the U.S. National Museum (Smithsonian Institution) in 1996. Ann and Peter Bosted provided the project with photographs taken in Dixon, Long, and Mammoth caves. Gary Berdeaux (Diamond Caverns, Kentucky) took digital images of several interesting areas within the project area. Art Palmer and Peg Palmer accompanied the project on several trips. Their enthusiasm has given me a boost when my own waned. I, along with many others, have been inspired by the Palmer's long-term dedication to the study of caves. Colleen O'Connor Olson, Rick Olson, and Kitty Pup Olson have been gracious hosts and friends on my many fieldtrips. They are excellent purveyors of the campfire veggie burger and s'mores.

In short, the sum of the knowledge, tenacity, enthusiasm, and far-sighted vision of all the above mentioned parties serves to encourage all of us researchers engaged in long-term projects and the often-time lonely pursuit of doing one's small part to augment the knowledge of a particular field of study. Again, I apologize to anyone that I have forgotten to thank.

Paleontological Inventory Project: Vertebrate Remains Found in Select Passages and Caves at Mammoth Cave National Park, Kentucky

PROJECT BACKGROUND

Mammoth Cave National Park is famous for being home to the world's longest cave, Mammoth Cave (with more than 365 miles of mapped passage), but the Park has not been recognized for producing an abundance of vertebrate fossils. In fact, few of the Park's paleontological resources—within caves or outside; vertebrate, invertebrate, or botanical—have received attention. The little research that has been conducted is obscure and has not received the follow up that it deserves. Forty-five years ago, Davies and Chao (1959) studied the less than glamorous sediments in Chief City that turned out to be a spectacular a pile of bat guano. Jegla and Hall (Jegla 1961, Jegla and Hall 1962) studied the Chief City guano and associated bones, and identified them as *Tadarida brasiliensis*, Brazilian free-tailed bat (sometimes called Mexican free-tailed bat, a subspecies), whose present range is several hundred miles south of Kentucky. Jegla (1961, 1963) also examined large accumulations of bat bones found in Bat Cave and Fossil Avenue in the New Discovery Section, two areas of the Park that are not open to the public. In late 1970-early 1980, Ron Wilson and members of the Cave Research Foundation (CRF) located isolated fossils of Pleistocene animals in a remote area of the Proctor Section of the Mammoth Cave System, but the bones had not received sufficient follow-up investigation.

Nineteenth century journal articles, tourist accounts, scientific descriptions, and map names and old place names allude to the fact that the historic portion of Mammoth Cave was a large hibernaculum for wintering bats in the 1800s. Sutton et al. (1998) elucidated many old place names. From scientific descriptions written in the early 20th century it can be seen that Mammoth and other caves in the system were used by hibernating bats; but, when these observations are juxtaposed with the 19th century observations one can see that the bat populations had declined and that previous roosts had been abandoned. This realization led to a new phase of paleontological investigations.

A new round of investigations began informally in 1994 when Rick Olson (the Ecologist at Mammoth Cave National Park) invited Dr. Rickard Toomey (then a Research Associate at the Illinois State Museum) to examine some of the Cave's paleontological resources. Preliminary examinations were done under the auspices of the Cave Research Foundation. Since 1992 George Crothers has been conducting a search for archaeological evidence in the Cave with the help of Earthwatch volunteers (see Crothers 1998, Crothers et al. 2000, Sims 2001). In 1995, Toomey and Colburn tried a similar approach in a search for paleontological remains, leading a team of Earthwatch volunteers in an examination of one specific in-cave location, Lookout Mountain (Toomey, Ward, Olson, and Colburn 1995). That project gave us a preview of the meticulousness and diligence that would be required to conduct a large-scale search for paleontological resources encompassing other areas of the Mammoth Cave System.

It was envisioned that a paleontological inventory would contribute not only knowledge about Mammoth Cave's past, but also information that could be helpful in managing the cave resources. When the concept of the Historic Entrance Ecotone Restoration Project (Olson 1995, 1996) was being developed, a means was needed to determine cave microclimate prior to the extensive modification of the Historical Entrance. It was speculated that an examination of the historic bat roosts might be useful to assess pre-disturbance microclimate conditions in Mammoth Cave. Such information derived from paleontological remains would then contribute baseline data, which could be used in strategies for restoration projects aimed at a major effort to bring large hibernating populations back to Mammoth Cave. One concern is the restoration of hibernaculum conditions conducive for two endangered species of *Myotis* -- *M. sodalis* (Indiana bat) and *M. grisescens* (gray bat). Also of concern is the preservation of known paleontological resources (the most obvious being the *Tadarida* guano at Chief City that is being trampled by the Lantern Tour) and of unknown resources. The only way to know which resources are being impacted by tourists, maintenance workers, CRF explorers, and cave researchers is to actually get down on hands and knees and search for faunal remains. The results of a comprehensive inventory provide the National Park Service with information that can be used by managers in devising strategies to minimize future impact and destruction of resources.

In order to collect baseline data about paleontological resources within the cave system, Mammoth Cave National Park and the Illinois State Museum entered into two cooperative agreements. The first of these agreements was made in support of the Historic Entrance Ecotone Project, "Characterization of Past Bat Usage of the Historic Entrance Area, Mammoth Cave." In 1997-1998, the Illinois State Museum surveyed a small section of the cave known as the "Historic Entrance Area." The results are reported in *Late Holocene Utilization by Bats of the Mammoth Cave Historic Entrance Area, Mammoth Cave National Park, Kentucky* by Toomey, Colburn, and Schubert (1998).

The second cooperative agreement, "Conservation of Threatened Vertebrate Paleontological Resources at Mammoth Cave" was mandated to widen the scope of the underground inventory. The second project was far more extensive than the first; it continued surveys in the Historic Section and it expanded investigations to other sections of Mammoth Cave and to several other caves in the park. The National Park Service provided three-years of funding through the Natural Resources Preservation Program; and the Illinois State Museum provided additional funding. The report in hand is a description of results for the second cooperative agreement. I will often refer to the project as the "Paleontological Inventory Project" or the "Paleo Project," for short. The goals of the Paleontological Inventory Project were to do the following:

1) Locate, identify, describe, and map paleontological remains in the major passages with tourist routes between the Historic Entrance and the Violet City Entrance
2) Locate, identify, describe, and map paleontological remains in known bat roosts (both past and active) located in various other caves/sections in the park
3) Search for resources in passages and caves where previous investigators have already located faunal remains
4) Search for paleontological remains in areas with high potential -- pits, old entrance sinks, and collapsed entrances

5) Collect a limited number of samples for dating, for identification purposes, and as voucher specimens
6) Determine the condition of remains and identify threats to the resources
7) Obtain an idea of the age of vertebrate remains and vertebrate-bearing deposits within the study area
8) Attempt to reconstruct past environments, climates, and cave conditions based on the vertebrate remains identified from the caves
9) Integrate the results from Mammoth Cave National Park with efforts to understand the past vertebrate faunas on a regional and national level via database projects like FAUNMAP (FAUNMAP Working Group 1994)
10) Give site-specific conservation recommendations.
11) Provide information to the Division of Interpretation and Visitor Services for interpretation of paleontological remains and past vertebrate life in the cave and surrounding area

Going into the project, everyone was aware that major modifications had taken place over the last 200 years both inside the passages and outside of Mammoth Cave, and many other caves in the park. There is no doubt that they imposed a negative toll on the cave's paleontological resources; as one can imagine, we will never know the extent to which resources were destroyed. Examples are the saltpeter mining activities of the early 1800s and the large-scale modifications accomplished by the Civilian Conservation Corps (CCC) in the 1930s preparing the park and Mammoth Cave for National Park status (Figure 1-1).

FIGURE 1-1. Two examples of cave modifications made by the Civilian Conservation Corps. Left is a photograph of trail building in the Historic Section, 1935; right, construction of the Frozen Niagara Entrance, 1938. (NPS images from Western Kentucky University, http://www.wku.edu/Library/nps/ccc).

However, as the inventory project proceeded, it became obvious that faunal remains were far more abundant (primarily in the form of bat bones) than had been anticipated and that an inventory would require far more time than had been proposed. In addition, although Toomey initiated fieldwork for the second project when he was at the Illinois State Museum, he took a new job elsewhere before the completion of fieldwork, and was unable to finish the inventory project. Subsequently, the Mammoth Cave Paleontological Inventory Project was completed by Mona Colburn at the Illinois State Museum. She completed the fieldwork, processed and identified the collected samples, and wrote the report. The Cave Research Foundation has supported this project by providing the following: personnel (some volunteered outside the time of planned expeditions) to assist in locating and mapping resources, information on potential resources that had been previously observed, copies of old trip reports, and copies of maps on which to plot paleontological sites. National Park Service personnel have also been volunteers in the fieldwork. Illinois State Museum volunteers provided many hours of help, both in the field and at the Museum's laboratory in Springfield, Illinois. The efforts of all these parties were cited in the Acknowledgments.

PROJECT METHODOLOGY

Vertebrate paleontological materials were located, identified, and evaluated following a detailed survey conducted in various sections of Mammoth Cave and in caves of lesser length that are located within the boundaries of Mammoth Cave National Park. The search focused on fossil and subfossil remains and traces of vertebrate animals that had entered the caves long after passage formation (so-called "allochthonous" remains). Fieldwork was conducted, often with the aid of volunteers, in portions of the following sections and caves:

- Historic Section of Mammoth Cave
- Colossal Cave
- Dead Bat Avenue
- Fossil Avenue
- Frozen Niagara Entrance area
- Sophy's Avenue
- Fox Avenue, near Kentucky Avenue
- Proctor Cave

- Bat Cave
- Dixon Cave
- Wilson Cave
- Various pits and small caves
- Long Cave (reported in a separate volume)

The search for animal remains (bones, mummified remains, feces, tracks, stains, etc.) was conducted on hands-and-knees. Human activities over the last 200 years have destroyed, damaged, or obscured evidence; therefore; more protected/undisturbed areas like ledges, under and around *in situ* boulders, and alcoves were given special attention, because remains in these locations would have had the best chance for survival. Localities that yielded only isolated guano pellets, thinly scattered bat guano, thin and scattered rat feces, or isolated distal bat wing bones were not recorded as data points because these material types were widespread and relatively uninformative for this study.

Team members inventoried the cave in small segments; first they searched for and marked faunal remains with pin flags or flagging tape. Then, the team returned to each flag to evaluate the remains and to record pertinent data before moving on to another segment of passage. Information collected at each flagged spot included assigned data point number, description of the location, description of the faunal material, quantity of material, taxon and element(s) present, and information about digital imagery. Although volunteers helped to locate some resources, project staff members always made the final evaluations, descriptions, and identifications. Typical views taken with a digital camera included one or more of the following: general shot of the area, close-up of deposits and specimens *in situ*, and staged close-up views of important specimens. Measurements were taken to the nearest 0.1 mm on specimens such as skeletal elements, scats, and mummies using 150 mm dial calipers (General Hardware Manufacturing Company nylon calipers or Spi 2000 polyester calipers). While in the field, data point locations were plotted on photocopies of cave maps that were provided by the Cave Research Foundation.

A critical task was the taxonomic identification of remains while in the field. Identifications were made based on morphological characteristics of specimens. The level to which faunal remains could be identified varied depending on the material.

Some remains and traces, like bat guano, staining, and most post-cranial bat remains cannot be identified more precisely than the level of bat (that is, to family Vespertilionidae or to Order Chiroptera). An animal's mummified remains are probably the ideal faunal resource for determining species identification; this was rare except in the case of bats. It should be noted that unknown numbers of mummified bats may have been collected in the 1930s by Campbell and Cutliff who are reported to have been looking for them and Native American artifacts when they found Lost John, the mummified human (Pond 1937). For this study, several types of finds were record as mummified specimens:

- desiccated, whole individuals
- entire, odiferous, hanging specimens
- *in situ* skeletons and partial skeletons with remnants of tissue holding multiple elements together (wings with bones and membrane are a common example, a single element such as a humerus with tissue was not counted as a mummified remain)
- masses of skin and fur where bones may be absent

The ideal skeletal element for species identification is the skull. For bats, other elements like dentaries, teeth, and some humeri and the size of an element can be used to identify genus, and sometimes, species. The ease of identifying remains from animals other than bat varies; post-cranial remains of some taxa are easily identified in the field but other bones can only be identified to the family level. Small specimens, such as bat dentitions, were examined with a hand lens (10X or 20X depending on the lens). In the case of bat dentaries and skulls, the most useful characters include size (both overall size and individual measurements), skull shape, tooth counts, and the presence of a sagittal crest. For mummified remains, the most useful characters were ear and tragus features, pelage color, forearm length, calcar features, toe hair length, and skull features. Published characteristics of various species and comparison with modern comparative materials were used to identify individual specimens.

It is important to note that in this project, the majority of unassociated dentaries with 3-1-3-3 tooth counts were identified as *Myotis*. This dentition also occurs in the genera, *Corynorhinus* and *Lasionycteris*; thus, there is a possibility that some of the dentaries identified as *Myotis* could represent one of these genera. However, because skulls of only a few *Corynorhinus* and no *Lasionycteris* were found, it is likely that nearly all of these dentaries represent *Myotis*.

Raccoon (*Procyon lotor*) scats containing bat bones are a type of remain encountered in caves. Material identified as raccoon scat consisted of cylindrical feces that average between 1.5 and 2.0 cm in diameter, and, approximately 1 cm to 15 cm in length. Scat can be found as isolated fragments (not usually recorded unless the passage was depauperate of scat), perhaps the result of dispersal by woodrats; and, as a single episode of defecation. Often times, a scat was found in a number of associated smaller fragments. Usually, the raccoon scats contained a multitude of bat bones aligned with the long axis of the scat and the ends of the feces usually were not pinched. Scats yielded not only fragmented and somewhat crushed bones of bat, but also unbroken elements such as the dentary, scapula, and delicate wing bones. The cylindrical scats are identical to descriptions and pictures of raccoon feces in Murie (1954). When a scat degrades, an accumulation of crushed and highly fragmented bone remains. Because raccoons sometimes use communal latrines, large masses of scats or sizeable areas of crushed bone can be created. The few scats containing bat bones, but not having the characteristics of raccoon scat were identified only as carnivore.

Woodrat (*Neotoma floridana*) feces and trails are widely distributed throughout the study area. In general, they were recorded if they were sizeable accumulations, if they were associated with other material that was of interest, or if only a few pellets were found in an area otherwise devoid of woodrat feces.

The method for assigning Paleo data points was not conducive to recording three types of bat remains: “modern” bat guano found on the surface, “ancient” bat guano found on the surface and stratified, and roosting stain. The term *ancient guano* was coined to describe deposits that visually *resemble* the guano discovered at Chief City by Davies and Chao (1959), which were found to be more than >38,000 years old. Most commonly, ancient guano is a deep, rich brown color, although it can be reddish brown or medium brown. Usually the guano no longer occurs as distinctive, cohesive pellets, although a chunk may have a granular-looking texture from degraded pellets. It can be in an expansive accumulation or a narrow layer. Ancient guano presents in a variety of forms, including: dark stripes or layers in a profile of exposed sediments, compressed into a mass that has a granular appearance, or smears in the trail where it has been scuffed up. When trampled, it quickly transforms to an extremely fine "fluffy" powder reminiscent of cocoa powder. Often an *in situ* deposit has an associated white colored layer(s), which appears to be a reaction zone at the contact between guano and matrix, whether limestone rock or sediment. Bone associated with the free-tailed bat guano is fairly distinctive compared to other bone found in the study area -- the bones are generally darker color than other bones recovered in the cave, being a rich, reddish-brown.

Rather than occurring as a single point or small area, both guano and staining are gradational and cover amorphous areas of varying dimensions. Staining can vary from being barely noticeable to being very well developed with associated corrosion. Density of bat guano varies greatly in Mammoth Cave; it ranges from being present as a thin scatter of bat fecal lightly dispersed over a large area to being thick, isolated deposits. For these reasons, an attempt was made to approximate coverage of these resources by indicating them in colored pencil on the field maps: the area colored showed the extent and a deepening of color indicated extreme intensity/density of the resource. Also, particularly thick or important guano areas were assigned one or more data point numbers to represent the deposit in the database. Sometimes ancient guano occurred as a stripe.

Staining attributed to roosting bats was identified on walls and ceilings in various parts of the study area. The discoloration is generally dark, reddish-brown, sometimes has a greasy appearance, and varies from being a very subtle feature to being quite obvious. Corrosion pitting occurring in association with dark staining is interpreted as a heavily used roost. Roosting stain was evaluated conservatively because other forms of staining - including soot, possible humic acid, and organic staining due to water infiltration – can be similar in appearance to roosting stain. Discolorations in areas that would have been preferred bat roosts (domes, cracks, and ceiling contour breaks) were attributed to bats. General staining on a flat ceiling was less likely to be identified as roosting stain.

Vertebrate specimens were collected for several reasons. The first, for identification, included cases in which specimens required more detailed identification or material was too abundant to identify while in the field. Secondly, some specimens serve as vouchers of important identifications. The third reason was for radiocarbon dating. During the collection process, specimens were placed in either small vials or Ziploc bags. The bags and vials were labeled with point provenience, name of collector(s), and date.

In 1995, Lookout Mountain was inventoried with the help of Earthwatch Volunteers. That project was summarized (Toomey et al. 1995), but the data had not been entered in a database, tabulated, or analyzed. Therefore, information from the 1995 Earthwatch project field notes was incorporated into the current study: Paleo Data Point numbers were assigned and the data was entered in the Paleo database. However, the Earthwatch data points do not appear on the Paleo Project's map set, but a copy of the map from Toomey et al. (1995) is included in this report. All field data sheets, maps, and collected specimens for the Paleontology Inventory Project were processed at the laboratories of the Illinois State Museum in Springfield, Illinois. Activities included the following:

- Information recorded on field data sheets was entered into Filemaker Pro 4.0 by Colburn.
- Appropriate CRF maps were digitally scanned.
- Field map notations regarding data points, bat staining, "recent"/surface guano accumulations, and ancient guano deposits were transferred to the digital files using Photoshop 4.0, 5.0 or 6.0 by Blaine Schubert and David Schroder.
- All samples of sediment and bone collected by the Paleontological Inventory Project (except those from Bat Cave), were washed, sorted, and identified by Colburn (Bat Cave samples were processed by Schubert).
- Field photographs were labeled with passage abbreviation and numbered Data Point location by Colburn.
- Data records were sorted, analyzed, and described by Colburn.
- Samples were submitted for radiocarbon dating by Toomey and Schubert.

Radiocarbon dating can be done on bone, mummified tissue, bat guano, and raccoon scat. Two different types of radiocarbon analyses were performed. The first was conventional radiocarbon analysis, which requires a sample of at least 20 grams. Samples for conventional dating were submitted to Geochron Laboratories in Cambridge, Massachusetts. Geochron Laboratories uses a scintillation counter to count ^{14}C decay. This information is used to derive an age; these dates are designated with the prefix GX. The second type, Accelerator Mass Spectrometry (AMS) radiocarbon dating, is able to analyze small samples of less than 1 gram. Mass spectrometry measurements for AMS dates were conducted by the Center for Accelerator Mass Spectrometry (CAMS) at Lawrence Livermore National Laboratory in California. Sample pre-treatment was done either at CAMS or under the direction of Dr. Thomas W. Stafford (either at the Institute for Arctic and Alpine Research, University of Colorado or at Stafford Research Laboratories, Boulder Colorado). AMS dating uses a particle accelerator and mass spectrometer to count individual ^{14}C atoms. From this information an age is calculated; these dates are designated with the prefix CAMS. A table of all samples submitted for radiocarbon dating appears in the Results and Discussion Section.

CHAPTER 1
Vertebrate Paleontological Resources in the Historic Section of Mammoth Cave

INTRODUCTION

Early journal articles, tourist accounts, old place names, and scientific descriptions are a valuable resource because they allude to the fact that bats utilized the Historic Section as a winter hibernaculum in the 1800s. The scores of hibernating bats were a wonder to behold for the early visitors - and perhaps even a nuisance. Many authors likened the Mammoth Cave hibernaculum to a winter home, using such terms as rooms, quarters, and apartments. Their descriptions of seeing bats by the thousands contrast starkly with the now depauperate winter populations, underscoring the need to scientifically quantify the present and past microclimate of the cave. In the early 1800s, the naturalist Constantine Rafinesque (1832:30) wrote that the cave was “the wintering quarter of thousands of bats of five new species of mine which resort to it in winter only from 100 miles around: and remain suspended to the roof in a half sleepy or torpid state. Each species appears to occupy a gallery or room by itself.” Ebenezer Meriam (1844:319) saw hibernating "bats hang in clusters like bees swarming." In the mid-1800s, Benjamin Silliman noted the following:

> Bats are numerous in the avenues within a mile or two of the mouth of the cave, and Mr. Mantell thinks he has secured at least two species. Several specimens are preserved in alcohol. It was not yet quite late enough in the season when we were at the cave, Oct. 16th-22d, for all the bats to be in winter quarters, as the season was very open and warm. Still in the galleries where they most abound, we found countless groups of them on the ceilings chippering and scolding for a foothold among each other. On one little patch of not over four by five inches, we counted forty bats, and were satisfied that one hundred and twenty at least were able to stand on a surface a foot square; for miles they are found in patches of various sizes, and a cursory glance satisfied us that it is quite safe to estimate them by millions. (Silliman 1851:337)

Rhoads (1897:59-60) described seeing *Vespertilio lucifugus* (an old name used for bats now recognized as two different species, *Myotis lucifugus*, Indiana bat, and *M. sodalis*, little brown bat) in "the “Bat Chamber:”

> … during the last week in April, there were at least two thousand at one time. They seemed to prefer the higher ledges of the dome, hanging in long, interrupted, single or triple rows, or in other places, covering irregular patches so thickly as to blacken the walls. Among them appeared to be a larger species, which looked like *Adelonycteris fusca* [previous name used for *Eptesicus fuscus*, big brown bat], but no specimens of these have come to hand.

Thirty years later, hibernating bats had become a rarity rather than the norm. In 1929 Vernon Bailey, of the U.S. Bureau of Biological Survey, and Leonard Giovannoli, of the Kentucky Geological Survey, were involved in a project for the U.S. Department of Agriculture Bureau of Biological Survey to report on Kentucky Cave Life. As part of this project, they conducted an inventory of the cave life in the Mammoth Cave region. Bailey (1933:457) wrote the following in an account of *Myotis sodalis*: "Very few bats were seen or collected in Mammoth Cave, but there is ample evidence in the old guano deposits that this was once a great resort for them." Either the "old guano deposits" to which Bailey referred have been removed, or, he may have been referring the guano at Lookout Mountain. Of interest in the Bailey report is a photograph on page 459 of hibernating *Myotis*. It shows linear aggregations of bats clinging to narrow wall ledges in Mammoth Cave. The caption labels the location as Little Bat Avenue. However, the fracture pattern of the wall is characteristic not of Little Bat Avenue, but of Audubon Avenue; and, by comparing fracture patterns in the photograph to those on the cave wall, Colburn determined that the exact spot with hibernating bats was actually on the left wall of Audubon, approximately a quarter of the way between the Rotunda and the mouth of Little Bat Avenue. [Left wall and right wall refer to the sides of the passage, or tourist trail, as a person walks away from the Historic Entrance.] Three quarters of a century have passed since Bailey’s study and we longer see aggregations of *Myotis* hibernating in this location, nor any other area of the main cave. At most, a lone *Myotis* might be visible somewhere in the cave.

Until the paleontological inventory was conducted, these early descriptions provided our only view of a Mammoth Cave that is no longer visible. The method of conducting a search on hands and knees, from wall-to-wall was labor intensive, but it produced 1553 locations with noteworthy faunal remains in the Historic Section. These find spots were numbered and may be referred to in this report as "paleo data points," "data points", or just "points." Fieldwork was carried out in B-level passages along the Historic Tour Routes between the Historic and Violet City entrances between October 1997 and April 2001 (Figure 1-2). The geographic scope included the main trunk passage, all major side passages (except Harvey's Lost Way, which was only perused), and the old high-level passage that lies in the upper portion of the B-level.

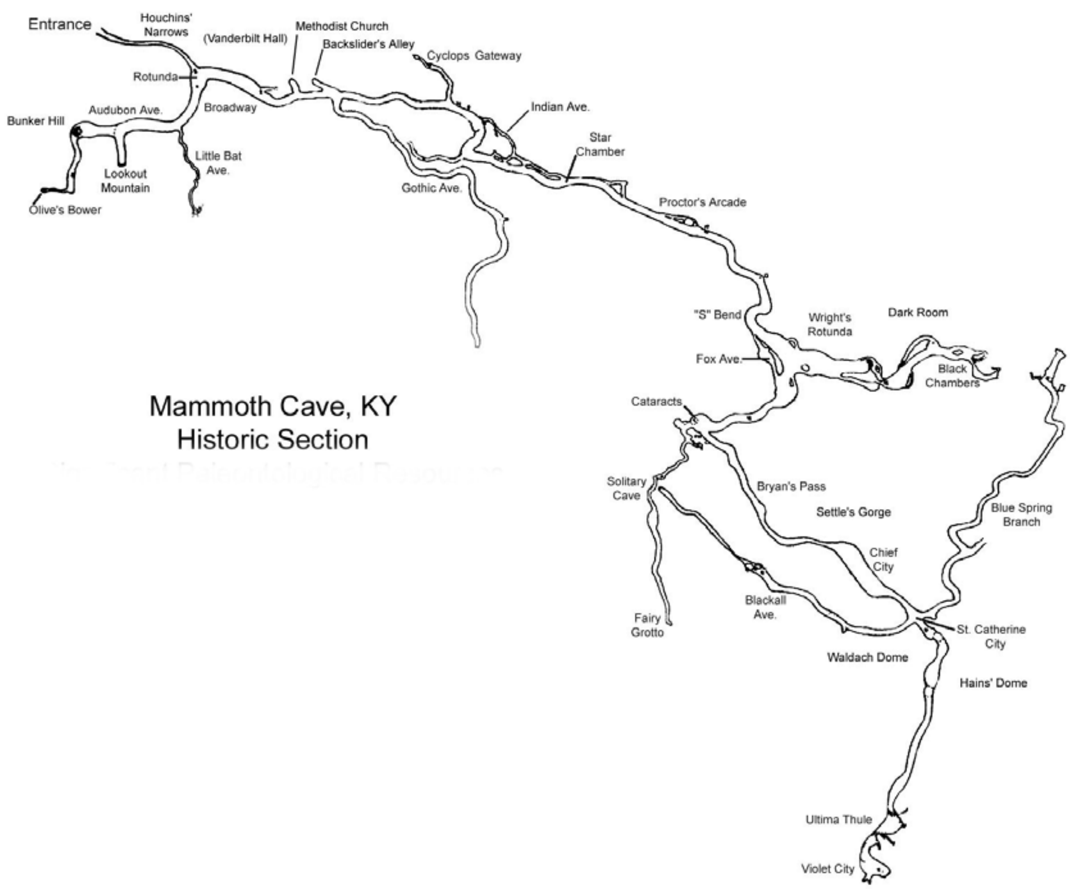

FIGURE 1-2. B-level main trunk passage and side passages surveyed by the Illinois State Museum Paleontological Inventory Project between 1997 and 2001. Adapted from Kaemper Map, 1908 (redrawn by Diana Daunt, CRF 1981).

RESULTS AND DISCUSSION OF THE HISTORIC SECTION

Faunal remains were discovered and recorded for 1553 data points in the Historic Section of Mammoth Cave. The vertebrate remains include the following: isolated bones, partial and whole skeletons, partial and whole mummified animals, *in situ* deposits of bones, bat guano pellets, masses of *in situ* guano, woodrat feces, raccoon scats, and trace fossils (scratchings, footprints, trails, and staining). However, the taxonomic range is narrow because the vast majority of the material is from bats. Some ubiquitous remains and traces, such as bat guano, rat feces, and rat footprints and trails, were recorded only if the finds were notable (due to location, position, abundance, or quality) or were representative of a section of cave passage. Table 1-1 lists the common names that correspond to the scientific nomenclature used to identify remains found throughout all portions of Mammoth Cave's Historic Section.

TABLE 1-1. Scientific nomenclature and common names of vertebrates whose remains were found in the Historic Section of Mammoth Cave. This includes the trunk passages between the Historic Entrance and the Violet City Entrance (Audubon and Main Cave) and major side passages. Taxonomy follows Banks et al. 1987.

Taxon	***Common Name***
Class Mammalia	**Mammals**
Scalopus aquaticus	Eastern mole
Desmodus stocki	Extinct vampire bat
Eptesicus fuscus	Big brown bat
Lasiurus borealis	Red bat
Myotis austroriparius	Southeastern bat
Myotis grisescens	Gray bat
Myotis leibii	Small-footed myotis
Myotis lucifugus	Little brown bat
Myotis sodalis	Indiana bat
Myotis lucifugus or *sodalis*	Little brown or Indiana bat
Myotis septentrionalis	Northern long-eared myotis
Myotis sp., small-sized	Small myotis
Myotis sp., medium-sized	Medium myotis
Myotis sp.	Indeterminate species of myotis
Nycticeius humeralis	Evening bat
Pipistrellus subflavus	Eastern pipistrelle
Corynorhinus sp.	Big-eared bat
Vespertilionidae	Indeterminate vespertilionid bat

Taxon	***Common Name***
Tadarida sp.	Free-tailed bat
Chiroptera	Bat order
Canis sp.	Dog/coyote
Procyon lotor	Raccoon
Mephitis mephitis	Skunk
Carnivora	Indeterminate carnivore
Sus scrofa	Domestic pig
Bos taurus or *Sus scrofa*	Cow or pig
Odocoileus virginianus	White-tailed deer
Artiodactyla	Indeterminate ungulate
Marmota monax	Woodchuck
Sciurus sp.	Tree squirrel
Tamias sp.	Chipmunk
Neotoma floridana	Eastern Woodrat
cf. Neotoma	Probably woodrat (but a few remains could be old world rat)
Rattus sp.	Old world rat
Peromyscus sp.	Deer or white-footed mouse
Pitymys pinetorum	Pine vole
Mus musculus	House mouse
Rodentia	Rodent order
Sylvilagus sp.	Cottontail rabbit
Homo sapiens	Human
Class Aves	**Birds**
Gallus gallus	Chicken
Phasianidae	Pheasant, grouse, quail family
Meleagris gallopavo	Turkey
Otus asio	Screech owl
Colaptes auratus	Northern flicker
Passeriformes	Perching bird
Class Reptilia	**Reptile**
Testudines	Turtle
Colubridae	Family of colubrid snakes
Crotalus sp.	Rattlesnake
Serpentes	Snake
Class Amphibia	**Amphibian**
Cryptobranchus sp.	Hellbender
Caudata	Salamander
Bufo sp.	Toad
cf. *Rana* sp.	Frog
Anura	Frog or toad
Herptile	Amphibian or reptile
Class Osteichthyes	**Fish**

Taxon	***Common Name***
Moxostoma sp.	Redhorse genus
Catostomidae or Carp	Sucker family or carp
Ictaluridae	Catfish family
Centrarchidae	Sunfish family
Indeterminate Vertebrata	Unknown vertebrate

An analysis of the 1553 data points can be presented in many ways. Following the format that I used in describing Holocene-aged remains located within 1/4 mile of the Historic Entrance (*Late Holocene Utilization by Bats of the Mammoth Cave Historic Entrance Area, Mammoth Cave National Park, Kentucky* by Toomey, Colburn, and Schubert 1998, Cooperative Agreement No. 1443 CA5530 97 001), I present results of the Paleontological Inventory Project survey in the Historic Section of Mammoth Cave in a passage-by-passage description. In addition, data from the Illinois State Museum's previous report are summarized and used in the present report. For the most part, passages correspond to major changes in the cave topography; e.g., main trunk passage vs. side passageways, a sharp bend in a passage, or a noticeable constriction in passage size. Their names are the traditional appellations familiar to anyone who has studied the cave, read old accounts, or has toured the cave.

Results for the Historic Section of Mammoth Cave are divided into two parts: Part I) the large trunk passages of the B-level of Historic Mammoth Cave and Part II) major side passages that intersect the main trunk. Within each of these parts, I describe the results for smaller segments/subdivisions of a passage. To aid readers in visualizing the cave layout and described segments, the names used are those familiar place names used on the Kaemper Map, in Hagan and Sutton (1998), and in Palmer 1981; and, a map accompanies each of the passage divisions (except Backslider's Alley and a portion of Gothic for which no maps were available). The details are not meant to be legible; rather, the purpose of the maps is to show the general distribution of data points (red dot, line, and number); and, on some maps, guano (blue), ancient guano (green), and stain (brown) can be discerned. At the ends of Part I and Part II, I provide tables listing the vertebrate taxa found in each segment of passage.

PART I: AUDUBON AVENUE, BROADWAY, AND MAIN CAVE – FAUNAL RESOURCES IN MAIN TRUNK PASSAGES BETWEEN THE HISTORIC AND VIOLET CITY ENTRANCES

A discussion of inventory results in the large trunk passages of Audubon and Main Cave are presented for the following segments of passage. The data point numbers found within each named segment are given in brackets. A summary table of the taxa found in each of the segments appears at the end of the descriptions.

- Audubon Avenue from the Rotunda to Bunker Hill [140 data points: 103-104, 107-172, 174-236, 287-294, 950, and 1402]
- Broadway/Main Cave from the Rotunda to Acute Angle (includes Methodist Church) [96 data points: 265-286, 295-301, 302-314, 349-356, 373-386, 409-422, 424-435, 437-441, 565]
- Main Cave segment from Acute Angle to Star Chamber [32 data points: 442-472, 560]
- Star Chamber and Proctor's Arcade [123 data points: 473-494, 502-559, 561-564, 567-593, 597-607, 817]
- Cave passage beyond Proctor's Arcade to the S-Bend [50 data points: 594-596, 608-649, 653-656, 729]
- Wright's Rotunda (including Cross Cave and passages leading to Black Chambers) [81 data points: 650-652, 657-673, 763-816, 1276-1281, 1588]
- Area of the Cataracts (including passages between Wright's Rotunda and the Cataracts and between the Cataracts up to Bryan's Pass)
  [27 data points: 674-685, 730-744]
- Bryan's Pass and Settle's Gorge [18 data points: 745-762]
- Chief City (including the low sediment filled area just beyond Chief City) [57 data points: 938-946, 1096-1140, 1143-1145]
- St. Catherine City [35 data points: 1141, 1142, 1146-1176, 1178, 1179]
- Waldach Dome and Hain's Dome [24 data points: 1180-1203]
- Mayme's Stoop to Ultima Thule [25 data points: 1204-1228]
- Ultima Thule to Violet City (including the crawl through Ultima Thule that is known as the Kaemper Connection, Kaemper's Hall, and Elisabeth's Dome) [43 data points: 1229-1271]

Audubon Avenue from the Rotunda to Bunker Hill
[140 data points: 103-104, 107-172, 174-236, 287-294, 950, and 1402]

FIGURE 1-3. Trunk passage Rotunda to Bunker Hill (base map cartography by CRF).

As mentioned in the general introduction, early reports by 19th century visitors inform us that Mammoth Cave was a hibernaculum for wintering bats. William Blane (1824:26), an Englishman traveling in the United States and Canada in 1822-1823, reported, "There are myriads of bats hanging by their hind feet." Statements such as these were usually made in reference to Audubon Avenue and adjoining side passages. Indeed, many early historic accounts tell us that the passage now known as Audubon Avenue was once called the Great Bat Room, an appellation based on the thousands of bats that used the area. For example, in *Rambles in the Mammoth Cave during the year 1844*, Bullit (1845:15) wrote that the "passage to the right is the 'Great Bat Room.'" And, in a *New York Municipal Gazette* article entitled "Mammoth Cave", Ebenezer Meriam (1844:320) noted, "The improvements within the Cave commence about half a mile from the mouth, in that branch known as the great 'Bat Room,' but now as 'Audubon's Avenue,' named by the proprietor after his old friend, the celebrated Ornithologist." Binkerd informs us that bats were present year round in Audubon Avenue:

> Off to the right is a passage rarely shown to visitors, as it contains nothing of special importance. This is called AUDUBON'S AVENUE.
>
> Being near the entrance, it is generally passed without much attention, and the guides have finally dropped it from their course

> altogether. On part of this avenue presents an unusual attraction to the naturalist. Countless thousands of bats have taken possession of one of these caverns, wherefore it is known as THE GREAT BAT ROOM.
>
> Here the leathern-winged little animals cling to the walls and ceiling like huge swarms of bees, in bunches of many bushels, and doze away their existence in a semi-torpid state, in darkness and repose. What they feed upon is a question not easily settled. Some of them must remain here many months without once going out of the cave, as but few are seen outside at a time. It was formerly believed that they spent only the winter here; but I have never visited their apartment at any season without finding numbers of them. We will find plenty of them in the Rotunda for any experiment we may wish to make.
>
> (Binkerd 1869:18)

In the 1870s, Thompson (1879:77) wrote in *The Sucker's Visit to the Mammoth Cave*, "…on portions of the dome [the Rotunda] bats clustered…." Hovey included more details about the passage name and the bat population in Audubon and in an area beyond Audubon Avenue (Vespertilio Hall):

> It is related that when the great visiting ornithologist [Audubon] visited Rafinesque, the former smashed a fine violin in his eagerness to capture a unique specimen of the bat family. As a kind of amicable revenge the latter affixed Audubon's name to this avenue, where so many myriads of bats annually hibernate. ... Unless our visit is in late fall or winter, we find but a few clusters of bats; but in cold weather they gather here from near and far and hang head-downward till somehow, by a sense not explained, they know it is warm weather out-of-doors, and then they fly forth to the forests. Dr. Call boasts of a single catch that gave him six hundred and seventy bats, of many varieties, most of which were sent to the National Museum [where many are still curated].
>
> (Hovey 1909:35)

Based on all of these visitor accounts and more, a paleontologist should be able to find a plethora of bat fossils on the floor of Audubon Avenue. But large numbers of fossils have not been found – likely due to the impact of historic activities. Among the human activities that impacted Audubon Avenue resources were the following:

- Numerous activities related to the 1812 production of saltpeter: sediment mining, niter beer production, feeding miners, and stabling oxen
- One of Dr. John Croghan's tuberculosis patients lived in a cottage in Audubon Avenue
- Post cards, photographs, and maps show that in the early 1900s there was a dining hall with rows of tables located between the Rotunda and the entrance to Little Bat Avenue
- Supplies for a Civil Defense fallout shelter were stored in Audubon between Little Bat Avenue and Rafinesque from 1963 to 1978
  (C. Olson 2002)
- Millions of tourists have walked, climbed, and explored the passage with their attendant noise, trampling, dust raising, litter, lint, hair, and smoky lamps
- Several episodes of moving breakdown and adding sediment (and most recently, paving stones and a boardwalk) in order to accommodate mining and tourists have remodeled the floor

Remnants of the saltpeter vats, pipes, and pump tower are visible today, but virtually all traces of the tuberculosis hut, old dining hall, and Civil Defense shelter have been cleared away. Thus, one might assume that all indications of past bat activity would have been swept away with the human debris. Despite the thorough cleaning, the Paleo Project's painstakingly close inspection produced a surprising amount of faunal debris on the surface; paleontological remains were found at 140 data points between the Rotunda and Bunker Hill. In 2000, archaeologist George Crothers performed shovel testing in areas that were to be covered with concrete paving stones. One shovel test (Crothers' Hole #150 left, assigned Paleo Data Point 1402) was located in the middle of Audubon, just before the entrance to Little Bat Avenue (Figure 1-4).

FIGURE 1-4. Audubon Avenue, Data Point 1402.

The test hole provided a small glimpse of a pre-modern surface; it showed a mixture of bat guano, fur, and possibly fungus.

Visible bat guano and roosting stain indicate that use intensified progressively along Audubon Avenue. Between the Rotunda and Little Bat Avenue, stain is not discernible on the high ceiling and very little bat guano was found. However, between and Little Bat Avenue and Rafinesque Hall, a light to moderate degree of bat stain occurs on the ceiling steps and on breaks along the walls and bat guano is preserved in divots and cracks of large breakdown blocks. Staining is heavier here than in the previous segment, and thousands of tiny scratches and corrosion attributed to bats occur on the left wall. Stain on the edges of ceiling breakout in Rafinesque Hall ranges from light to moderately heavy; and guano is preserved on large breakdown blocks and between rocks. Bat staining is widespread and moderate to heavy on ceiling steps along the entire length of passage between Rafinesque Hall and Bunker Hill; and pellets of guano are widespread on ledges and breakdown along the walls. At Bunker Hill, itself, the concentric ledges of the breakout dome is heavily stained. Bat guano is scattered over the entire breakdown pile and there are large amounts of guano on the right side of the hill, preserved where it filtered down into large cavities in the breakdown.

Another strong indicator of hibernating bats, raccoon scats containing bat bones, was found at 74 of the 140 data points, indicating that raccoons frequently visited/hunted in this segment of Mammoth Cave. Between the Rotunda and Little Bat Avenue, there is a large raccoon latrine (measuring 60 cm by 30 cm and several centimeters thick) with degrading scats containing bat bones. In the 1800s, the Bunker Hill breakdown was excavated to carve a narrow tourist trail. Several raccoon scats, located on a wall ledge at Bunker Hill appeared to be *in situ* deposits that predate excavation of the breakdown to make the narrow tourist trail around Bunker Hill. As it turned out, one piece of scat from along the excavated trail was dated to 540 ± 90 radiocarbon years before present (RCYBP) (CAMS-46215). In addition scratch marks possibly made by raccoon were found at 3 data points.

The surface evidence in Audubon Avenue was unevenly dispersed due to the impact of human disturbance. Most was discovered on ledges, behind rocks, and eroding from cave sediment, all of which afforded the fossils some protection. Mummified remains (whole or partial carcass that has all or some of its tissue) and skeletal material are direct evidence of taxa that utilized the area. Eight mummified bats were located, as well as, several wings with tissue and clumps of fur. Species represented were *Lasiurus borealis, Pipistrellus subflavus*, and indeterminate bat. Some were covered with white and green fungus; this is probably an indication that they are modern in age. The red bat located on top of fallen ceiling slabs, post-dates the January 1994 roof fall in the Rotunda. Wing elements from one of the three mummified bats lying on the surface at Bunker Hill were radiocarbon dated to 1960± 40 radiocarbon years before present (RCYBP) (prepared for accelerator mass spectrometry dating by Stafford Research Laboratories, Boulder Colorado and dated at Lawrence Livermore Laboratories, CAMS-55909). The following bat taxa were identified from skeletal remains: *Eptesicus fuscus*, cf. *Myotis leibii*, cf. *M. grisescens*, *M. sodalis*, medium-sized *Myotis* (most likely *M. sodalis* or *M. lucifugus*), cf. *Myotis* sp., and *P. subflavus*.

In addition several non-bat taxa were identified: a domestic rat, *Rattus* sp. (partially skeletonized, fungus-coated mummy located between the Rotunda and Little Bat Avenue), a single chicken bone, *Neotoma* feces (fairly prevalent on ledges and in anastomotic pockets; woodrats can be seen in the vicinity today), juvenile woodrat (bones with tissue), *Peromyscus* sp., *Pitymys pinetorum* (skull fragment), and unidentifiable mouse.

Broadway from the Rotunda to the Acute Angle [96 data points: 265-286, 295-301, 302-306 (Methodist Church), 307-314, 349-356, 373-386, 409-422, 424-435, 437-441, 565]

> Leaving the Rotunda, we pass huge overhanging rocks, called Kentucky River Cliffs, and enter the Methodist Church …In this part of the cave, and in all the avenues near the entrance, millions of bats make their winter quarters. We saw only a few flitting about, but were told they returned in the autumn by hundreds.
>
> (Anonymous 1872:624 in the *Catholic World*)

This is another of the most intensively impacted portions of main trunk in Mammoth Cave. There are 96 data points between the Rotunda and Acute Angle. The extreme height of the ceiling and the presence of heavy smoke and soot make it impossible to detect bat stain. Moderate to heavy amounts of roosting stain were observed on the edges of ceiling breakouts and in a small dome in Main Cave, just past the intersection with Gothic Avenue.

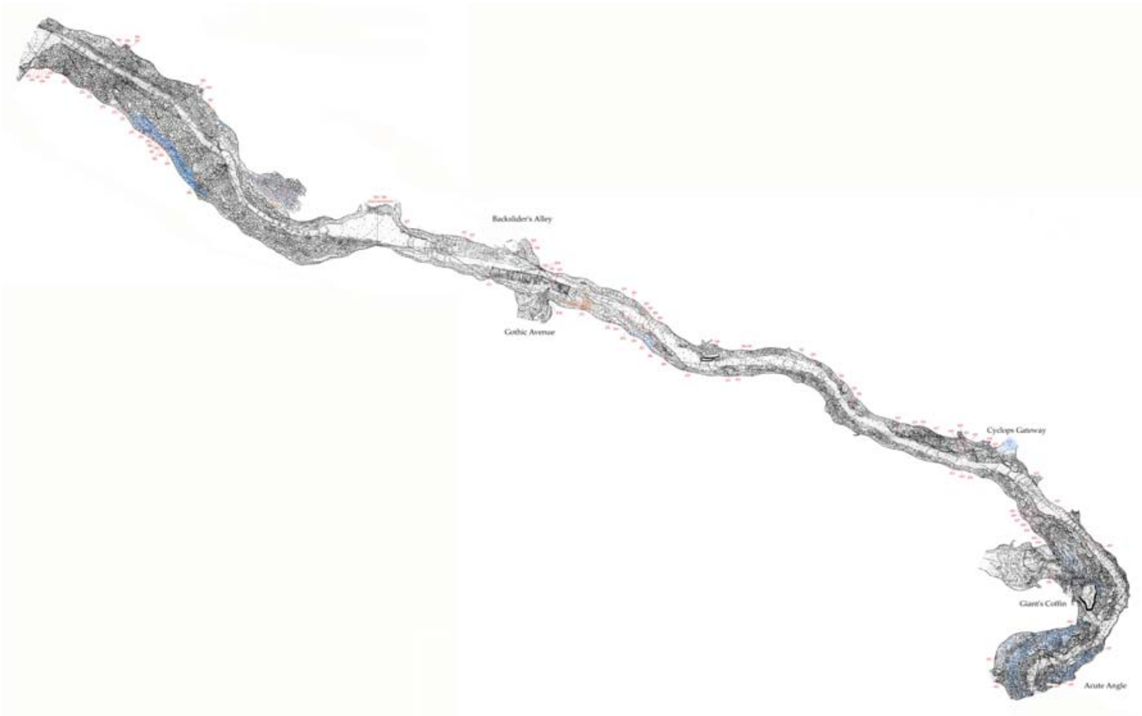

FIGURE 1-5. Trunk passage Rotunda to Acute Angle (base map cartography by CRF).

Bat guano was probably ubiquitous prior to historic disturbance. Remnants are now found in protected areas under overhangs of large rocks and on less accessible ledges. Guano is abundant on breakdown underneath a small breakout dome midway between the Rotunda and Methodist Church, and a thin layer of guano is widespread on huge pieces of breakdown at the back of Methodist Church. This guano coating indicates heavier usage than do the skeletal and mummified remains. Tiny parallel scratches (3-5 in a group) attributed to bats are visible on a wall between the Rotunda and Methodist

Church, on the sooty face of a breakdown block at the back of Methodist Church, and in the low crawlway at the top of Methodist Church.

Twenty-one data points had remains of mummified bats: 3 *Corynorhinus* sp., 7 *Lasiurus borealis*, 1 *M. lucifugus*, 1 cf. *M. sodalis*, 1 medium-sized *Myotis* sp., cf. *Myotis*, 7 *P. subflavus*, 3 unidentified taxa, and several wings with tissue. The mummified little brown bat was hanging just past the mouth of Methodist Church in 1994, but it had fallen by 1999. Skeletal remains were attributed to the following bats: *Corynorhinus* sp. *E. fuscus, Lasiurus borealis, M. grisescens*, *M. leibii*, *M. lucifugus*, *M. sodalis,* medium-sized *Myotis*, cf. *Myotis, P. subflavus*, and indeterminate bat.

Raccoon scats containing bat bones were recorded at 23 data points, but no raccoon bones were found. Other animals represented among the remains in Broadway are *Gallus gallus,* cf. *Canis familiaris, Neotoma floridana* (feces and bones of a subadult), *Peromyscus* sp., *Sus scrofa* (foot bones of a juvenile), and a partially skeletal mouse mummy. Tourists, woodrats, or raccoons left the chicken, pig, deer, and fish bones.

As has been concluded for other areas of the cave, historic modifications have obscured patterns of bat use in Broadway. The guano accumulation at the shallow breakout dome between the Rotunda and Corkscrew provides a weak indicator of a possible winter roost. If this was a roost area, it does not appear to have been used very intensively.

A paleontologically significant area is located just beyond the Gothic Avenue saltpeter spoil piles where relict sediments lie below the level of the current tourist trail. Within these sediments are *in situ* pockets of bone (data points 380-386). The deposit was exposed when dirt was excavated, probably for saltpeter production or for trail fill, from under the overhanging cave wall. The bone deposits are in a pebbly, lighter colored grayish and pinkish upper layer that varies from 5 cm thick to being absent; the underlying sediment is very fine-grained. Soot and burned cane lie on the surface. Some of the bones are protected in solution pockets. Point 380 denotes the first visible pocket of bone (before which the mining spoil piles obscure signs of any remnant sediments), and Point 386 denotes the last *in situ* bone pocket. Beyond 386, the in-place sediments become gravelly. Most of the bones protruding from *in situ* layers are bat wing elements and shafts. Identifiable elements belonged to *E. fuscus*, *Myotis grisescens*, *M. leibii*, and medium-sized *Myotis* sp.

Main Cave from Acute Angle to Star Chamber [32 data points: 442-472, 560]

Because of repeated, and heavy disturbance, this segment of cave was thought to hold little promise for preservation of paleontological remains. Not only have thousands of tours passed through here, but also Dr. Croghan's tuberculosis hospital activities were centered here in the 1840s. In the early 1800s, saltpeter miners and oxen would have traveled through this relatively narrow passage enroute to mining operations in Blue Spring Branch.

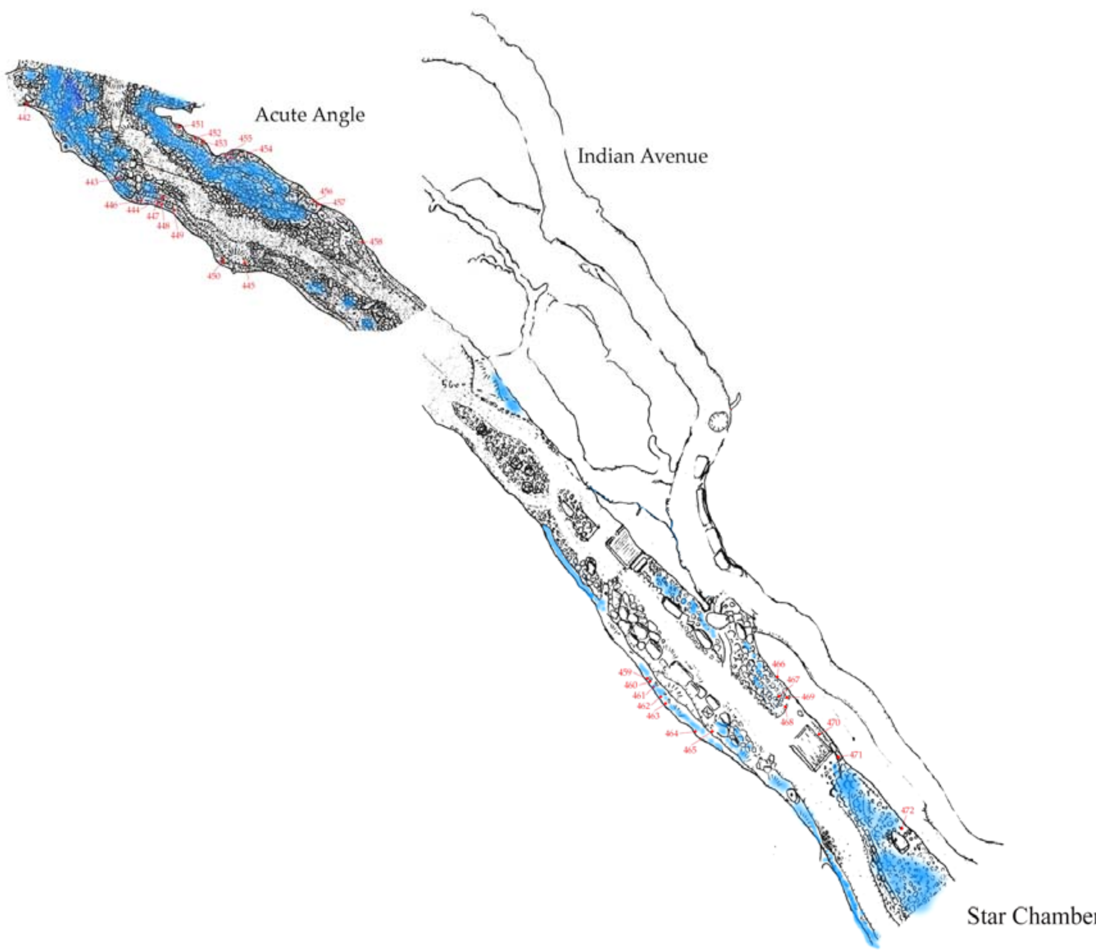

FIGURE 1-6. Trunk passage between Acute Angle and Star Chamber (base map cartography by CRF).

Roosting stain is not noticeable in this area. Eleven data points with bone had guano pellets present; however, there were no accumulations. Two raccoon scats were located. One scat containing bat bone was found in a woodrat accumulation (Point 453) that also held a human paleofeces containing small bones. The other scat, full of cricket parts, is located in an undercut of the left wall. Ten data points had mummified remains of bat: *Lasiurus borealis* (1 point), *Myotis* cf. *grisescens* (1), *M. lucifugus* (1), *M. sodalis* (1), *M. lucifugus* or *sodalis* (1), *Pipistrellus subflavus* (4), and indeterminate vespertilionid (1). Bones of a possible gray bat and numerous vespertilionid elements, many with remnants of adhering tissue, were measured and recorded.

The heavy human impact in this segment is reflected in the greater density of data locations with Euro American artifacts and by the unusual debris content. Nineteenth century signatures, a large bird feather, chicken eggshell fragments, and chicken bones were found. Pieces of eggshell were located with a 12-inch square fragment of aboriginal matting and a twisted bundle of fiber. The most interesting find was a hidden deposit of historic food debris that included a clump of fabric with small blue and white checks, egg shell, animal bones, and plant fibers. Animals identified in this cache were chicken (femur, pelves, ulnae, vertebrae, furculum, humerus, fibula, radius, coracoid), possibly quail (sternum, femur, tibiotarsus), possibly flicker (carpometacarpus, femur, tibiotarsus), squirrel (scapulae, frontals, zygomatic, femora, ribs, vertebrae, ulna, humerus), pig (phalanges and saw cut rib), and large mammal (saw cut rib).

Star Chamber and Proctor’s Arcade area
[123 data points: 473-494, 502-559, 561-564, 567-593, 597-607, 817]

This segment of Mammoth Cave begins a little before the benches at Star Chamber and continues southeastward to just beyond the last cut-around in Proctor’s Arcade. With 123 data points, fossil remains are dense in this segment of Main Cave. Numerous desiccated, soot covered mummified bats and wings with deteriorating membranes are concentrated on ledges – particularly along the right wall and atop the septum just to the left of the tourist trail (the “Keel Boat”) and somewhat less on the ledge along the left wall. These ledges are covered with loose red sediment filled with pea-sized to walnut-sized gravel; the sediment is covered with a dark gray soot layer and flakes of gypsum crust. Burned and unburned wood, sticks, cane, and remnants of historic cloth torches litter the surface. Small divots in the sediment hold mummies, crickets, and charcoal. The surface of the ledge is very disturbed. Remnant patches of guano suggest that guano accumulation was moderate to heavy prior to trampling. Mummified bat remains are difficult to distinguish from small burned sticks under the coating of soot. The walls above the ledges are extremely battered. Under the ledge at current floor level are many anastomotic solution tubes with red sediment floors and long gypsum needles.

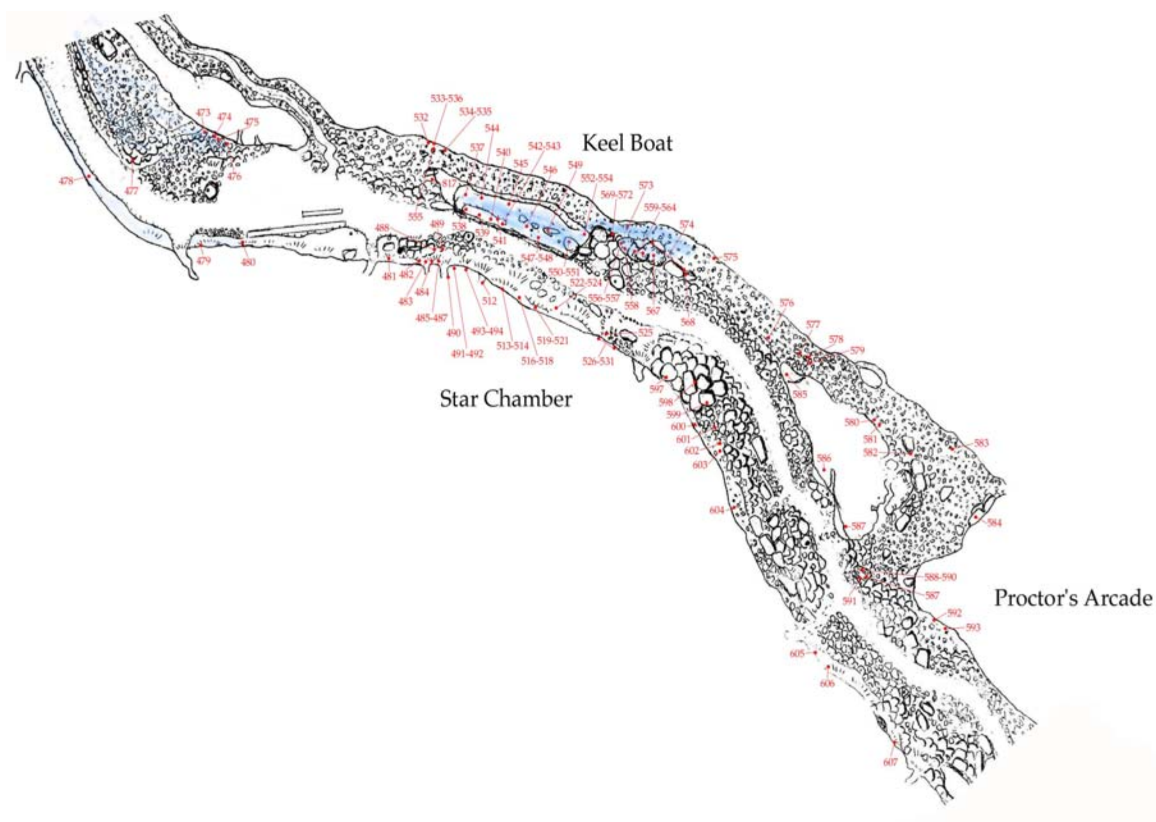

FIGURE 1-7. Trunk passage Star Chamber and Proctor's Arcade area (base map cartography by CRF).

Data points 569-584 are located in a passage that undercuts the left wall of Main Cave beginning just past the far end of the Keel Boat. The passage is under a ledge on which points 556-564 and 567 are located. The archaeologically rich area and has several woodrat nests, degraded raccoon scats, bat guano, newspaper, human paleofeces, and historic basketry. The side-cut is partially open to the main trail, but is enclosed at points 578-584. In the latter part of the passage are fragments of two prehistoric sandals, abundant paleofeces and cane, newspaper fragments, and, back in a small crawl, a freshwater mussel shell.

Mummified bats are prevalent in the Star Chamber and Proctor's Arcade area. Bat guano is prevalent but not thickly accumulated in Proctor's Arcade, being recorded at nearly half of the data points. Like mummified remains, guano was concentrated on ledges in divots in the sediment. Roosting stain was not noted; much has probably been destroyed or obscured by human battering, natural exfoliation of the gypsum crust, and layers of smoke. Mummified remains of the following bat taxa were found at 76 different data points:

- *Eptesicus fuscus* (1 point)
- *Lasiurus borealis* (1 point)
- *Myotis leibii* (1 point)
- *M. lucifugus* (11 points)
- *M.* cf. *lucifugus* (7 points)
- *M.* sodalis (12 points)
- *M.* cf. *sodalis* (5 points)
- *Myotis lucifugus* or sodalis (10 points)
- *M. sodalis* or small *M. grisescens* (1 point)
- Medium-sized *Myotis* sp. (7 points)
- cf. *Myotis* sp. (1 point)
- *Pipistrellus subflavus* (4 points)
- cf. *Pipistrellus subflavus* (1 point)
- Indeterminate Vespertilionidae (15 points)

The cause(s) of the accumulation of mummified remains in this area of the cave is not known. Perhaps this accumulation is representative of the amount of remains that littered the surface before historic disturbance. The area may have been a preferred roost for Indiana and/or little brown bats. However, stain is not noticeable and the area does not appear to be particularly suitable as a bat roost because gypsum crusts cover much of the wall and ceiling. If this area had been a significant bat roost, it might indicate that the microclimate in this area of the cave used to be different. The walls are battered extensively; the aboriginal people appear to have used all the all of the ledges on which we found mummified remains to reach gypsum. Two samples from mummified remains were radiocarbon dated to 420±50 and 700±40 RCYBP; thus indicating that they postdate the aboriginal gypsum mining in the area.

No additional bat taxon was represented by skeletal elements alone. Remains of at least 11 other animals, including human, were recorded from Proctor's Arcade. *Procyon lotor* remains were limited to scats (7 points), which contained bat bones aligned in the characteristic longitudinal pattern. Scat at Data Point 606 also contained frog or toad bones.

An entire mummified house mouse (*Mus musculus*, Point 569) was located near the opening to the undercut of the left wall. A mandible located before the side-cut and by a nest and larder found in the side-cut passage represented *Neotoma*; no latrine was located. Point 574 denoted a woodrat accumulation extending for about 20 feet along the right side of the undercut. A 4x6 foot larder area was found in a 30-inch high space on a ledge that measures about 10 feet deep by 15 feet long; and, a nest is located below this ledge in a space that is 2-12 inches high. Woodrat feces were not noticeable in either the larder or the nest. The soot covered larder material lies on top of a 1-inch thick layer of bat guano. The accumulation includes chicken bones from multiple individuals, a turkey bone, bone-filled raccoon scats, wood, cane, seeds, human feces, and shredded plant fibers. The nest is a more concentrated mass than the larder. Again, everything is covered with soot. Visible were bat guano, a chicken bone, human feces (modern looking), newspaper, wood, several cloth torch fragments, cane, a piece of hard rubber with a nail through it, plant material (more than in larder) from a straw-type hat or fiber mat, acorn, paper, straw, and a gourd fragment. Point 576, also located in the undercut, is a woodrat larder with sticks, cane, and four pieces of raccoon scat containing bat bones. Rodent tracks (rat or mouse) were sporadic throughout Proctor's Arcade.

Several locations yielded interesting remains of historic age. Point 601 and 602 are two squirrel (*Sciurus* sp.) skeletons, which have no skull, no feet, and no tail – a pattern typical of skinning. There are many rodent tracks in the soft sediment around the skeletons; however, both sets of bones are lying in correct anatomical position. The individuals are mostly skeletal with some tissue present and slightly greasy. Based on ossification of its long bones and the presence of suspensory tuberosities, one of the squirrels (Point 601) was a mature male (see Colburn 1986). Cut marks were visible on its right distal femur and proximal tibia. The other individual, possibly female, was immature with unfused epiphyses.

Point 554, located at the southeastern end of the Keel Boat, is a stack of 15 artiodactyl ribs (some saw-cut, with red mold growth), cow or pig left and right hyoids (one saw-cut), and rabbit left femur and left innominate (with fatty tissue adhering). An unossified greater trochanter (still greasy and with adhering tissue) of a pig or deer-sized artiodactyl and a human paleofeces occur at Point 568. At Data Point 590 articulated leg elements (right tibia, calcaneum, astragalus, and lateral maleolus) of a deer have tissue, red mold, and soot on them. Bird remains include the following: chicken (bone at Point 574), turkey (feather at 477 and bone at 574), and indeterminate bird (bone at 484, feather at 488, and a vertebra in human paleofeces at 582).

Human feces, most likely prehistoric in age, were found at or near eight of the data points; two contained small bones. Those at Point 582 contained a bird vertebra and indeterminate bone. The paleofeces at Point 557 had been stepped on and broken into two large pieces and one small (90mm x 37mm, flattened and 37.3mm x 50mm, not flattened, and 30mm x 27mm, flattened). Many bat bones were within the paleofeces and a few were found underneath the fragments.

Beyond Proctor’s Arcade to S-Bend [50 data points: 594-596, 608-649, 653-656, 729]

This section includes the relatively long segment of Main Cave passage that lies between the southeastern end of the side-cut at Proctor’s Arcade and the southeastern end of the S-Bend. Only a light scatter of bat guano is apparent here (guano was recorded at only six data points). Much has probably been destroyed by human impact. A number of prehistoric and historic artifacts were seen in this section (historic oil lamp, prehistoric woven slippers, numerous mussel shells, stashes of unburned cane, a projectile point, and the ubiquitous fragments of burned cane and sticks).

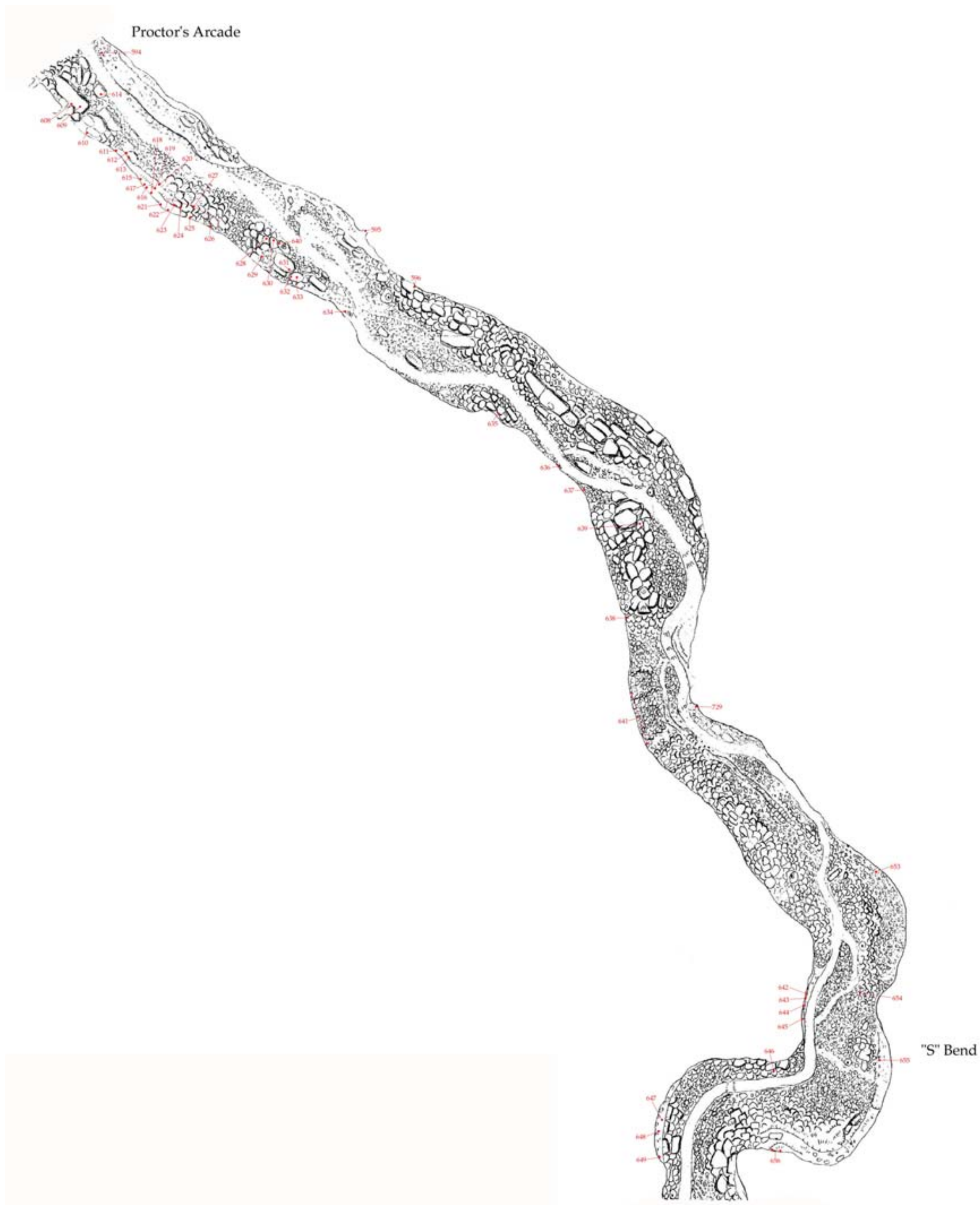

FIGURE 1-8. Trunk passage Proctor's Arcade to S-Bend (base map cartography by CRF).

The fact that mummified bat materials were recorded at 76% of the data points attests to utilization of the passage as hibernaculum and flyway. Some data locations yielded multiple individuals. Seven species of bat were identified from mummified remains, but no additional bat species was identified from bone, alone. Taxon and number of data points for mummified remains are as follows (two locations had multiple taxa):

- *Eptesicus fuscus* (1 point)
- *Lasiurus borealis* (1 point)
- *Myotis* cf. *leibii* (1 point)
- *M. lucifugus* (1 point)
- *M. septentrionalis* (1 point)
- *M.* sodalis (13 points)
- Medium-sized *Myotis* sp. (5 points)
- cf. *Myotis* sp. (1 point)
- *Pipistrellus subflavus* (13 points)
- Indeterminate Vespertilionidae (3 points)

Chicken bones, a possible turkey feather, an entire screech owl, a phasianid feather, woodrat/rat tracks and runs, and human paleofeces containing bones account for the non-bat materials found between Proctor's Arcade and the S-Bend. Earthwatch Volunteers inventorying archaeological artifacts first sighted the screech owl in the summer of 1997. Interestingly, one year later, the carcass still smelled bad and had not been chewed on by rodents or crickets.

Wright's Rotunda area [81 data points: 650-652, 657-673, 763-816, 1276-1281, 1588]

For the purposes of the paleontological study, Wright's Rotunda includes the area of passage that lies between the end of the S-Bend and continues southward along the tourist trail until the passage narrows and turns west toward the Cataracts, Cross Cave (a.k.a. Fox Avenue), the huge room known as Wright's Rotunda, and back through the left and right branches that lead to the Small Chimney and the Big Chimney. Cross Cave is a side-cut, the northern end of which has been filled with breakdown. It has a deep fill of fine beige sediment, which has been heavily impacted by tourists and sediment mining.

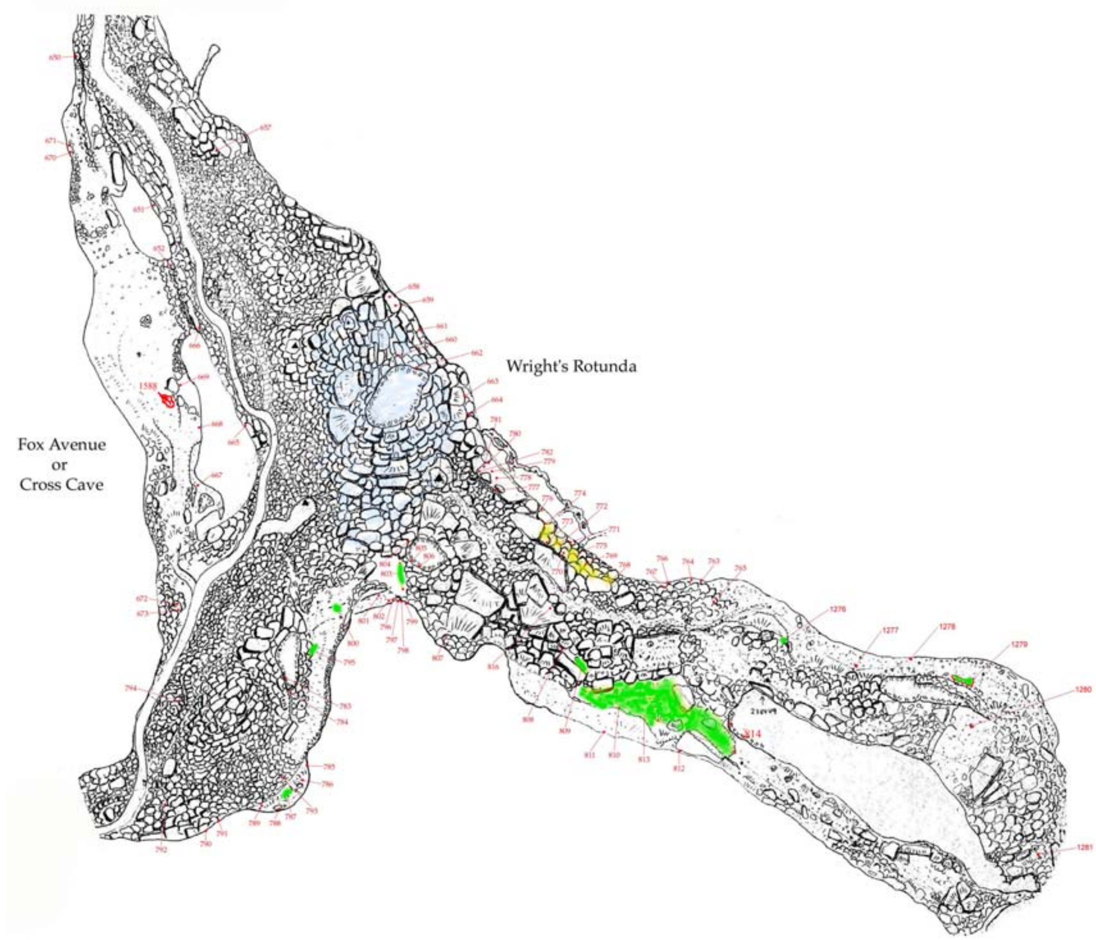

FIGURE 1-9. Trunk passage: area of Wright's Rotunda (base map cartography by CRF).

Only 6 data points were located in Cross Cave. Three are indeterminate bat bones, 2 are rat tracks and nesting material, and 1 is an area of bat stained ceiling.

Most of the ceiling in Wright's Rotunda is too high or too sooty for roosting stain to be evaluated. Stain was detectable on the overhanging wall of an undercut of the left side, near the first pillar in Wright's Rotunda. Bat guano is dispersed over the entire area, but notable accumulations occur at only 19 data points. Heavy tourist traffic over the years not only has left a lot of trash and soot, but also has destroyed much of the guano and purportedly large quantities of Indian artifacts. A few deposits of guano, some several inches thick, are protected in breakdown cavities.

Mummified Remains of 31 bats were found at 30 data points. The taxa and their ubiquity are as follows: *Corynorhinus* sp. (1 point), *Lasiurus borealis* (2), *Myotis* leibii (1), *M.* cf. *lucifugus* (1), *M. sodalis* (7), *M.* cf. *sodalis* (2), medium-sized *Myotis* (4), *Pipistrellus subflavus* (10), small bat (*Pipistrellus subflavus* or *Myotis leibii*, 1 point), and indeterminate Vespertilionidae (2). Additional bats identified from bone are *Eptesicus fuscus* (1), *Myotis grisescens* (2), and *Tadarida* sp. (1). *Tadarida* bone was found at a single point (791); however, the loose sediment that it was with does not appear to be in primary context.

Points 768-774 are located in a long narrow room created by huge breakdown slabs on one side and an anastomotic channel in actual cave wall on the other. A thin layer of bat guano pellets covers the floor and a few deep pockets of guano. The guano appears to be very old, but not of the "ancient" quality. Some areas of the floor are darker due to the mixing of guano and sediment. Point 768 is a hole in which three bands of brown colored guano are visible. The first band lies below 2 cm of soot-coated yellow sediment; the second, which is 4 cm thick and darker in color, appears to have two stripes of brown guano in it. It is underlain by 2 cm of yellow sediment. The third band is a thin dark brown stripe.

Point 774 is a thicker pocket of pellets having an accumulation of 6 inches. The guano was sampled in 1998 and two samples were submitted for radiocarbon dating. Twenty-nine grams of pellets were dated conventionally by GEOCHRON and yielded a date of 9,170 ± 130 RCYBP (GX24446). An accelerator mass spectrometry dating by Lawrence Livermore Labs returned a date of 8,460 ± 40 RCYBP (CAMS 63100). A dentary of *Myotis grisescens* and a few bones of indeterminate *Myotis* were on the floor of the room; some are orange in color.

In Wright's Rotunda near the southern edge and before the branch leading to the Big Chimney, is an extensive area with guano that has been tentatively attributed to free-tailed bat (cf. *Tadarida*). Within this area are an expanse of trampled guano (designated Point 813) and an *in situ* deposit with layers of dark brown guano (Point 814). Point 809 is a thin 4-foot long deposit of guano in orange colored sediments near (but not touching) the 813/814 complex. These guano deposits have been identified as cf. *Tadarida* based on their extensive nature and similar quality to known deposits at Chief City (discussed later in this report). The identification is very tentative (it could even be *Myotis grisescens*) because no bone was found associated with the *in situ* guano. The area of disturbed guano is approximately 27 meters long by 6 meters wide and consists of powdery, dark brown guano with several small spots of *in situ* guano. This fine sediment/guano, coated with soot in many places, is the color and texture of powdered cocoa (it billows up when stepped on). The guano is variously exposed from four inches below the surface. The powdery texture is the result of trampling that began with prehistoric Amerindian explorers.

Point 814 denotes an *in situ* deposit of dark brown guano that has retained a granular texture. The slab fell from the roof after deposition of the guano, thereby protecting it. From the edge of the limestone slab to four back, the deposit has been mined away. Originally, the deposit was a massive pile of unknown height. Degrading pellets from within the in situ layer(s) easily disintegrate when handled. A sample of the dark brown layer (assessed as dark reddish brown, 5YR 3/3, on the Munsell Soil Chart) returned an AMS date of 42,440 ± 720 RCYBP (CAMS – 63092). Minimally, the exposed guano deposit is 2 meters long and from top to bottom it exhibits the following profile (Figure 1-10):

- Soot covered, solid yellow-beige sediment circa 2 cm thick
- Cocoa-colored transition layer circa 2 cm thick (7.5YR 5/6, strong brown)
- Dark brown layer of guano that is 3 cm thick (5YR 3/3, dark reddish brown; assessment was same looking at vial of guano under incandescent light in laboratory)
- Whitish-colored layer that is 2 mm thick (10YR 8/2, white)

FIGURE 1-10. "Ancient" guano strata in Wright's Rotunda at Data Point 814.

Six other deposits of ancient guano (data points 787, 795, 800, 803, 1276, and 1279) were only identified as Chiroptera because they are small spots or thin exposures. Points 787, 795, 800, and 803 are smears or bands of ancient guano found in the vicinity of the second and third pillars. At Point 787 a 2.5 cm thick dark brown layer is visible in a hole that was dug (at some time in the past) into loose yellow-orange sediment on the ledge behind the third pillar in Wright's Rotunda. Point 795 is a patch of exposed guano that is a dark brown band in loose yellow sediment. Point 800 is brown guano that has been scuffed up by foot traffic on the ledge behind pillar #3 in Wrights. Point 803 is a band of old guano about 11 feet long at the base of the breakdown around the bottom of pillar #2. The guano is visible in a low area covered with loose yellow-orange silty sediment. Points 1276 and 1279 are located in the left branch going to the Small Chimney. At point 1276, ancient guano is exposed in a hole dug by someone prior to our study. The sequence from top to bottom in the hole is as follows: 1) upper portion consists of several thin bands of lighter brown guano; 2) yellow sediment layers that are not continuous; 3) dark brown guano pellets falling out of hole wall; and 4) yellow sediment at bottom of hole. From the top of the light brown guano layers to the bottom of the dark brown band is approximately 15 cm. The dark brown band of guano is circa 9 cm thick, still pelletized, not greasy looking; and is dotted with white spots (possible reaction with limestone pieces). Point 1279 is a 4-meter long stretch where a thin lens of ancient guano has been exposed (discontinuously) at the surface by foot traffic.

Signs of woodrat/rat (latrines, larders/nest, tracks, and runs) are present, but no bones, were found. Bat bones and seeds were extracted from one previously trampled human paleofeces.

Cataracts area (Potter Hall and the Cataracts) [27 data points: 674-685, 730-744]

Basically this area is the part of Main Cave that lies between the distal end of Wright's Rotunda up to the Bryan's Pass area; thus, it includes not only the Cataracts (points 674-685), but also Potter Hall (the constricted passageway before and after the Cataracts that has fractured walls and piles of shattered material (points 730-744).

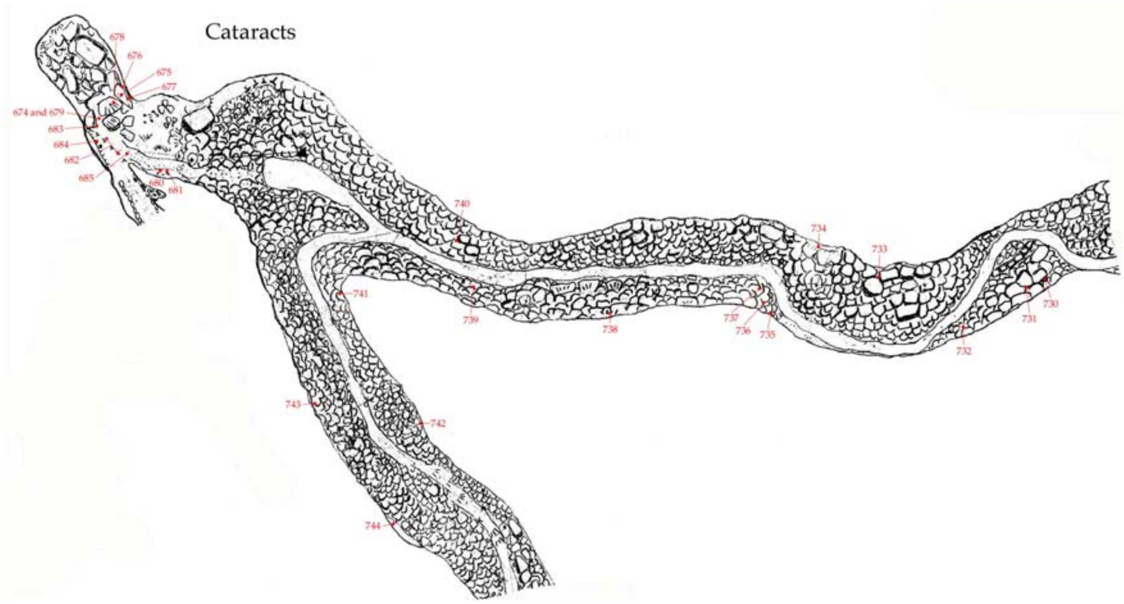

FIGURE 1-11. Trunk passage: area of Cataracts (base map cartography by CRF).

No roosting stain was detected in the entire area. Bat guano (noted at only four data points) and woodrat/rat bones, scratch marks, and latrines were found mainly in the passage segments, probably due to poor conditions for preservation in the Cataracts, itself. An entire skeleton of a *Neotoma* sp. was found in the shaft beyond the falling water. Mummified remains of an indeterminate bat and a fungus-covered *Lasiurus borealis* were present. Bones of *Eptesicus fuscus*, *Lasiurus borealis*, *Myotis sodalis* (multiple individuals), and medium-sized *Myotis* sp. were found in the 10 x 4 foot area designated as Point 682.

Bryan's Pass and Settle's Gorge [18 data points: 745--762]

This long, narrow section of passage lies between the Cataracts and Chief City. It produced a low density of relatively recent materials – no roosting stain, only 2 points with notable accumulation of guano pellets, four points with mummified bat remains (*Lasiurus borealis*, medium-sized *Myotis* sp., and Vespertilionidae), two points that are rat latrines, and one point with rat tracks. Curiously, four turtle bones were found at point 750.

FIGURE 1-12. Trunk passage: Bryan's Pass to Settle's Gorge (base map cartography by CRF).

The latter half of this segment (the end of Bryan's Pass and in Settle's Gorge) produced *in situ* materials of paleontological interest – bones of *Tadarida* occur in association with ancient guano deposits. Nine data points were flagged for *in situ* deposits of ancient guano. Three of these points also contain bones that could be identified to *Tadarida*. In Bryan's Pass guano can be seen as one or more thin layers of brown, often overlying a stripe of degraded white material. As one approaches Chief City the deposits of guano in Settle's Gorge become thicker; and, in the narrow passage at the base of Chief City, guano extends to both walls and is trampled by tours.

Data points 752, 756, and 759 yielded *in situ* guano and bones of *Tadarida*. A sample of sediment with bone was collected from each location. Point 752 is a 24-meter long area along the trail in which a medium brown stripe of old guano can be followed. *In situ* pockets with *Tadarida* bones occur at each end of the area. Interestingly, bone lenses have been preserved in place under roof fall. The sediment is beige in color (not the dark brown that is seen in most of the deposits of *Tadarid*a guano); however, it has a granular appearance (as from pellets). The *Tadarida* bones are brownish-orange in color.

Area 752a is the point closest to the Historic Entrance that has produced an *in situ* lens of *Tadarida* bone. Here, bones are located in sediment under a slab that has fallen from the ceiling, effectively protecting the bones. The sediment is not the chocolate brown of the Chief City deposit; rather, it is tan in color with a granular-looking texture, perhaps from guano pellets. Flecks of charcoal are in the surface sediments. The fossil bones are brownish-red/orange in color. *Tadarida* bones identified from this point are a rostrum, right maxilla, distal 3/4 of 2 right humeri, teeth, vertebrae, sternum, proximal right humerus, metacarpals, and sacrum. A piece of left dentary of *Myotis* lying on the surface is light colored, not dark like the free-tailed material. A sample of bones was collected from the sediment for identification at the labs. Among the bones identifiable to *Tadarida* were the following: humeri, left and right dentaries, maxillae, a rostrum, and a radius. Additional elements are a fragmented left dentary of *Pipistrellus* and hundreds of bones from indeterminate bat (e.g., wing elements, ribs, innominate fragments, vertebrae, sternebrae, maxilla fragments, loose teeth). Most of the bones are dark red-brown and a few are light colored, probably being more "recent." A return trip to Point 752 in 2000 produced *Tadarida* radii with incomplete fusion of the distal epiphyses. These elements from immature *Tadarida* are the first concrete evidence that Mammoth Cave once housed a maternity roost for the free-tailed bats.

Area 752b is a bone deposit at the far end of this flagged area just before Monument Hill, under a slab at trail level. Elements identified to *Tadarida* are a proximal humerus; right half of a rostrum, and a left scapula. Brownish colored bones that are most likely associated with the old deposit are a vertebral fragment, a finger bone, a scapula fragment, 2 proximal radii, and 2 distal radii. A bat radius is white in color.

Data location 756 is a seven-meter long crescent-shaped exposure, just before Monument Hill, where sediment and breakdown have been mined. A thin layer (s) of ancient guano is visible at each end of this demarcated area; and in between are *in situ* bones with a small patch of brown guano below them and rocks, above. Orange to brown colored bones were identified from loose sediment that had eroded out of the *in situ* deposit. Bone was identified to *Tadarida* (dentaries, a humerus, a femur with gypsum growing on distal end, and scapula fragment) and cf. *Tadarida* (wing fragments and auditory bullae).

Point 759 is a 5-meter long area along the right wall past Monument Hill where a layer of dark guano is visible in a sediment bank; the area has been dug for saltpeter dirt and/or for use as trail fill. The following were identified from loose sediment: *Tadarida* (left and right humeri, a left radius) and cf. *Tadarida* (radius and scapula).

Chief City [57 data points: 938-946, 1096-1140, 1143-1145]

Chief City is one of the largest rooms in Mammoth Cave. The floor is covered with so much breakdown that it effectively forms a hill; and, high overhead is an expansive breakout dome. Palmer (1981:167) writes that the large size of the room was possible because the breakdown rocks fell into a lower passage and/or were partly dissolved or transported by water. The tourist trail climbs up and over the pile to drop back to the original trail level. While the levels of the trail at each end of the Chief City breakdown pile are similar, the composition of portions of the Chief City trail sediment is quite atypical. It is chocolate brown in color, powder fine in texture, and is largely composed of trampled bat guano.

Since the late 1950s, the quarter mile long Pleistocene-aged guano deposit at Chief City (Davies and Chao 1959) has been Mammoth Cave's best-known paleontological site. Jegla (1961) and Jegla and Hall (1962) attributed the guano to *Tadarida brasiliensis* based on bones found in the deposit. Indeed, *Tadarida* dominates the remains flagged in this area of the study. Dark reddish brown (5YR 3/3 on the

Munsell Soil Color Chart) guano is visible over the entire midsection of the hill and has been disturbed by people traversing the area.

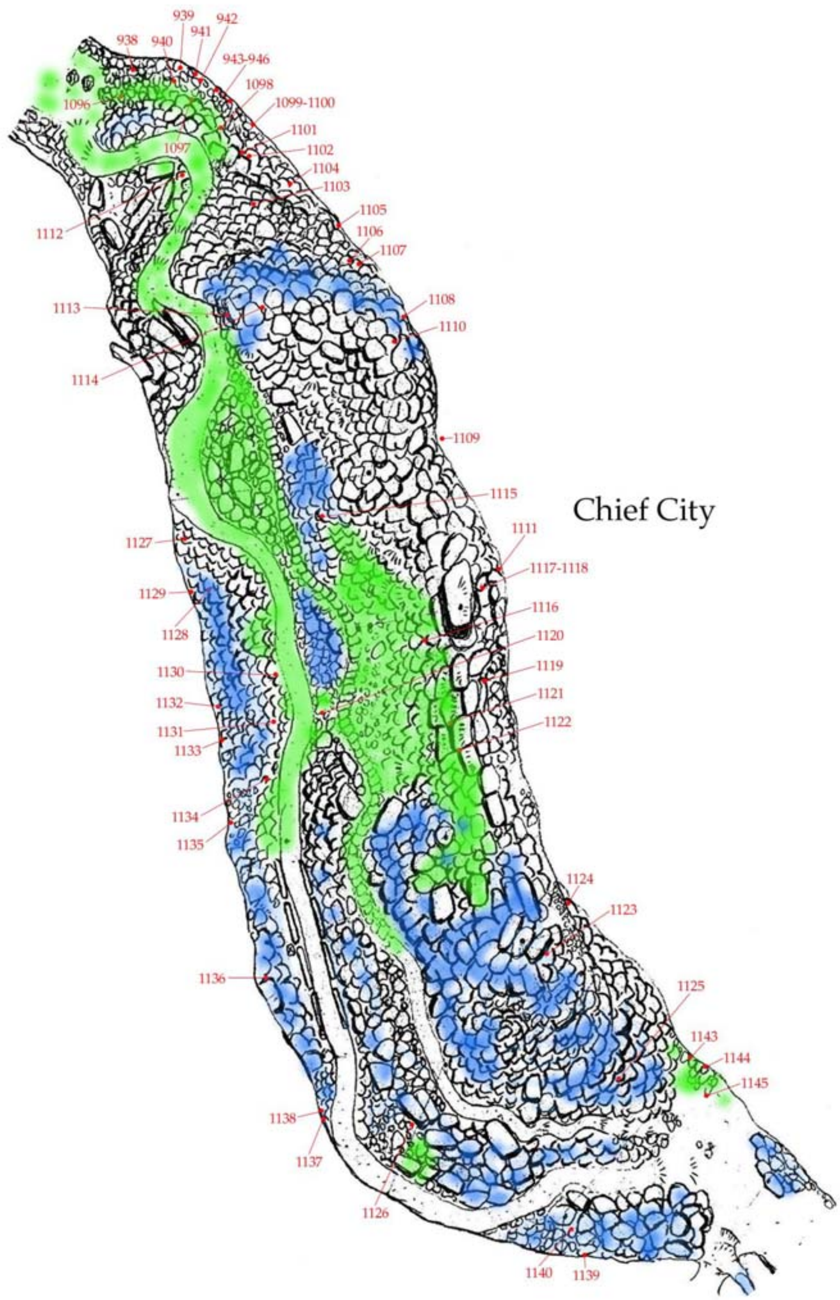

FIGURE 1-13. Trunk passage: Chief City (base map cartography by CRF).

The old guide trail and the modern tourist trail are literally composed of the chocolate-colored, pulverized guano. Masses of compressed dark brown, granular guano have been protected *in situ* under breakdown blocks (some masses have been broken loose and lie on the surface); and guano pellets that turn to powder when touched are sifting through breakdown at base level in the chamber (Figure 1-14).

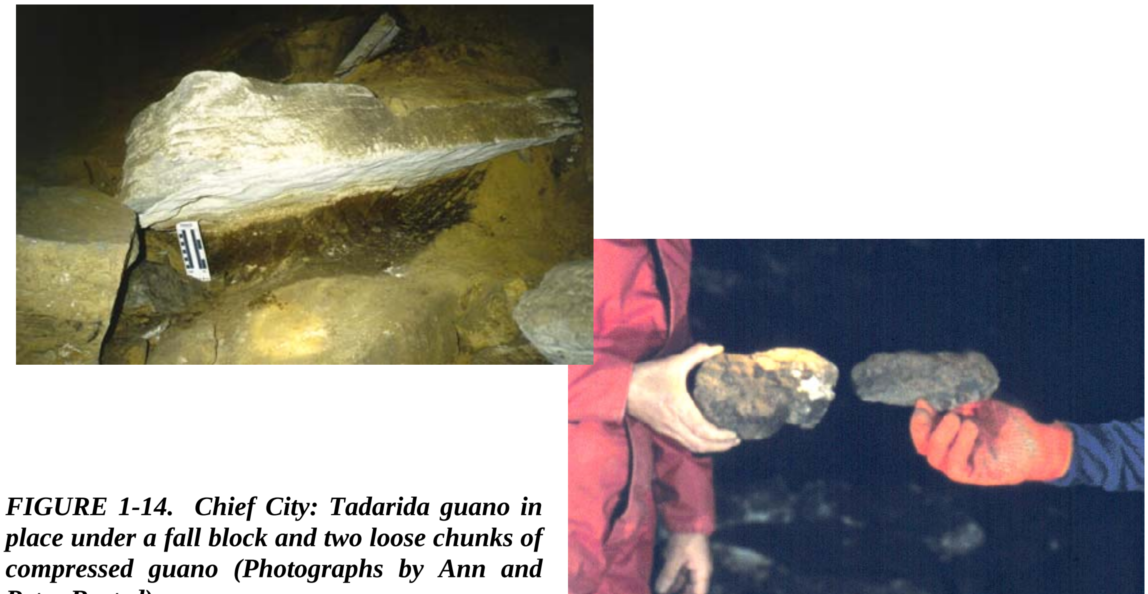

FIGURE 1-14. Chief City: Tadarida guano in place under a fall block and two loose chunks of compressed guano (Photographs by Ann and Peter Bosted).

Guano attributed to *Tadarida* is visible over the large expanse of Chief City and much of the chocolate colored, silty-textured sediment is actually guano or a guano/sediment mixture. Twelve accumulations of *Tadarida* guano were flagged to represent its different manifestations (*in situ*, eroding, compressed mass, pelletized) or to mark spots that appear to have been previously sampled. Four points have very old guano (either fragile light beige pellets or loose reddish-beige powder/sediment that was identified only as "Chiroptera or *Tadarida*" because the guano does not have the dark brown, massed appearance that is characteristic of *Tadarida*. Skeletal elements identified to *Tadarida* were found at 18 points, only two of which also had guano; in both cases the guano was loose and the bones were on the surface. *Tadarida* identifications were based only on the following elements: humerus, radius, scapula, dentary, and skull parts. Eight of the localities with *Tadarida* remains (data points 939, 942, 1101, 1104, 1117, 1118, 1129, and 1143-1145) are worthy of description.

Point 939 is a soot-coated beige-yellow sediment, containing bat bones. Because *Tadarida* elements were identified (left dentary, right humeri; left humerus, scapula) a small sediment sample was collected; it consisted of the following reddish-brown bones: *Tadarida* (5 partial left dentaries, 1 partial right dentary, 1 partial right maxilla), *Eptesicus fuscus* (1 partial left dentary), and *Myotis* sp. (left and right dentary fragments).

Point 942 is an *in situ* deposit of bat bone and beige-yellow sediment caught under a breakdown slab. Sediment is eroding out of the deposit. Five subsamples were collected from Point 942 based on their positions under the slab; numerous fragmentary bones and the following identifiable elements were present:

- 942a) subsample from under outer lip of the slab, the bones were pulled from the soot covered beige-yellow sediment:
    - Bat: radius and femur
    - *Tadarida*: cranial and postcranial material, including dentary fragments
- 942b) taken from *in situ* pocket of bone, which was directly under the left hand end of the slab
    - *Tadarida*: left and right dentaries, and fragmented scapulae, radii
- 942c) laminated silty sediment taken from same area as 942b; contained no bone
- 942d) bones pulled from sediment under rock; not from an *in situ* layer, but appear to have fallen out of such a pocket
    - *Eptesicus*: right dentary fragment
    - *Tadarida*: left and right dentaries, dentary, right radii, left and right humeri, and several postcranial and cranial fragments
- 942e) bones from *in situ* pockets, smashed under a fallen slab; some of protruding portions are sooty
    - *Tadarida*: left and right dentaries, left and right radii, left and right humeri
    - Bat: femur

Point 1101 is located near the base of the Chief City collapse, under a large breakdown block about 10 feet away from the left (north) wall. The feature is a hole that appears to have been sampled prior to the current study, perhaps by the Davies and Chao

(1959) study; bat metacarpals protrude from the walls of the hole and loose guano pellets are in the vicinity.

Point 1104 has lots of loose reddish-beige colored guano in a person-sized cavity under large breakdown blocks. Although it is not chocolate brown in color, the guano is very old, soot free, and the pellets disintegrate to powder when touched. It might be *Tadarida* guano with a dry, loose, tan colored, and pelletized condition (as opposed to the compressed dark brown, oily-looking guano masses) could be due to its having filtered through the breakdown rather than being compacted by years of accumulating guano. A partial skull (part of palate and orbit) of *Tadarida* was present.

Point 1117 is located between Sacrifice Rock and the left wall, down in a cavity under breakdown. The floor of the area is pulverized red-brown guano with some pelletization and it appears to be untrammeled. The deposit has a high degree of time averaging with several *Tadarida* bones being found on the surface along with archaeological torch material. All identifiable bone is dark reddish brown. *Tadarida* humeri and radii were easily spotted. A soot-coated *Tadarida* skull was on the surface and another *Tadarida* skull was found in the sediment guano mixture under pieces of breakdown. A sample of bone was collected; preservation is exceptional (even very fragile bones are preserved). Three partial crania, dentaries, radii, and humeri of *Tadarida* were collected, along with numerous bone fragments and complete small elements attributed only to bat.

Point 1118 is also located in the same breakdown cavity as Point 1117 and about 7 feet away. At this particular spot, bones (a right humerus of *Tadarida* and a left radius of bat) were found in a loose, powdery, red-beige guano-sediment mixture that is more than 18 inches deep.

Point 1129 is about 10 feet into a narrow crawl formed by breakdown located in an undercut of the right wall. Fragments of burned cane are on the surface. Here, red-brown to dark brown colored *Tadarida* bones were pulled from the beige-yellow sediment: left humerus, right radii, and pieces of maxilla, wing bones, humerus, and radius.

Points 1143-1145 lie within an area of deep fine-grained mixture of sediment and guano located at the distal end of Chief City at the base of the talus. In this low area ancient guano extends about 20 feet along the left wall and 10 feet out from the base of talus pile. The sediment-guano mixture is churned up and some bone is exposed on the surface. Visible throughout the area are patches of dark brown guano and an *in situ* deposit of guano pellets. Point 1145 lies at the far end of the mixture where sediment has been dug away, exposing a cut of a 4-foot high embankment in which two strata of *Tadarida* guano are visible about 2-4 inches below the top of the profile. Point 1143 is an *in situ* bone deposit that is exposed under a small overhang where the sediments have been dug away. The bone is red to brown in color and all appear to be from *Tadarida*: (parts of 2 skulls, a left dentary, humeri, and radii). Other elements found on the surface and pulled from loose sediment include numerous metacarpals, scapulae, and radii.

Bat roosting stain was not noticeable in Chief City. However, much of the ceiling that holds the Pleistocene-aged stain collapsed long ago; and, most of the current ceiling is so high that stained areas are not visible. A thin veneer of relatively recent guano pellets is present, particularly below the lower ceiling steps. Accumulations were noted at only 4 points. There is little doubt that various human activities carried out since the time of the first Native Americans (artifact fragments littering the floor attest to early visitation) have destroyed both ancient and modern guano.

The following mummified bat remains were found at 10 locations in Chief City: *Eptesicus fuscus* (1 point), *Myotis lucifugus* (2 points), *Myotis sodalis* (1 point), medium-sized *Myotis* (1 point), *Pipistrellus subflavus* (4 points), and indeterminate vespertilionid (1 point). *Myotis grisescens* was identified from a dentary. The non-bat remains are comprised of a chicken eggshell, cf. *Peromyscus* sp. dentary, indeterminate mouse footprints, and two woodrat latrines.

St. Catherine City area [35 data points: 1141, 1142, 1146-1176, 1178, & 1179]

At the southeast end of the Chief City breakdown pile, the trail descends to the level of the Main Cave trail. For the purposes of this report, the St. Catherine City *area* lies between the southeast end of Chief City and the USGS benchmark located near the base of the breakdown pile before Mummy's Ledge. Thus, the St. Catherine City area includes the narrow, sediment-floored passage at the base of Chief City; the breakdown pile known as St. Catherine City; and the low-lying, sediment-floored passage that lies just beyond the intersection of Main Cave and Blue Spring Branch and Blackall Avenue (parts of the same old higher-level passage.

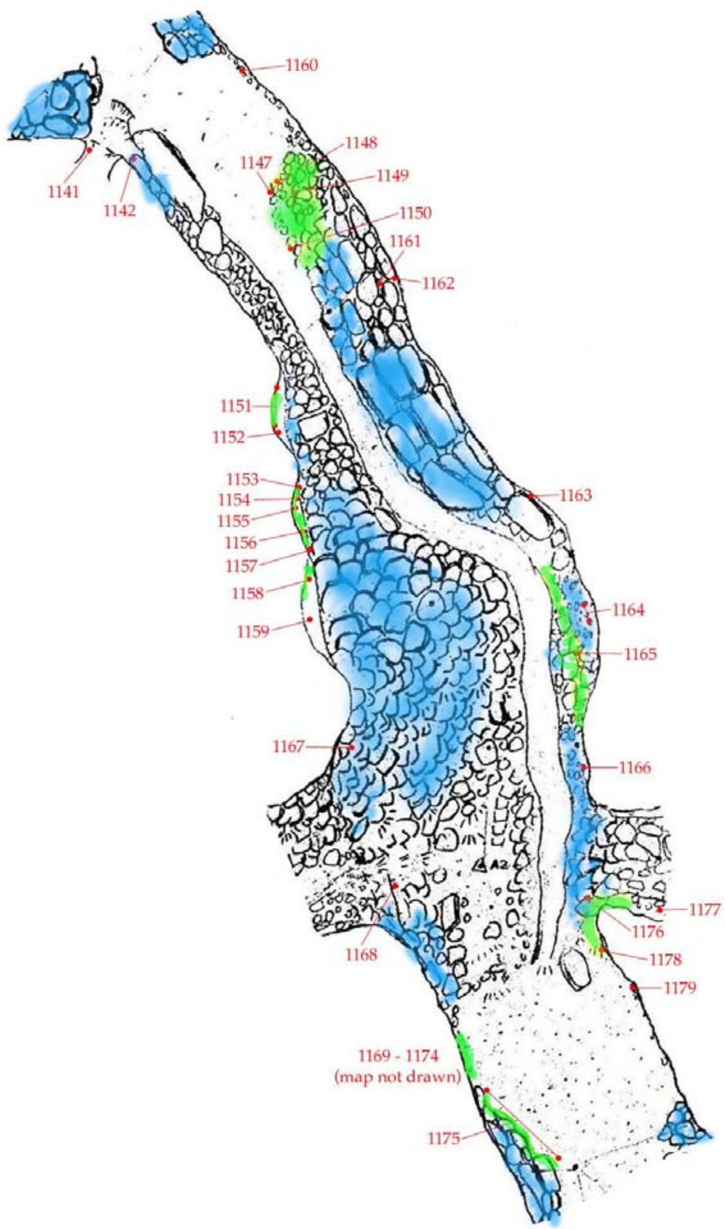

FIGURE 1-15. Trunk passage: area of St. Catherine City (base map cartography by CRF).

Roosting stain was absent and pellets of bat guano were thinly scattered over breakdown. Before human impact, the area may have had moderate to heavy amounts of bat guano as indicated by several patches of accumulated guano pellets. For example, an overhang at Point 1149 has protected an accumulation of soot-covered bat guano pellets from trampling. Another accumulation of old guano pellets has been protected by breakdown rocks along the left edge of the Main Cave trail at the bottom of the climb into Blue Spring Branch. Mummified bats were found at 2 data points: a medium-sized *Myotis* mummy hanging on the left wall and an odiferous *Pipistrellus subflavus*. Additional taxa identified from bone were *Eptesicus fuscus*, *Myotis* cf. *grisescens*, and small and medium-sized Myotis.

Bones and guano attributed to *Tadarida* have a sporadic presence; they were found in the following spots:

- *Tadarida* guano is visible at the beginning of the area where the tourist trail returns to its original level and the floor is characterized as being very dusty and has little breakdown.
- At the far end of the narrow passage where the trail begins to ascend to St. Catherine City, guano appears as dark smears in the floor and as small compressed chunks.
- Another spot is in a series of three alcoves in the right wall between data points 1151 and 1159.
- Points 1151 and 1152 mark the two ends of a 10-foot long stripe of *Tadarida* guano, which is located in one of the small alcoves. Here also are dark reddish-brown *Tadarida* bones lying loose on the yellow-beige sediment; they probably derived from a 30-inch long *in situ* deposit of bone.
- Points 1169-1174 denote an 18-foot long area where 12-18 inches of sediment has been removed (based on a sediment line above the current floor level), revealing a profile of *in situ*, discontinuous lenses of guano and bones of *Tadarid*a, *Myotis*, *P. subflavus*, and *E. fuscus*.
- Point 1175 is a 20-foot long and circa 3-foot high embankment of fine, silty sediment; which is porous and old, but becomes powdery when scraped or trampled. Mining in the bank of sediment has exposed a thin *in situ* layer of pelletized, reddish-brown guano with an accompanying white strata near the top. This layering was observed only at the uppermost level of the embankment about 1-2 inches below the orange-beige sediment.

> The surface is littered with loose red-brown colored bat bones that are sliding down slope. At least some are *Tadarida* (radii fragments and a left humerus).

A few non-bat remains were found at 8 data points in the area of St. Catherine City. Two points had chicken bones, the result of historic-aged activities. A dentary of cf. *Peromyscus* sp. and another dentary and track of a mouse-sized rodent were present. Three points had signs (tracks, bone, and an old latrine) of *Neotoma floridana*.

Waldach Dome to Hain's Dome [24 data points: 1180-1203]

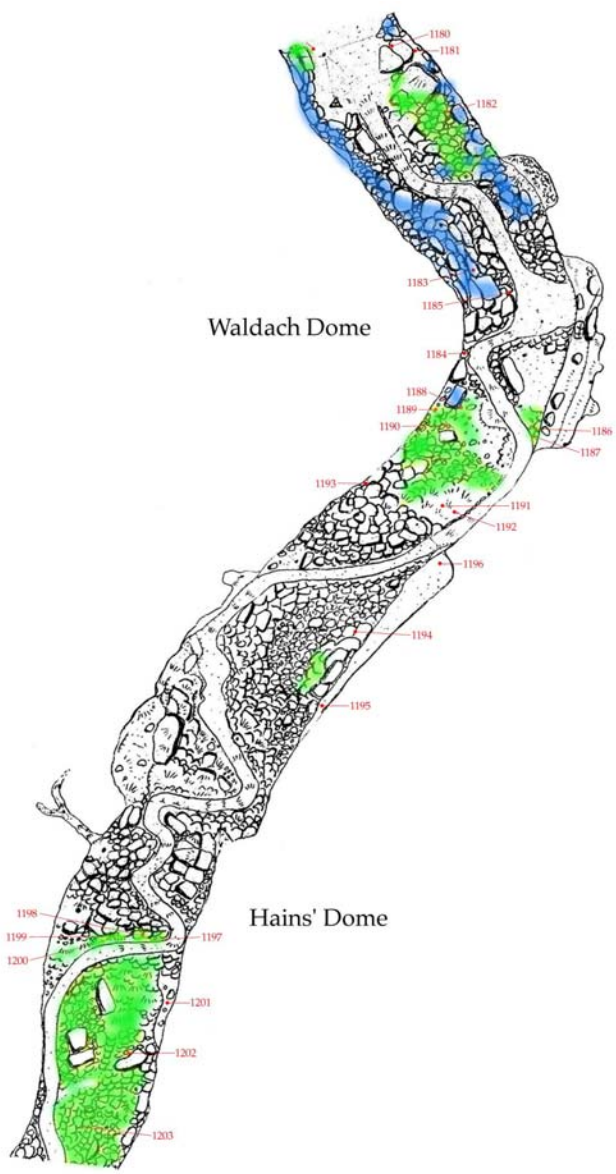

FIGURE 1-16. Trunk passage: Waldach Dome to Hain's Dome (base map cartography by CRF).

The main geological features characterizing this section of passage are two large talus piles that are associated with breakout domes – Waldach Dome and Hain's Dome. Preceding and following each pile are low areas with fine, cocoa-colored mixtures of sediment and pulverized ancient guano. Waldach Dome has a greater exposure of ancient guano. In the 1930s, the resources at Waldach Dome were subject to extreme trampling during the efforts to recover Lost John's mummified body from beneath a six-ton block of limestone. Piles of nails, cardboard from light bulbs, flash bulbs, metal cable, and other debris are testaments to the construction of wooden scaffolding, hoists, and photography. As is the case in Chief City, the tourist trail impacts ancient guano.

Holocene-aged bat bones were scarce. Relatively modern bat guano pellets, rat feces, and three mummified bats (*Lasiurus borealis*, medium-sized *Myotis*, and indeterminate bat) were found amongst the breakdown. However, remnants of ancient guano were widespread. *In situ* deposits of ancient guano were found only in low-lying segments of the passage and aggregations have the characteristic deep brown colored, semi-pelletized appearance observed in Bryan's Pass, Settles Gorge, and Chief City. Trampled guano quickly transforms to a fine powdery dust that looks like rich cocoa powder. The ancient guano has been identified as *Tadarida* based on the presence of *Tadarida* bones in this segment of cave, some associated with guano.

Sixteen data points have distinctive *in situ* bands or chunks of guano and five data points yielded reddish-brown colored *Tadarida* bones. The following are the major areas with Tadarida guano in this segment of passage:

- *Tadarida* guano is present in the low areas that precede the climb up to Waldach Dome and Mummy Ledge.
- Guano and bone occur in the low-lying area below Mummy Ledge, to the right side of the tourist trail. Despite much disturbance, remnants of dark brown masses of guano, some up to 7 inches deep, are preserved under breakdown where it has lain protected.
- Stripes of guano along the hilly trail that climbs over the Hain's Dome talus.

- The sediment in the low area between the base of the talus and the beginning of the narrow passage known as Mayme's Stoop is composed of chocolate brown powder that is pulverized ancient guano; no pellets were observed.

Skeletal elements identified to *Tadarida* were found at the following five data points:

- Point 1180 – Guano and reddish-brown colored *Tadarida* bones (6 left radii, several broken radii; 1 right humerus) near surface in very light brown sediments located under a large block of breakdown; small sporadic patches and smears of brown guano are nearby.
- Point 1181 – Very light brown sediment with *Tadarida* radius and humerus located under breakdown; no guano was visible; the bones are reddish-brown.
- Point 1189 – Loose bones in a brown guano/sediment mixture were found at top and middle of the 20-foot long embankment; undisturbed guano is still pelletized, but disintegrates easily; numerous fragments of brown colored bone; 2 right dentaries, 1 left dentary, 2 right radii identified to *Tadarida*
- Point 1190 – A sizeable chunk of ancient brown guano that measures 7 x 5 x 5 inches and loose bat bones; surrounding guano/sediment mixture is brown, and old guano is plastered under a rock; *Tadarida* elements are radii and humeri
- Point 1195 – Reddish-brown colored humerus of *Tadarida* lying on small limestone chips

Mayme's Stoop to Ultima Thule [25 data points: 1204-1228]

With a low ceiling and narrow passageway, Mayme's Stoop is a tunnel-like passage between two large rooms, the area of Hain's Dome and Anzer's Hall. As the name suggests, one has to stoop at times to walk through Mayme's. Neither roosting stain nor recent pellets of bat guano were observed in this section. The mummified remains of 4 bats were found at 1 point in Mayme's (*Myotis lucifugus*) and 3 points in Anzer's Hall (*Eptesicus fuscus*, and *M. sodalis*, and *M. sodalis* or *lucifugus*). Other taxa represented by bones were *M. leibii* and an indeterminate *Myotis*.

Two paleontological finds are significant in this section of Main Cave. One, is that *Tadarida* may have had minor roosts in Anzer's Hall. A 60-foot long stretch of light cocoa-colored, powdery sediment occurs on breakdown between the tourist trail and the

FIGURE 1-17. Trunk passage: Mayme's Stoop to Ultima Thule (base map cartography by CRF).

left wall; it has been labeled as ancient guano. The powered guano appears to have been dispersed by the impact of very large slabs of limestone that fell from the ceiling. In addition, *in situ* remnants of extremely compressed ancient guano are visible as dark brown stripes located at several spots. These pockets can be seen sporadically for about 10 feet under the large rock slabs. No doubt the deposit was originally contiguous and has been truncated by the limestone slab. Because the deposit is located under a huge slab of old roof fall, and is not surficial, its accessibility and visibility are reduced making the deposit difficult to locate for the untrained eye. In order to collect a small vial of the guano from Point 1214, which was so fine, compressed, and hard, it had to be scraped with a spoon in order to be retrieved.

Because no bone was found in association, this ancient guano has been tentatively identified to *Tadarida*. However, several nearby data points support the possibility that the guano derived from *Tadarida*. Near the beginning of Mayme's Stoop ancient guano is being exposed by foot traffic on the tourist trail. A fluffy guano/sediment mixture and a possible *Tadarida* humerus were found at several points in the undercut right wall, below breakdown slabs in Mayme's Stoop. Finally, the adjacent area of Hain's Dome is a known *Tadarida* roost. A *Tadarida* humerus was found at point 1228 in the undercut of the left wall at Ultima Thule; however, it is clearly a secondary deposit -- no guano is nearby, it was on the surface, and it could have easily been transported by a cave crawler (rodent or human).

The second interesting paleontological resource inventoried in the Mayme's Stoop to Ultima Thule section of Main Cave, is a concentration of mouse bones and numerous bat bones from multiple individuals located on a ledge of the left wall in Anzer's Hall just before Ultima Thule (data points 1219 and 1220). Some of the animals may have been caught in a crack in the wall where the limestone has since spalled, revealing the bones. The bone is friable and breaks easily when handled for taking measurements. At least five left dentaries of *M. leibii* and several bones of *E. fuscus* are in the assemblage.

Signs of *Neotoma* included feces, found at two points and bone, at one point. Bones of mouse-sized rodent, possibly *Peromyscus* sp., were noted at two data points. Fragments of chicken eggshells were found in Mayme's Stoop and Anzer's Hall.

Ultima Thule to Violet City [43 data points: 1229-1271]

This section of Main Cave includes the crawl through/under Ultima Thule (known as the Kaemper Connection), Kaemper's Hall, Elisabeth's Dome (and several small dome/pits such as Wells' Dome and Lena's Dome) and Violet City. Small amounts of *Neotoma* feces were seen at 4 data points; however bat roosting stain, bat guano, and mummified bat parts were not detected. This is not surprising because moist conditions in a series of large rooms, dome pits, and wet shafts would not be conducive to long-term preservation of organic matter. Much of the bone was brittle due to loss of organics.

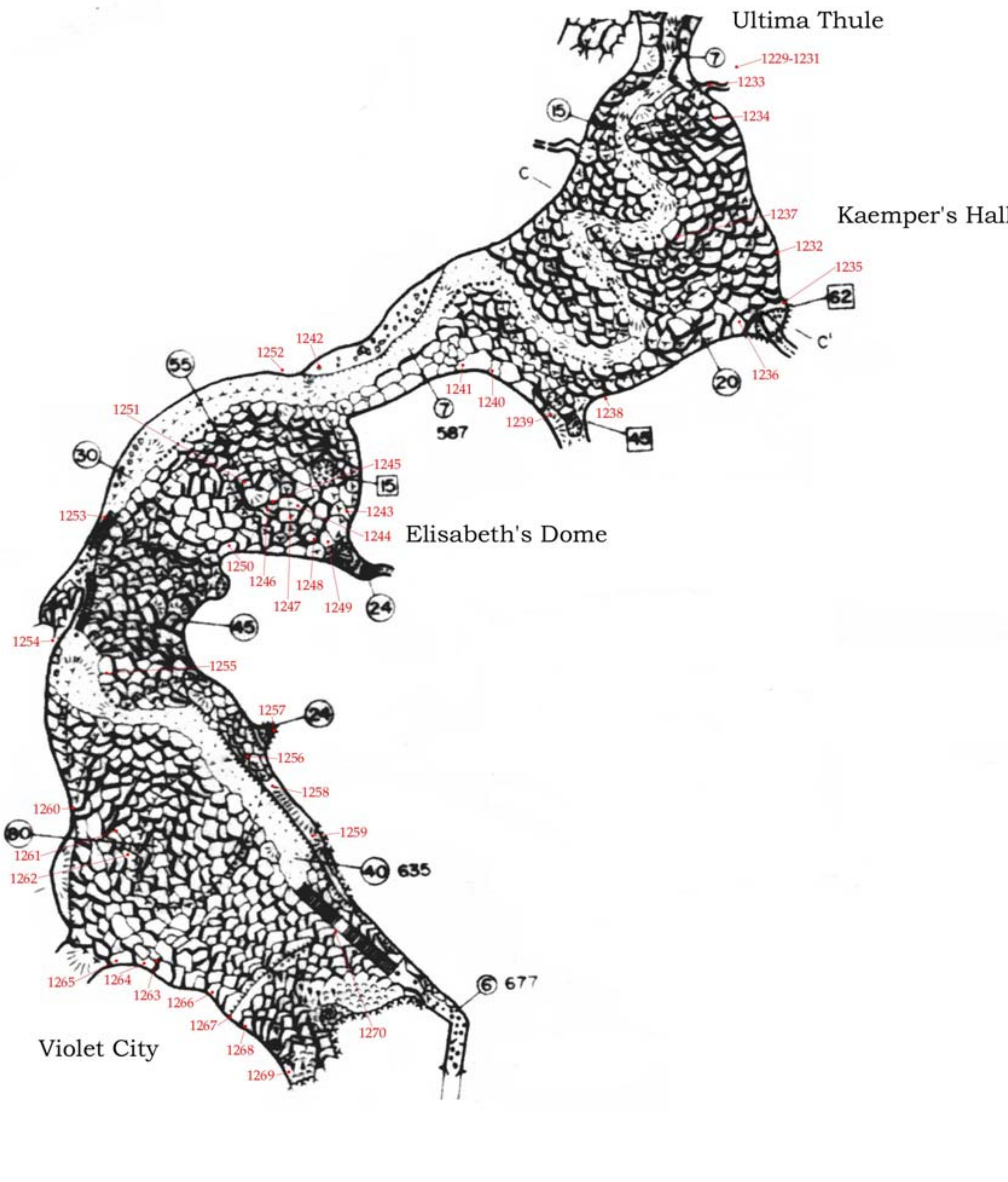

FIGURE 1-18. Trunk passage: Ultima Thule to Violet City (base map cartography by CRF).

Between Ultima Thule and Violet City, the most commonly found bat remains were *Eptesicus fuscus* (16 data points, including tentative identifications) and *Myotis leibii* (9 points). They were found at the same locations and sometimes more than one individual was represented. Data points 1230, 1235, 1240, 1241, and 1248 yielded assemblages with multiple individuals, and all had bones of both *E. fuscus* and *M. leibii*. Also represented in the segment of Mammoth Cave are *M. grisescens*, *M.* cf. *lucifugus*, *M. sodalis*, and *P. subflavus*.

Non-bat taxa were *Mephitis mephitis* (eastern skunk), *Sciurus* sp. (tree squirrel), *Neotoma floridana*, *Peromyscus* or mouse, and small bird (Passeriformes). The left 3rd upper incisor of *Mephitis mephitis* was found in a *Neotoma* activity area, located in an anastomotic tube above the trail. The accumulation also included bat, mouse, and *Neotoma* bones and feces. A live *Neotoma* and an active nest were seen next to the Violet City staircase.

TABLE 1-2. Vertebrate remains found in segments of two major Mammoth Cave trunk passages, Audubon Avenue and Main Cave. Cells contain the number of data points at which each taxon was located. Total number of data points for each section appears in parentheses.

Taxon	***Audubon: Rotunda to Bunker Hill (140)***	***Rotunda to Acute Angle (96)***	***Acute Angle to TB Huts (32)***	***Star Chamber to Proctor's Arcade (123)***	***Proctor's Arcade to S-Bend (50)***	***Area of Wright's Rotunda & Cross Cave (81)***	***Cataracts area (27)***	***Bryan's Pass & Settle's Gorge (18)***	***Chief City (57)***	***St. Catherine City (35)***	***Waldach Dome to Hain's Dome (24)***	***Mayme's Stoop to Ultima Thule (25)***	***Ultima Thule to Violet City (43)***
MAMMALIA													
Desmodus stocki													
Eptesicus fuscus	11	5		2	1		1		1	2		3	13
cf. Eptesicus fuscus	1	3				1						2	5
Lasiurus borealis	1	4	1	1	1	2	1	1			1		
cf. *L. borealis*		2											
cf. *L. cinereus*													
cf. *Lasiurus*													
Myotis grisescens	1	3				1			1				1
M. cf. *grisescens*	5	2	1			1				1			
Myotis leibii	1	4		1		1						1	9
M. cf. *leibii*	4	2		1	1								
Myotis lucifugus		2	1	11	1				2			1	
M. cf. *lucifugus*				7		1							1
Myotis septentrionalis					1								
Myotis sodalis	2	1	1	15	13	9	1		1			1	2
M. cf. *sodalis*		1		5		2							1
Myotis lucifugus or *sodalis*	2	2	2	11		2						1	
M. sodalis/small *grisescens*				1									
Myotis sp., small-sized	1									1			
Myotis sp., medium-sized	47	13	1	9	5	6	2	2	1	1			2
Myotis sp.	5	2		1		1			8	3	1	1	8
cf. *Myotis* sp.	2	5		1	1								
Pipistrellus subflavus	5	9	4	5	13	10			4	2			1
cf. *Pipistrellus subflavus*	2	1		2		2							
Pipistrellus or *M. leibii*		1		1		2							
Corynorhinus sp.		2				1							
cf, *Corynorhinus* sp.		1											
Vespertilionidae	123	58	17	82	11	37	15	1	1				25
Tadarida sp.						1		9	29	19	18	2	

Taxon	***Audubon: Rotunda to Bunker Hill (140)***	***Rotunda to Acute Angle (96)***	***Acute Angle to TB Huts (32)***	***Star Chamber to Proctor's Arcade (123)***	***Proctor's Arcade to S-Bend (50)***	***Area of Wright's Rotunda & Cross Cave (81)***	***Cataracts area (27)***	***Bryan's Pass & Settle's Gorge (18)***	***Chief City (57)***	***St. Catherine City (35)***	***Waldach Dome to Hain's Dome (24)***	***Mayme's Stoop to Ultima Thule (25)***	***Ultima Thule to Violet City (43)***
cf. *Tadarida*, "ancient" guano						3		2	2	2		4	
Chiroptera "Ancient" guano						12			4			3	
Chiroptera								4	24	15	5	6	
Procyon lotor	82	22		7									
cf. *Mephitis mephitis*													1
cf. *Canis* sp.		1											
Sus scrofa		3											
Odocoileus virginianus				1									
Bos taurus or *Sus scrofa*				1									
Artiodactyla		2		1									
Marmota monax													
Sciurus sp.			1	2									1
Neotoma sp.	1	1		1			1						4
cf. *Neotoma* sp.				2									
Rattus or *Neotoma*			2		3	14	10	3	2	3	2	3	6
Peromyscus sp.	1	1	1									1	1
cf. *Peromyscus* sp.									1	1			
Pitymys pinetorum	1												
Mus musculus				1									
Rodentia, mouse-sized	2	1							1	2		1	11
Rattus sp.	1												
Rodentia, rat-sized	16	9											
Rodentia				3									
Sylvilagus sp.				1									
Homo sapiens			2	8	2	1							
Mammalia, medium to large		1											
Indeterminate mammal													
AVES													
Gallus gallus	1	5	6	1	1				1			2	
Phasianidae			1		1					2			
Meleagris gallopavo				1									

Taxon	***Audubon: Rotunda to Bunker Hill (140)***	***Rotunda to Acute Angle (96)***	***Acute Angle to TB Huts (32)***	***Star Chamber to Proctor's Arcade (123)***	***Proctor's Arcade to S-Bend (50)***	***Area of Wright's Rotunda & Cross Cave (81)***	***Cataracts area (27)***	***Bryan's Pass & Settle's Gorge (18)***	***Chief City (57)***	***St. Catherine City (35)***	***Waldach Dome to Hain's Dome (24)***	***Mayme's Stoop to Ultima Thule (25)***	***Ultima Thule to Violet City (43)***
cf. *Meleagris gallopavo*				1	1								
Otus asio					1								
cf. *Colaptes auratus*			1										
Passeriformes													1
Indeterminate bird			1	3									
REPTILIA													
Testudines								1					
Serpentes			1										
AMPHIBIA													
cf. *Cryptobranchus* sp.													
Caudata													
Bufo sp.													
cf. *Rana* sp.													
Anura				1									
Indeterminate Amphibia													
cf. Amphibia													
Herpetile			1										
Fish or salamander													
OSTEICHTHYES													
Catostomidae or Carp		1											
Centrarchidae		1											
Unknown Fish		1											
Indeterminate vertebrate				1	1								

PART II: FAUNAL RESOURCES IN SIDE PASSAGES OF THE MAIN TRUNK

This section of the report describes paleontological resources found in side passages that intersect the mainline trunk passage of Historic Mammoth Cave. Table 1-3, showing taxonomic ubiquity for each side passage, appears at the end of the passage descriptions. The following side passages are summarized in this portion of the results:

- Houchins' narrows [121 data points: 819-936, 947-949]
- Little Bat Avenue [34 data points: 315-332, 357-372]
- Lookout Mountain [152 data points: 951-1095, 1574-1580]
- Bunker Hill to Olive's Bower [96 data points: 1-18, 20-43, 47, 49-71, 74, 76-86, 88-102, 173, 263, 264]
- Corkscrew and Vanderbilt Hall [29 data points: 237-262, 1273-1275]
- Backsliders' Alley [39 data points: 333-348, 387-408, 566]
- Gothic Avenue [133 data points: 937, 1364-1385, 1403-1512]
- Cyclops Gateway [55 data points: 423, 818, 1521-1573]
- Indian Avenue [7 data points: 495-501]
- Solitary Cave [43 data points: 686-728]
- Black Chambers [74 data points: 1282-1354, 1363]
- Blackall Avenue [6 data points: 1360-1362, 1518-1520]
- Blue Spring Branch [6 data points 1177, 1355-1359]

Houchins' Narrows [121 data points: 819-936, 947-949]

Modern tourists may think of Houchins' Narrows as being the beginning of the Cave because that is where they start the Historic Tour. However, Houchins' Narrows was actually formed later than Audubon Avenue as a diversionary route for water flowing from Broadway/Main Cave to the Green River (Palmer 1981:156). In historic times Houchins' Narrows was reported to have been a stoop walk. In the early 1800s, the black slaves who mined saltpeter cleared the right side of Houchins' Narrows. They made a walking-height passage with a packed clay floor that accommodated miners, oxen, carts, and two wooden pipes that carried water into the cave and leachate to the surface. Even after modifications to accommodate mining, descriptions let us know that Houchins' Narrows was still much smaller throughout the 1800s than the 8-foot high by 20-foot wide corridor that accommodates the present-day tourists. Blane (1824:266) described the entrance passage as "very narrow, and so low, that I was obliged to stoop to avoid knocking my head against the roof." In 1841 *The American Magazine* (Anonymous 1841:89) reported, "The cavern now becomes smaller and smaller unto the Gullet where it is only 4 ½ feet high by 8 wide." In 1844, Meriam wrote that the "opening is in the solid rock, and is about [4] feet wide" (Meriam 1844:317, width correction on page 328). Cave guide, William Garvin, warned his visitors of the low clearance:

> "Danger overhead! Gar' a' la tete!" This produces an instantaneous effect, and we all duck our heads to escape a ponderous mass of rock only an inch or two above us. William remarks sententiously, "It's g'inst the rules for visitors to knock out the ceiling with their heads…"
>
> (Johnston 1892:447-448)

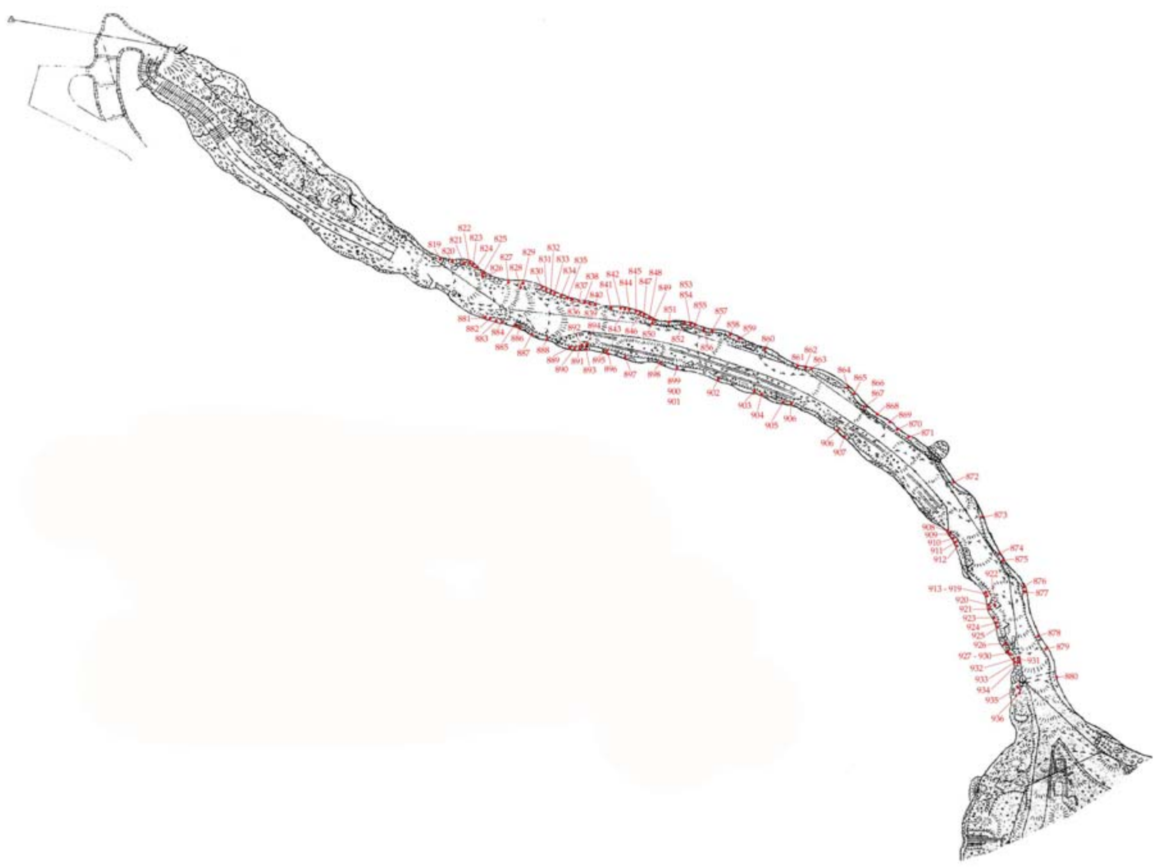

FIGURE 1-19. Side passage: Houchins' Narrows (base map cartography by CRF).

Johnston (1893:14) found Houchins' to be "nearly blocked by piles of loose stone, stacked along the walls by the saltpeter miners to clear the other avenues for their work. Hovey (1912: 23) wrote that "the walls are close on either hand and the roof is so low that one must stoop as he passes along. … On either side the loose rocks have been piled in compact manner, leaving a narrow passage of but a few feet in width." De Paepe (1985:12) reports that miners stacked rocks such that "At one time, continuous walls spanned the distance from Houchins' Narrows into the Rotunda." In the 1930s, the CCC worked in Houchins' Narrows during their efforts to ready the cave for National Park status.

The historic accounts are very important for their characterization of the early passage. From the descriptions, one would not expect to find fossil remains in an area, which had undergone so much modification. Thus, it was quite surprising that the Paleontological survey located identifiable remains at 121 points. Several data points are *in situ* bone deposits. A few are sediments containing bat bones packed tightly into horizontal crevices in the wall. These deposits are paleontologically significant because they are probable indicators of pre-modification floor levels. Most of the *in situ* deposits are three to four feet higher than the present floor level, suggesting that the passage may have been only about three feet high along the walls. This seems shorter than Blane's stoop-height passage in 1824 and the *American Magazine*'s 4.5-foot high passage in 1841.

Skeletal remains were identified to the following bat taxa: *Corynorhinus* sp., *Eptesicus fuscus*, *Myotis* sp., medium-sized and large-sized myotis, *M. grisescens*, *M.* cf. *leibii*, *M.* cf. *lucifugus*, *M. sodalis*, and *Pipistrellus subflavus*. Mummified remains were identified to *Corynorhinus* sp., *P. subflavus*, and indeterminate bat. Ceiling and wall stain are absent and there are no accumulations of bat guano; however, one small area has hundreds of tiny scratches (attributed to bats).

Non-bat taxa were Anura, cf. *Gallus gallus*, *Neotoma floridana* (fecal pellets, midden areas, and bones of a juvenile *Neotoma*), mouse, and *Tamias striatus*. The most commonly encountered non-bat taxa was raccoon, represented by scats. Carnivore scat (not noticeably of raccoon) containing bat bones was recorded at one point.

In 1997 George Crothers (1998) excavated test units in Houchins' Narrows. Colburn assigned data point numbers to Crothers' excavated samples (Test Units A7, A8, and C3 are Paleo Data Points 947, 948, and 949, respectively); sorted and identified the bones, and included them in the Paleontological Inventory Project tallies. Crothers' excavations are interesting because they suggest that the pre-modern floor contains a substantial amount of faunal debris. Data Point 947 (Test Unit A7) lies within the Houchins' Narrows Pipe section; it produced shell fragments of gastropod and pelecypod, a fish dentary tentatively referred to redhorse (cf. *Moxostoma*), bone shaft fragments of a bird or mammal, ribs of a very small mammal; and many elements of indeterminate bat, big brown bat, red bat (*Lasiurus borealis*), and many elements of myotis and little brown or Indiana bat (*M. lucifugus* or *sodalis).* Data Point 948 (Test Unit A8) is also from within the Houchins' Narrows Pipe section; it yielded numerous elements of unidentifiable bat, cranial elements of *Myotis* sp., a dentary referred to small-footed myotis (*Myotis* cf. *leibii*), cranial elements of little brown or Indiana bats, and a humerus of a possible pipistrelle. The following taxa were identified from remains excavated from Data Point 949 (Test Unit C3) located at the Houchins' Narrows/Rotunda intersection: gastropod shell, a catfish (Ictaluridae) spine, a possible redhorse (cf. *Moxostoma* sp.) maxilla, indeterminate fish, frog or toad bone, elements of very small bats (these could be small-footed myotis or eastern pipistrelle), big brown bat, myotis, more than a thousand fragments of indeterminate bat, mouse, incisor, and indeterminate mammal elements. The non-cave dwelling fauna are probably food debris from raccoons, Native Americans, or possibly early Euro-Americans.

Because Houchins' Narrows has undergone such radical changes, it was surprising to find so many faunal remains. The remains were found protected in sediments on ledges and in wall cracks. A Myotis humerus from a bone-laden sediment dated to 9810 ± 50 RCYBP (CAMS 63091), reflecting bat usage in early Holocene times. The diversity of bat taxa in Houchins' Narrows reflects its functional diversity as a flyway, temporary roost, and swarming locale. Because the Historic Entrance has been a major entrance in Pleistocene and Holocene times, Houchins' Narrows has been a flyway for nearly all of bats that roosted in Mammoth Cave, particularly bats seeking hibernacula near the Historic Entrance. During the earlier Pleistocene times, bats may have accessed passages via now collapsed sinks. Faunal evidence shows that Houchins' Narrows may have been a winter roost for *Eptesicus fuscus* and *Myotis leibii*. Several taxa many have used Houchins' Narrows for non-winter, occasional day roosting (during the course of this study, many live *P. subflavus*, one *M. sodalis*, and one *M. leibii* were observed in this passage). The entrance would also have been a swarming site. Numerous bone-filled raccoon scats, coupled with the lack of ceiling stain and guano in the Narrows, support the idea that raccoons were hunting bats further inside the cave, and perhaps catching bats as they flew down the constricted passageway. Because the flyway was much more constricted in prehistoric times, this would have been a successful foraging strategy.

Little Bat Avenue [34 data points: 315-332, 357-372]

Little Bat Avenue is a side passage off of Audubon Avenue that was once noted for its large population of hibernating bats. This is reflected in the passage name and in the early visitor accounts. In the 1840s, Bullit (1845:18) wrote the following in *Rambles in the Mammoth Cave during the year 1844*: "The Little Bat Room Cave ... is remarkable for its pit of two-hundred and eighty feet in depth; and as being the hibernal resort of bats. Tens of thousands of them are seen hanging from the walls, in apparently a torpid state, during the winter, but no sooner does the spring open, than they disappear." Fifty years later, Hovey and Rhoads affirmed that bats were still hibernating in the passage. Hovey (1896:76) noted, " Here myriads of bats take up their winter quarters, congregating for the purpose from all the region around. Deposits of bat-guano abound…." Rhoads provided a more scientific description of hibernating *Vespertilio lucifugus* [old nomenclature for the taxon that included bats now known as *Myotis lucifugus, M. sodalis*, *M. austroriparius,* and possibly *M. septentrionalis*].

> In a low, wide passageway (Little Bat Avenue), about one-fourth of a mile from the entrance to the cave, I found a cluster of little brown bats, which hung like a swarm of bees from a hollow space in the ceiling, just above the level of my head as I stood on the floor. The circular space covered by them was about 18 inches in diameter, and from this were suspended, head downward, nearly 150 bats in a compact, conical mass, several layers deep.
>
> (Rhoads 1897:59-60)

In 1912, Hovey (1912:25) again noted colonies of hibernating bats in Little Bat Avenue, "named for the myriad of bats which in winter may be found here."

The Little Bat Avenue of today shelters no hibernating bats and houses none of the deposits of bat-guano noted by Hovey. In fact, the passage floor and ledges appear to have been swept clean – no doubt the result of 200 years of mining and tourism. Amid the bubble gum, flash bulbs, and other modern debris, only 34 data points (315-332 and 357-372) were located in this once-favored hibernaculum. Extensive ceiling stain and raccoon scats are the only physical testament to the passage's heavy and

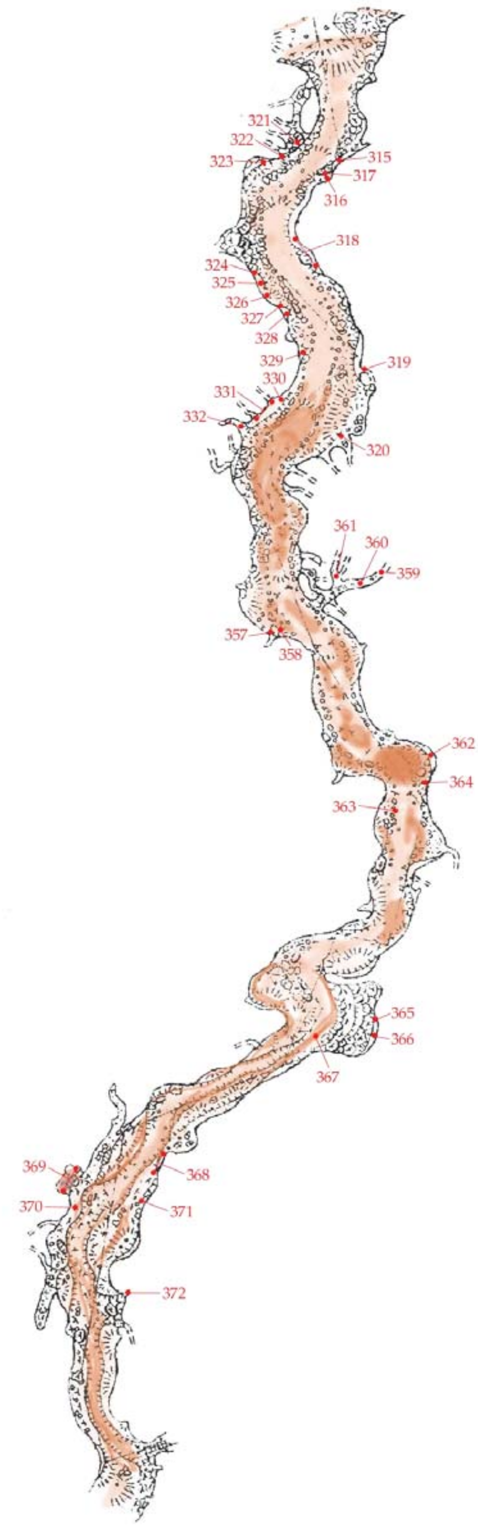

FIGURE 1-20. Side passage: Little Bat Avenue (base map cartography by CRF).

repeated use by hibernating colonial bats (i.e. little brown and/or Indiana bats). Only small amounts of relatively recent guano pellets were observed and no mummified remains were found. Bats identified from bone were *Eptesicus fuscus, Myotis* cf. *leibii, M.* cf. *grisescens, M. sodalis, medium-sized Myotis*, and *Myotis* sp.

Raccoon scats full of bat bones were located at 19 of the 34 data points and raccoon scratches, at one point. Other represented taxa were chicken (*Gallus gallus*), mouse-sized rodent, woodrat (*Neotoma floridana* by feces only), and deer (*Odocoileus virginianus* by a femur fragment found in a woodrat nest). Point 369 is a solution tube in the right wall containing at least five woodrat nests located on ledges at different levels in the tube.

As was found at Vespertilio Hall, Little Bat Avenue is too warm for *Myotis* species to hibernate (Jernigan 1998), airflow in these two areas has changed. For years, a block of concrete at the upper portion of the tower structure used to impede about 75% of the opening to Crevice Pit, which may have reduced incoming winter air in Little Bat Avenue (Olson, personal communication 1999). The stairs above the tower have been replaced and the implications are being studied.

Lookout Mountain [152 data points: 951-1095, 1574-1580]

Lookout Mountain is a large valley wall terminal breakdown that intersects the Audubon Avenue at Rafinesque Hall. At the summit of Lookout Mountain, huge sandstone blocks area rest on each other and create sizable cavities. Hagan and Sutton (1998) report that an 1815 map by Naham Ward (see Ward 1816) labeled this area "Bat Chamber." In August 1995, a survey of Lookout Mountain was undertaken as an Earthwatch Project funded by the Canon Corporation and the National Park Foundation (Toomey et al. 1995). Toomey and Colburn led a crew of five Earthwatch volunteers in an inventory that identified and mapped (Figure 1-21) approximately 300 bone and/or guano accumulations. Of these, 145 data points – those with the same type of information being captured in the current study - were assigned PIP point numbers and incorporated into the Paleontological Inventory Project. In 2001, Colburn and Olson re-examined the large breakdown block along the east wall (left side) of Lookout Mountain (Figure 1-22).

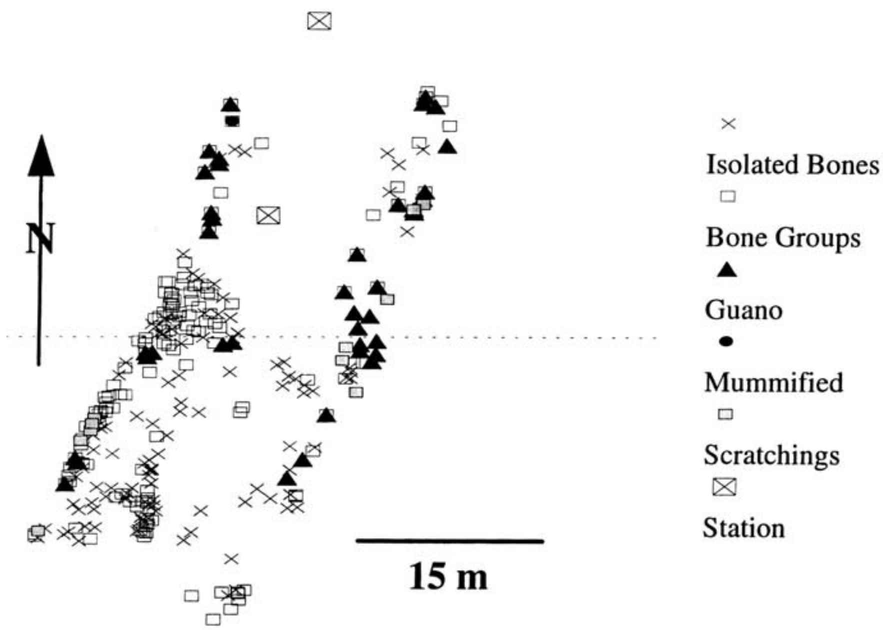

FIGURE 1-21. Lookout Mountain: schematic of data points inventoried by the Earthwatch Project in 1995 (from Toomey et al. 1995).

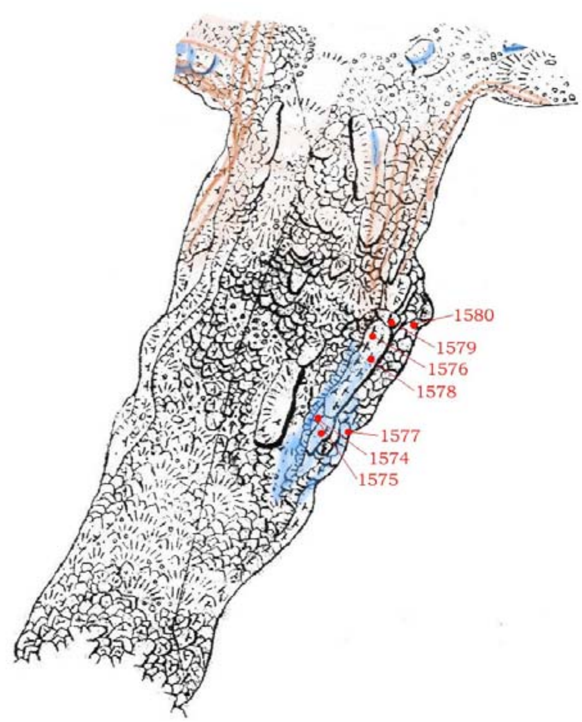

FIGURE 1-22. Side passage: Lookout Mountain (base map cartography by CRF); data points from 2001 visit.

Six bat species were identified from skeletal remains: *Lasiurus borealis, Myotis leibii, M. lucifugus, M. sodalis*, *Pipistrellus subflavus*, and *Eptesicus fuscus*. In addition, the masses of bat guano accumulated on ledges along the left wall of Lookout Mountain may indicate a summer gray bat roost (Figure 1-23). Because no gray bat bone was recovered, *M. grisescens* is denoted by a single point in the database (a representation that belies the population size and repeated use of the locale reflected in the area guano spread.) Perhaps, future sampling alond with focused examinations of the guano masses will yield more positive data.

FIGURE 1-23. Bat guano attributed to* Myotis grisescens *caught on wall ledges at Lookout Mountain.

Bones from three non-bat taxa were identified. A complete *Neotoma floridana* skeleton and parts of a second were found near the top of the breakdown, at the base of the sandstone blocks. A small, mummified passerine bird and one raccoon foot bone were located. Other signs of raccoon are abundant along the left wall, primarily in the form of highly fragmented bat bones and bat fur from degraded scats. Raccoon scats and claw marks are common along the left wall of Rafinesque Hall where they are concentrated on a large spall block that almost reaches the ceiling. Also present are intact raccoon scats full of bones of bats (most likely little brown or Indiana bats). It appears that raccoons had a long-standing tradition of entering Rafinesque Hall and eating hibernating bats that were within reach at Lookout Mountain.

Bunker Hill to Olive's Bower [96 data points: 1-18, 20-43, 47, 49-71, 74, 76-86, 88-102, 173, 263, 264]

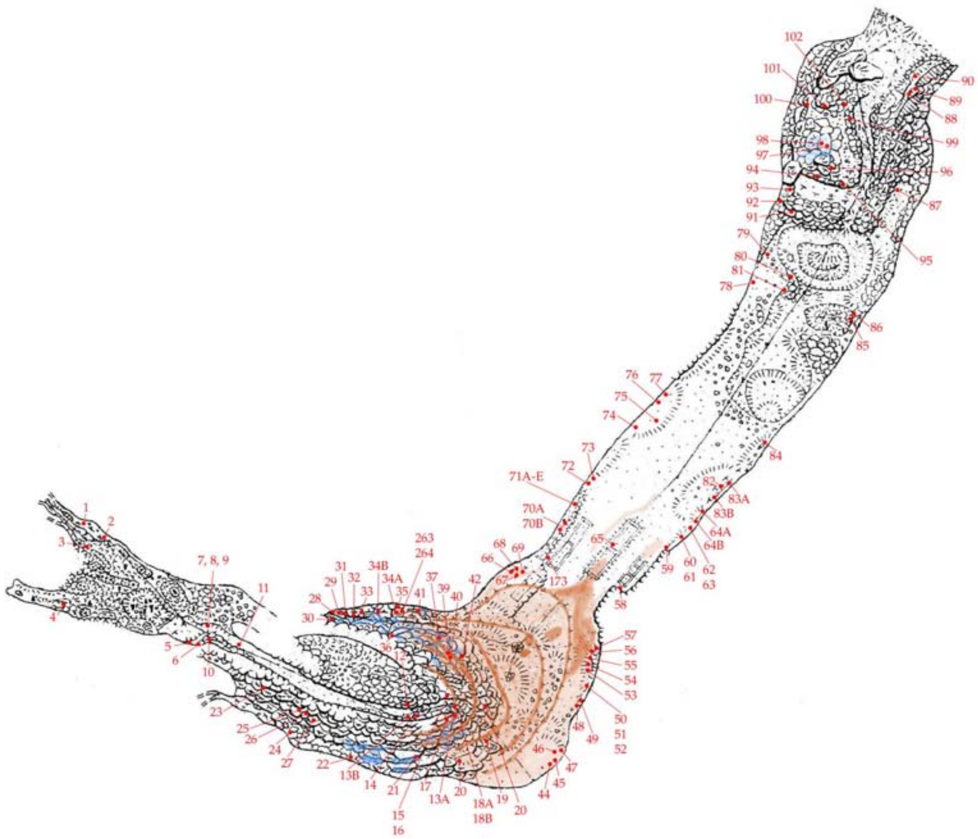

FIGURE 1-24. Side passage between Bunker Hill and Olive's Bower (base map by CRF).

The most prominent features in this passage, which begins behind Bunker Hill and ends at Olive's Bower, are 3 large borrow pits, remnants of the 1800s mushroom farm, Vespertilio Hall, and Olive's Bower. The most prominent characteristic is human disturbance. As in most of Historic Mammoth, the area is extremely sooty; however, because the area is small, the human impact is very apparent and the cave has not recovered. In historic times, a tourist trail was made by excavating through the talus to get around Bunker Hill, through slabs of roof fall behind Bunker Hill, and through breakdown between Vespertilio Hall and Olive's Bower. The passage was cleared of rock fall, which stands stacked along the walls and three large pits were mined for sediment. Remnants of the1880s mushroom farm (Hovey 1881:369) are still evident in the remains of the growing beds.

Olive's Bower was the destination of many tourists. In 1845, Bullitt (1845:17-18) wrote that the Bower had been recently discovered and described it as "a natural well, twenty-five feet deep, and containing the purest water … surrounded by stalagmite columns, extending from the floor to the roof, upon the incrustations of which, when lights are suspended, the reflection from the water below and the various objects above and around, gives to the whole scene an appearance equally rare and picturesque." Hovey (1909:36 and 1912:28) also described a pool of water that was 15-20 feet below the visitor. Today, no pool of water is present and Olive's Bower does not have a depth of 15 to 25 feet. It is a small formation room at the terminus of a path lined by man-made wall of rock stacked nearly to the ceiling. The ceiling of the walkway is damp and drippy, and the floor is wet and sticky with clay. Today the floor, ceiling, formation columns, and popcorn in the bower itself are covered in soot and many of the stalagmites are inactive. Recent drips on soda straws are white. Numerous buttons (including ones made of shell) litter the floor; they may have come from burned cloth torches that were used to highlight the formations during early tours. Today there is little faunal evidence for prehistoric bat use in Olive's Bower. Most of the identified bat material appears to post-date the opening of the tourist trail through the breakdown. Isolated wing elements of bat can be found throughout the area, some are encased in calcite, but there is no visible ceiling stain or bat guano (probably due to sooting, moisture, and decomposition).

The most significant area from a paleobiological standpoint is that of Vespertilio Hall and its branch passages. The very name –*Vespertilio Hall*– is anecdotal evidence that bats were observed in large numbers in the 1800s because Vespertilio is an old name for bats (the genus name, *Myotis*, was once *Vespertilio*). In addition, Hagan and Sutton (1999) note that the 1871 Blackall map labels the area "Bat Room." Hovey and Call wrote the following about Vespertilio Hall:

> Soon after leaving the Mushroom Beds the avenue again widens somewhat, though the ceiling is mainly low. But in the central portions the ancient waters had sculptured out an inverted kettle in the midst of a somewhat pronounced hall, and this is the rendezvous of myriads of bats. From the name of the genus which is so abundantly here represented we have given the locality the appellation of

> Vespertilio Hall. Thousands of bats, in winter season, suspended in great clumps, may here be seen. A single catch one night gave Doctor Call six hundred and seventy individuals, most of which went to the United States National Museum.
>
> (Hovey 1912:26-27)

The visible paleobiological evidence in the cave for Hovey and Call's hibernating bats are as follows:

1) The extremely heavy and ubiquitous roosting stain and corrosion (found in Vespertilio, in its right hand branch, and over the mushroom beds)
2) Bat guano (prevalent on and between the breakdown in the two branches off of Vespertilio Hall)
3) Areas of crushed bat bone derived from degraded raccoon scats (occur from Bunker Hill to the branches off of Vespertilio Hall)

In many places the ceiling is so heavily coated by smoke that any bat stain would be obscured. Human disturbance has destroyed the guano that must have been present. The mushroom farm, itself, may have utilized the guano that Hovey (1881:369) earlier had said would be a great boon for the proposed mushroom farm.

Based on a collection made by Call in 1896 (which is still curated at the Smithsonian Institution in Washington, D.C.), Vespertilio Hall is the area for which there is the strongest evidence for a *Myotis sodalis* hibernaculum. It is possible that *Myotis lucifugus* also used the hibernaculum, but there is no strong paleontological evidence for them. Staining over the mushroom beds and in small ceiling domes in the passage, on ceiling changes, and in the right hand branch provide evidence that the Vespertilio Hall hibernaculum was not limited to the inverted kettle; the population was quite large and overflowed into the passage (Figure 1-25). As pointed out in the Historic Entrance Area report, recent temperature data from the Mushroom Vat Cave Atmospheric Monitoring setup (Jernigan 1998) indicate that the temperature in this area is too warm for hibernating *Myotis sodalis* and is above their maximum tolerated temperature. The Olive's Bower popcorn formations provide evidence of past directional airflow and evaporation, indicating that there may have been an opening at Olive's Bower, which cooled the Vespertilio Hall hibernaculum.

FIGURE 1-25. Two images of bat stain in Vespertilio Hall; shown are the "inverted kettle" noted by Hovey and Call in 1897 and an example of stain on nearby ceiling changes.

Despite widespread disturbance, other faunal evidence is present. Mummified remains (some partially skeletonized) include *Corynorhinus* sp., cf. *Myotis grisescens*, *M. sodalis*, *M.* cf. *sodalis, Pipistrellus*, and cf. *Pipistrellus*. Bat taxa identified from bones include *Eptesicus fuscus*, *M. austroriparius, M. grisescens*, *M. cf. grisescens M. sodalis,* medium-sized *Myotis*, *Myotis* sp., and *P. subflavus*. An indeterminate carnivore scat and widespread *Neotoma* feces in breakdown areas represent non-bat taxa. Bone material was identified to Anura (frog or toad bones found in a degraded raccoon scat that was in a woodrat midden), *Procyon lotor* (raccoon), *Peromyscus* sp., most of the bones of a single individual mouse, *Neotoma* sp., and *Sylvilagus* (rabbit). Polished rock surfaces in the right branch off of Vespertilio Hall may be old woodrat (*Neotoma* sp.) trails. Animal remains found at the mushroom vats are as unusual as the human activity that took place there. Burned skeletal remains (vertebrae, ribs, and premaxillae with fangs) of a rattlesnake (*Crotalus* sp.) and charred boards (likely from a mushroom bed) lie on top of a man-made embankment. A *Scalopus aquaticus* (mole) skull was nearby on the embankment, and postcranial elements were found on the floor below. Near the mole skull are postcranial elements of a *Neotoma*. A mouse nest is located in the mushroom bed that lies in the middle of the passage. A partially skeletonized mummy of *Peromyscus* sp. (deer mouse or white-footed mouse) was found on a man-made wall across from the mushroom vats. Human feces are scattered throughout the passage.

Corkscrew and Vanderbilt Hall (no map) [36 data points: 237-262, 1273-1275, 1581-1587]

The Corkscrew and Vanderbilt Hall are two different jumbles of massive, collapsed limestone blocks. The Corkscrew provides a route from the main trunk to the lower river level, but Vanderbilt is accessible only from the lower level. The 19th century cave guide William Garvin is credited with discovering that the Corkscrew connected with lower levels when he "observed bats flying with reckless speed and suddenly disappearing in a small aperture, far above the Kentucky Cliffs" (Randolph 1924:92). In reality, Native Americans utilized the Corkscrew millennia before the arrival of Europeans. Perhaps, bats should be credited with notifying people of the shortcut between the Main Cave level and the river level. In 1837, an article in *The American Monthly Magazine* described the Corkscrew:

> Among these Kentucky Cliffs, just under the ceiling, is a gap in the wall, into which you can scramble, and make your way down a chaotic gulf, creeping like a rat under and among huge loose rocks, to a depth of eighty or ninety feet -- that is, you can do all this, provided you do not break your neck before you get half way.
>
> (Bird 1837:437)

Twenty-six data points were found in the convoluted Corkscrew. Light to moderate staining occurs ubiquitously on the breakdown blocks. Pellets of bat guano are scattered, with some heavy accumulations preserved in cavities of breakdown. Guano patches range in size from a few cubic centimeters to several hundred cubic centimeters; a large piece of human feces is coated with bat guano. The amount resulted from either a fairly large population (species unknown) or a long period of repeated use. Radiocarbon dating of guano from the Corkscrew provided an age of 1530 ± 50 years (CAMS-46.213). This age suggests that a long accumulation time may be the reason for the thick guano. Represented bat species are *Eptesicus fuscus, Lasiurus borealis, Myotis grisescens, M. leibii,* medium-sized *Myotis, Myotis* sp., and *Pipistrellus subflavus*. A mummified *L. borealis*, *M. leibii* (mostly skeletonized), and *P. subflavus* were found. Scats of *Procyon lotor*, larder debris and feces of *Neotoma floridana*, and several bones of *Gallus gallus* comprised the non-bat faunal remains.

Ten data points (1273-1275, 1581-1587) were assigned to Vanderbilt Hall. Like Corkscrew, it is a convolution of huge breakdown blocks that create passages and rooms. All is very sooty. Bat guano occurred as both scattered pellets and as heavy concentrations. Stain was often difficult to discern; however, there is extensive staining on the ceiling blocks in at least 3 areas (a room with stations TA2-TA3, one with TA4, and another with TA5- TA6). Bat bones were not abundant except in raccoon scats. Identified taxa were medium-sized *Myotis*, *Myotis* sp., *Pipistrellus subflavus*, and indeterminate bat. *Neotoma* feces were abundant in 3 latrines, nest and larder materials were abundant in some areas, and 2 bones were found. Raccoon scats containing bat bones were found at 5 data points, one of which was a latrine with more than 77 pieces. Bat guano from Data Point 1273 (station A3) was AMS dated to 8,255 ± 40 RCYBP (CAMS-83267) and guano from 1274 (station TA7) was dated conventionally to 2,090 ± 80 RCYBP (GEOCHRON GX-27144). Raccoon scats from the top of Vanderbilt Hall beyond station TA8 (data point 1275) dated to 920 ± 70 RCYBP (GEOCHRON GX-27148).

Backslider's Alley (no map) [39 data points: 333-348, 387-408, 566]

Waters originating at Double Cellars traveled northwestward through Gothic Avenue, passed over Main Cave, and flowed into Backslider's Alley where they continued on their northwestward course until looping and exiting at Methodist Church, where they joined upper level Broadway. Eventually, Backslider's Alley became a sediment-filled passage; its fine-grained fill is alluvial sand deposited by slow moving water during backflooding (Granger 1998, personal communication; and Palmer and Palmer 1998, personal communication). The fine sediments have since been mined from the proximal portion of Backslider's - shaping an anteroom of sorts - first by 1800s saltpeter miners, and later as fill for tourist trails. At the back of this anteroom, laminated sediments fill the room to within inches of the ceiling. Here, in the 1930s, compact, laminated sediments were dug through in order to excavate a crawlway in the pursuit of finding additional cave passages. Beyond the man-made crawlway, Backslider's Alley opens into a low, wide pancake room in which the floor is covered with large slabs of ceiling fall. This breakdown may obscure the ancient passage's connection with Methodist Church. Any old remains that may be present in Methodist Church have been long buried by sediment and roof fall. Interestingly, scallops in the crawlway indicate flow from the opposite direction, that is, from Backslider's toward Gothic Avenue.

In Backslider's Alley, paleontological remains (39 data points, #333-348, 387-408, 566) were recorded for the following contexts in the anteroom, crawlway, and pancake room at the distal end of the passage:

1. The anteroom (data points 333-348, 408, 566)
    - *in situ* deposits near the top of laminated sediment banks located to either side of the crawlway opening, (hand picked sample from 345)
    - bone adhering to the ceiling above the bone-bearing sediments
    - deposits of bone eroding out of sediments along the walls of the anteroom (collected samples of sediment with bone from 340, 342, 348)
2. *in situ* bone in the wall of the excavated crawlway (data points 387-392; bones were hand picked from 388 and 389-390)

3. Surface contexts in the pancake room beyond the man-made crawlway (data points 393-407).

The anteroom had no notable roosting stain or bat guano, but bat guano is plentiful in the undercut wall at the back of the pancake room; there 3 accumulations were recorded. Guano from Point 401 was sampled and dated to 2120± 80 RCYBP (CAMS 46216). Thus, although the crawlway was excavated to allow humans to pass, bats must have had enough room to fly over the sediment fill prior to excavation, or, they gained access from an unknown location.

In the anteroom, thousands of bat bones are eroding from fine sandy silt along the left and right walls and some appear to be eroding from pockets of bone. From the anteroom, three samples of loose eroding sediment containing bone were collected from Data P points 340, 342, and 348. The samples were not washed due to their fragile nature; rather, each was screened through geological sieves and adhering sandy/silty sediment brushed off easily. The specimens were very fragile and have lost most of their organics; some bone has a leached white appearance. During the 1995 Earthwatch Project, four anteroom samples were collected and submitted for radiocarbon dating, but all failed to yield enough carbon for a date. Data point 340 designated a 1-meter long area where bat bones are eroding out of a 6 cm thick layer of beige sediment that lies above an orange-red layer. The beige layer was probably exposed for a while and is eroding 40 cm down slope onto the churned up sediment. The sample from Point 340 yielded *Myotis lucifugus* (fragmented skull), medium-sized *Myotis* (skull fragments, dentaries, radii, and humeri), and numerous bones of unknown bat.

Point 342 was a similar assemblage of bones eroding 40-50 cm down slope on loose light sediment from a 6 cm thick layer located in a wall pocket (Figure 1-26). *Eptesicus fuscus* (radius, humeri), *Myotis grisescens* (right dentary), *Myotis leibii* (left dentaries), *M.* cf. *leibii* (left dentary), medium-sized *Myotis* (12 left and 16 right maxillae, 5 rostra, 33 left dentaries, 29 right dentaries), *Pipistrellus subflavus* (dentary, rostrum, maxilla), numerous bones of unknown bat, and mouse-sized rodent (several elements) were identified.

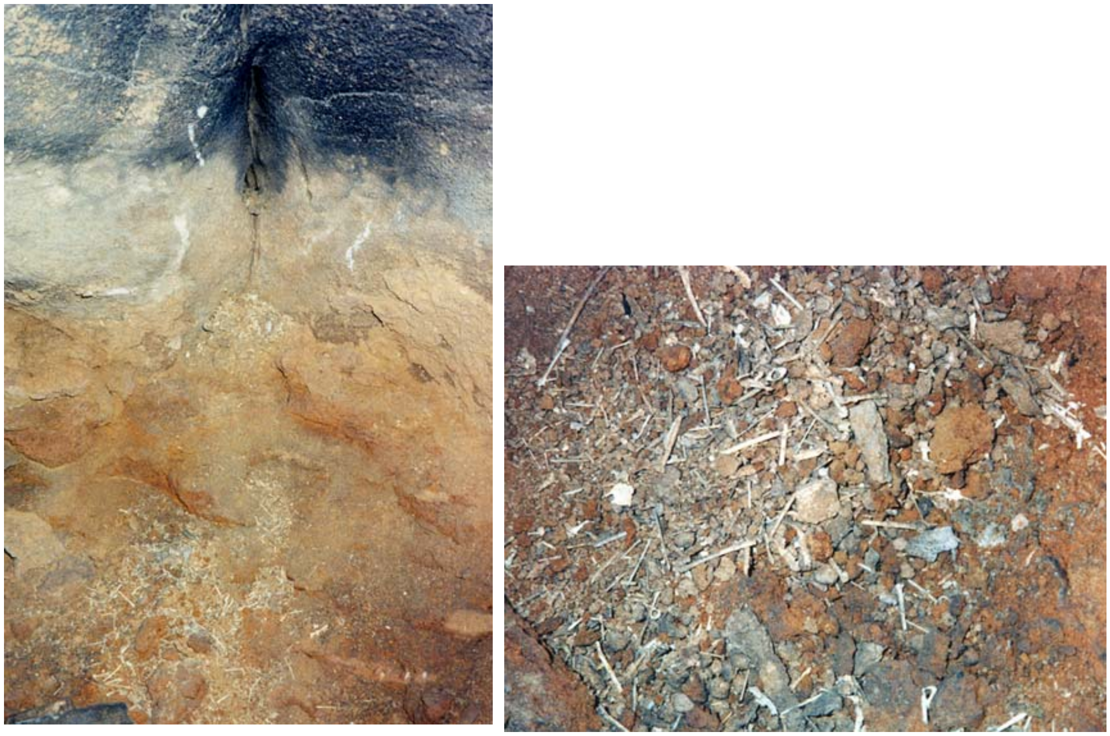

FIGURE 1-26. Backslider's Alley, general and close-up views of bones eroding from old sediments at Point 342.

Point 348 is a 3.5-meter area along the left wall where bat bones (white and brittle) are eroding out of a gray, shaly sediment layer. Identified taxa were cf. *Eptesicus fuscus* (dentary), *Lasiurus borealis* (dentary), *L. cinereus* (humeri, radius), *Myotis grisescens* (3 left dentaries), *M.* cf. *grisescens* (left dentary fragment, humerus), *Myotis leibii* (skull), *M.* cf. *leibii* (humeri), *M. lucifugus* (skull), medium-sized *Myotis* (5 rostra, 2 skulls, 6 left dentaries, 12 right dentaries, humeri), *Pipistrellus subflavus* (dentary), numerous bat bones, and mouse (femur).

Bats represented in Backslider's Alley were *Desmodus stocki*, *Eptesicus fuscus*, *Lasiurus borealis*, *L. cinereus*, medium-sized *Myotis*, *M. grisescens*, *M. leibii*, *M. lucifugus,* and *Pipistrellus subflavus,* and *Tadarida*. A total of 14 bat mummies were found in Backslider's Alley; most had mold/fungus indicating that they were relatively recent, and nearly half were *Lasiurus borealis*. In the anteroom were mummies of one red bat and two indeterminate vespertilionids. Some of the bat mummies (along with degraded raccoon scats) were located on the remnant of the passage floor (now a very narrow ledge that passes over Main Cave) that used to join Backslider's Alley and Gothic Avenue. The three mummies in the crawlway are cf. *Eptesicus fuscus*, *Pipistrellus subflavus*, and indeterminate vespertilionid. Mummified remains of 5 red bats and 3 vespertilionids (thick coatings of fungus made them unidentifiable at this time) were found in the pancake room. Interesting finds in the loose sediments were bones of both *L. borealis* and *L. cinereus*, which are tree-dwelling species, not cave inhabitants; and, of *E. fuscus* and *M. leibii*, which are associated with cold hibernation areas. These loose sediments are eroding from intact deposits that are still standing along the walls. Thus, these species did not roost in the anteroom; rather they may have been transported via water and deposited during backflooding.

Non-bat bones include mouse bones from the anteroom and the crawlway, a *Neotoma* incisor from the pancake room, and raccoon scats on the ledge over Main Cave. In addition, bones identified as cf. *Cryptobranchus* sp. (hellbender), indeterminate amphibian, unidentifiable vertebrate, and possibly fish or salamander were found in the crawlway. The hellbender bones are poorly preserved as they are chalky and fragmentary and, at this point, they can only be identified to the level of cf. *Cryptobranchus*. The presence of two fragmentary atlases indicates that at least two individuals are represented. The modern species, *C. ozarkensis*, is recorded from the Green River. The material recovered in the cave is consistent with the modern species and with an extinct species, *C. alleghanensis*. Additional material will be needed in order to attempt a more definitive identification.

A single bone, the proximal half of a right(?) femur, is that of an extinct vampire bat. Toomey and Colburn identified the specimen to the genus *Desmodus* based on its unique shape (its robust build and deep anterior groove are related to the terrestrial locomotion of the genus) and on comparison with femora of modern vampire bats (*Desmodus rotundus*) (Figures 1-27 and 1-28). Three extinct species of *Desmodus* (*D. stocki*, *D. archaeodaptes*, and *D. draculae*) and one modern species, the common vampire bat (*D. rotundus*), have been described. Ray et al. (1988) and Morgan (1991) summarize the current state of knowledge regarding fossil vampire bats.

D. archaeodaptes was similar in size to the modern species; and, *D. stocki* and *D. draculae* are larger than the modern, with the latter being significantly larger. *D. draculae* has been recovered only in South America. *D. stocki* and *D. archaeodaptes* occurred in North America, but the latter is known only from Florida (Morgan 1991). The width of the proximal end of the Mammoth Cave femur is 4.3 mm. This is larger than modern *D. rotundus*, but within the size range of *D. stocki* (Gut 1959). For this reason it is assigned to *D. stocki*.

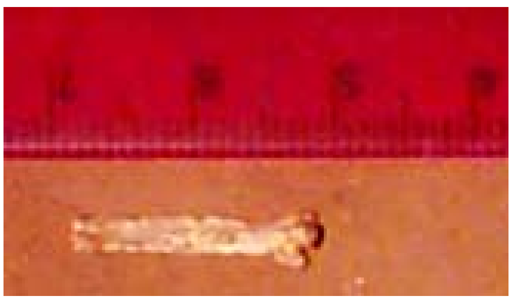

FIGURE 1-27. Femur of* Desmodus *from Backslider's Alley* (*identity unknown when found).

FIGURE 1-28. Femur of fossil* Desmodus stocki *(top) and modern* Desmodus rotundus *(bottom).

The bones of *Desmodus stocki*, possible *Cryptobranchus,* and *Tadarida* are important finds indicating that Backslider's Alley is a paleontologically significant location within Mammoth Cave. The *Desmodus* and *Tadarida* bones had fallen from the fine sandy sediments or from the fine laminated silts above. Items exposed in the crawlway wall were contained within the fill.

Gothic Avenue [133 data points: 937, 1364-1385, 1403-1512]

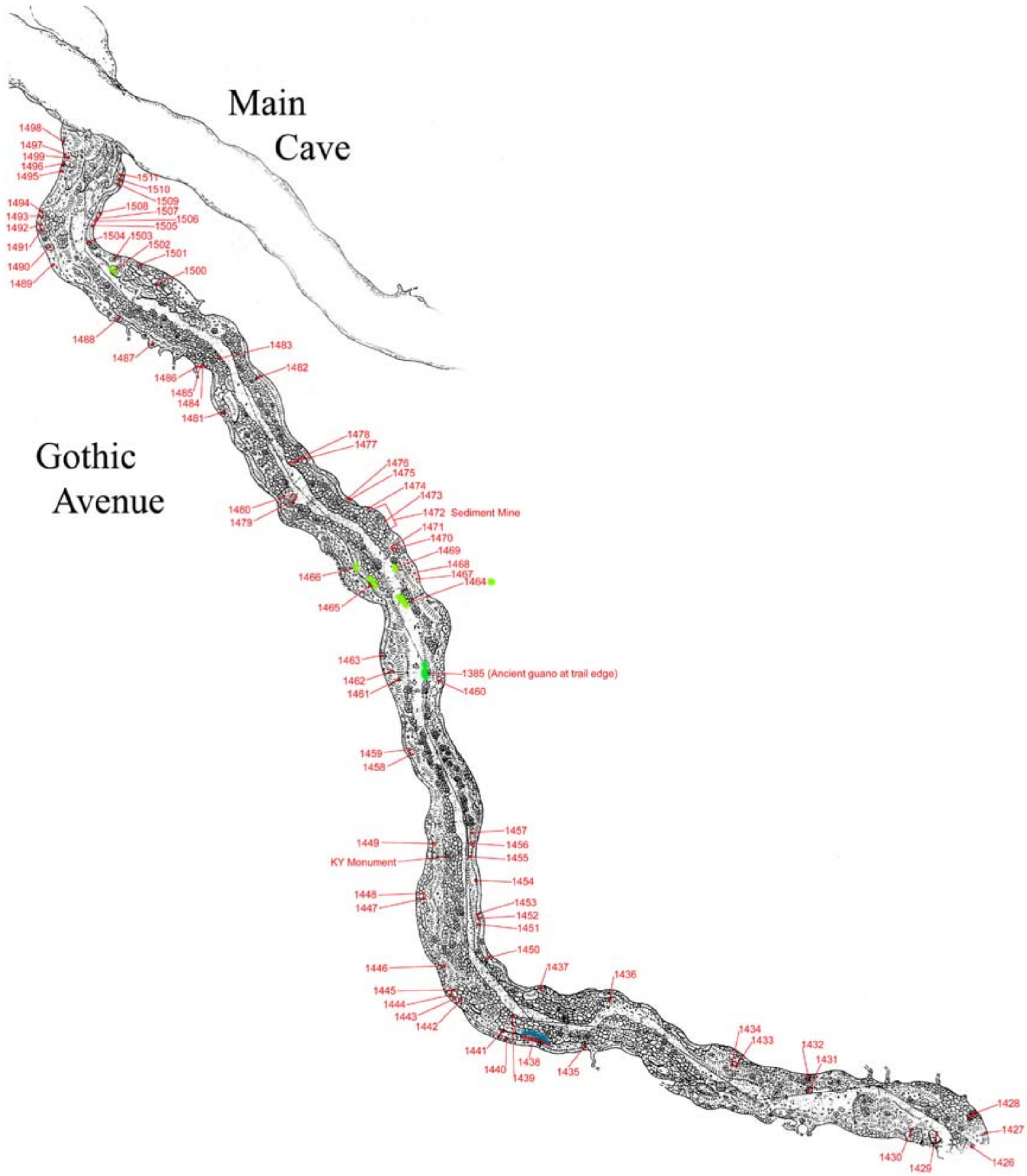

FIGURE 1-29. Ancient upper level passage, high in B-Level: Gothic Avenue (base map cartography by CRF).

Gothic Avenue is similar in length to the upstream segments of Blackall Avenue and Blue Spring Branch; however, it is far richer in paleontological resources. Originally Gothic Avenue was not slated for inventory because it was anticipated that the passage would yield little fossil evidence due to the high level of historic disturbance. Its sediments were mined for saltpeter dirt and perhaps for modern trail construction. Gothic was probably the most heavily toured passage in the 19th century. In the 1800s, not only were Gothic's formations among the few known in Mammoth Cave, but also they ranked among the most spectacular and were given names like the Post Oak Pillar, Pillar of Hercules, Bridal Altar, Napoleon's Breastworks, Loaded Camel, Elephants' Heads, and Lover's Leap (names from Hovey 1912). Even then, the formations were dry and corroded. That these speleothems and the avenue attracted tourists is attested in historic accounts detailing tales of lost saltpeter miners, the mummy placed in a niche, tours by famous visitors, weddings, its prominence as a tour route, and the plethora of smoked names on its flat ceilings.

Something missing from the tourist accounts of Gothic Avenue is the mention of bats in the passage. However 120 of the 133 data points denote locations with bat remains. The taxa identified and the radiocarbon dates indicate that different bats utilized Gothic at various times in the past. Guano pellets and roost stain are not widespread, but are present in circumscribed areas. Stain and guano are most prevalent in the area beyond Lover's Leap, which is beyond the formations and beyond the tourist area. Beyond survey station A28, some areas of the floor have a scattered to light coating of guano pellets, but no heavy accumulations, and some ceiling steps and pockets are quite dark with bat stain. Much of the guano is decomposing and the floor seems a bit damp for accommodating long-term preservation. A sample of guano collected from near A28 was radiocarbon dated to 450 ± 45 RCYBP (CAMS-83260).

Raccoon scats were not prevalent in Gothic Avenue. Only 6 data points marked scats, all of which were in decay. Data Point 1436 designates a pocket of bat bone derived from raccoon scats and burned cane, which were found under a 6-foot by 2-foot piece of breakdown at the edge of the tourist trail. A sample of the crushed bone and degrading scat was collected. Colburn identified bones of medium-sized *Myotis* (two partial rostra and 2 right dentaries) and indeterminate bat from the scat. A right humerus of *Lasiurus borealis* from this area was not part of the scat. The scat was dated to 1,240 ± 45 RCYBP (CAMS-83261).

Present-day Gothic Avenue is too warm for bat hibernation. As found in other warm sections of Mammoth (e.g., Black Chambers), there is a high prevalence of *Lasiurus borealis* mummies, many with fungus growth. Thirty-five data points produced bat mummies and of these, 27 had mummies of red bat. Other mummified bat remains were *Pipistrellus* (6 data points), a *Myotis grisescens*, a medium-sized *Myotis*, and parts of unknown bats at 4 data points. Bats identified from skeletal elements were *Eptesicus fuscus, L. borealis, L. cinereus, Myotis cf. austroriparius, M. grisescens, M. leibii, M. lucifugus, M. sodalis,* medium-sized *Myotis, Myotis* sp., *Nycticeius* cf. *humeralis*, *P. subflavus*, and *Tadarida*. Non-bat fauna were *Procyon lotor, Neotoma floridana, Peromyscus* sp., mouse-sized rodent, *Gallus gallus,* an unidentified colubrid, *cf. Bufo*, *Rana* sp., and salamander.

Gothic Avenue produced seven interesting types of resources. One is the presence of intensive roosting stain and guano pellets (the latter confirmed to be prehistoric) in an area that is too warm for hibernating colonial bats. A second type is the presence of several smears and thin layers of rich brown "ancient" guano (much older than the pellets) of indeterminate origin that lie below the current floor surface (Figure 1-30).

Figure 1-30. Two examples of ancient guano deposits at Point 1385 and Point 1465.

At Data Point 1464, a stripe of dark brown ancient guano can be traced for about 2 meters; it is up to 6 cm thick. A white layer (possibly degraded limestone) is below it. Cultural materials (soot, burned cane) have been trampled and packed into the upper most 1.5 cm of the ancient guano. The guano layer at Data Point 1465 was probably contiguous with the previous data point before being separated by trail construction. Point 1465 lies to the right of the tourist trail and the ancient guano layer is situated at the upper portion of orange water-lain bank of sediment. The ancient guano is overlain by grayish-white sediment and soot and under it is a layer of gray-white sediment. In the same sediment bank, Data Point 1466 is a thinner layer with bone in the brown and white mixture and preserved under a small piece of limestone roof fall. A small plastic bag of matrix and bone was collected; only elements and broken bone from unidentifiable bat were found in the sample.

The third type of paleontological resource is comprised of deposits of bat bones in matrix that is loose, gray to gray-brown colored sediment, and sometimes contains guano pellets and/or chips of limestone. They are at or near the surface; the gray sediment coloration may be a product of soot and cultural activity impact. Nothing from this category of resource was dated, although it is the context most likely to have early historic fossils mixed with prehistoric materials. A sample of this type was collected from Data Point 1496, which was very close to the surface, and the soot layer is gone/mixed. The collection included the following: *Eptesicus fuscus* (right dentary, clavicle, femur), *Lasiurus cinereus* (left maxilla and left humerus), *L. borealis* (left radius fragment), *Myotis* cf. *austroriparius* (skull), *M. grisescens* (left and right dentaries), *M. leibii* (3 left dentaries, 2 right dentaries, right humerus), medium-sized *Myotis* (8 right dentaries and fragmented skulls), cf. *Myotis* sp. (fragmented maxillae), indeterminate bat (maxillae of 6 different individuals), and *Peromyscus* sp. (skull and postcranial elements).

The fourth resource category is distinguished as being pockets of bat bone in old pinkish-beige colored sediment. Sediment and bone were collected from Data Points 1470 and 1471, which represent this category of fossil. Point 1470 has bones eroding out of an intact deposit of bone. The assemblage appears to be degraded raccoon scat because it is very fragmented and crushed. At the Illinois State Museum labs, Colburn sorted the faunal sample and identified the following: *Eptesicus fuscus* (dentary, bulla, innominates, scapula, femur, tibia), *Lasiurus borealis* (distal left humerus), *Lasiurus cinereus* (scapula fragment), *M. grisescens* (3 left dentaries, 1 juvenile left dentary, *M. leibii* (left dentary, right dentary, humerus), medium-sized *Myotis* (1 right and 6 left dentaries, 8 left maxillae, 9 right maxillae, 1 radius), *Myotis* sp. (fragments of 9 left and 5 right dentaries), *Pipistrellus* (maxillae, femur), and numerous indeterminate bats (many dentary fragments, tibiae, femurs, radii, humeri). Non-bat taxa at Point 1470 were *Peromyscus* sp. (right m_1), unknown mouse (right maxilla possibly from the *Peromyscus* that may have been ingested, right clavicle, lower right incisor), and a small-sized *Rana* sp. (left mandible). Located about 4.5 feet above the trail, Point 1471 is a primary deposit from which bone is eroding. The pocket contains limestone chips mixed with some guano and lies under a small pile of roof fall. Collections were made from two pockets of *in situ* bone matrix. The bones are brittle and their colors range from light beige to white. *Eptesicus fuscus* (femur, scapula, radii fragments, and a broken humerus that did not produce a date) and numerous bones of indeterminate bat were identified.

The fifth resource is represented by an odd find at Point 1479. At this location, bat bones were visible in a void about 1 meter above the current floor in the Post Oak Pillar. The sediments around the formation were excavated long ago (Figure 1-31) – perhaps by miners and/or by cave managers promoting early tourism – creating a large, level open area and a narrow path that goes around the column. The void in the column is located at or just above the old floor level, which is coated with soot, but the sediment in the void is beige and unsooted. A sample of sediment with bone was spooned out in order to collect materials for identification.

Many loose bones representing all body parts of small-sized to large-sized bats were present. Some had tissue adhering and a few had a coating of crystals. Elements representing at least 16 individual bats were in the hole. Two whole humeri of *Myotis* were dated to 1,195 ± 50 RCYBP (CAMS-83262). Based on the age, the contents of the hole in the Post Oak Pillar may typify materials that used to cover a previous floor surface throughout Gothic Avenue. The sediment in the column may be another example of the fourth resource type. Colburn identified the following taxa in the laboratory:

- *Lasiurus cinereus* (fragments of a right humerus and left scapula)
- *Myotis grisescens* (2 right dentaries, 2 left dentaries)
- *M. leibii* (postcranial material, a right dentary, and 4 left dentaries)

- *M. lucifugus* (1 skull)
- *M. sodalis* (6 skulls)
- small-sized *Myotis* (postcranial material)
- medium-sized *Myotis* (postcranial material and fragments of at least 7 skulls and 9 right dentaries)

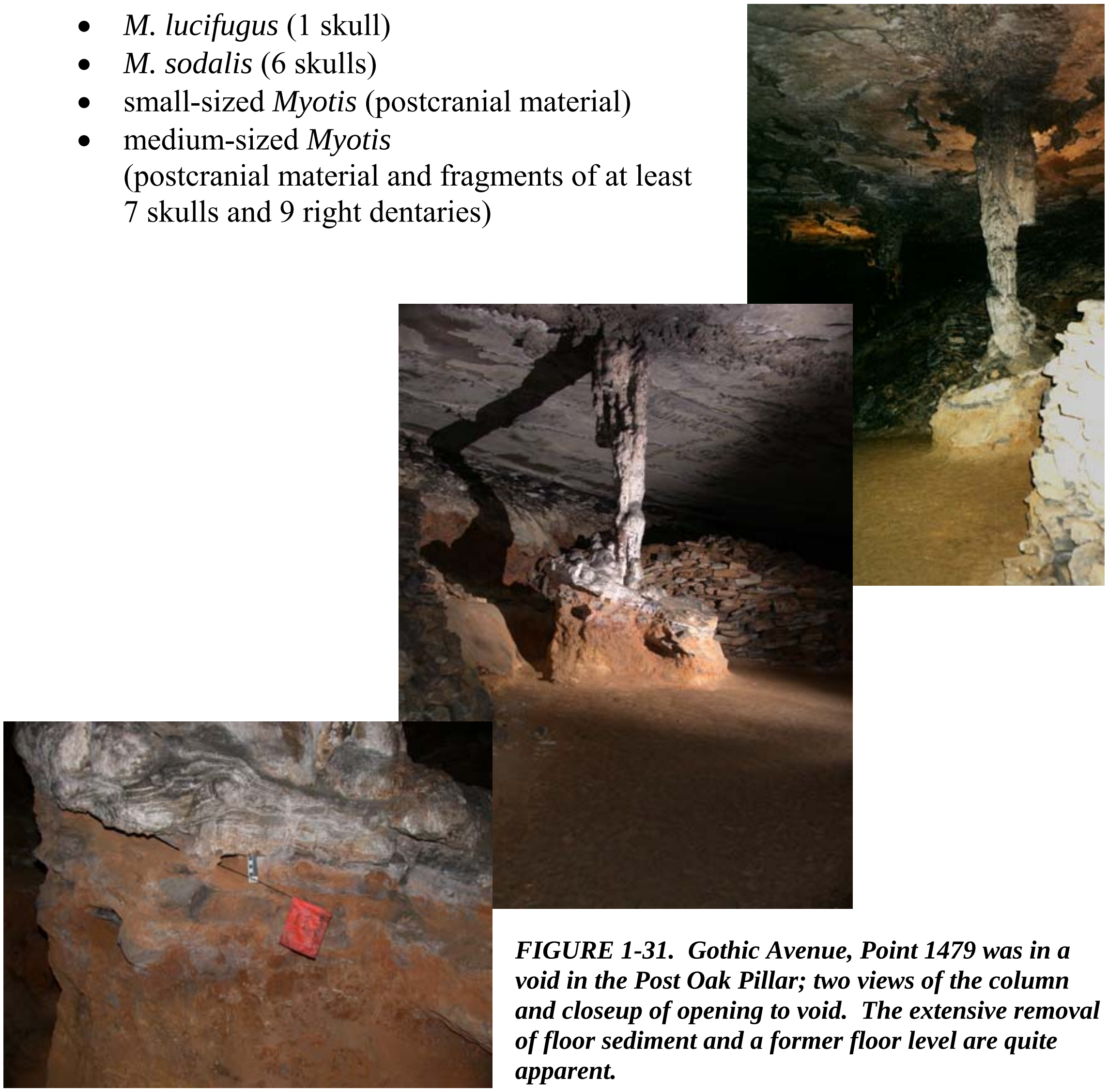

FIGURE 1-31. Gothic Avenue, Point 1479 was in a void in the Post Oak Pillar; two views of the column and closeup of opening to void. The extensive removal of floor sediment and a former floor level are quite apparent.

A sixth type of resource is that of old red sediments containing bones that do not appear to be crushed bones from scat (Figure 1-32). These contexts may be undisturbed, or at least not disturbed since early historic times. Data Points 1490-1493, located on the right side of the passage, and 1510, on the left side, were of this type. Samples of the bone-bearing sediments were collected from Points 1491, 1493, and 1510.

FIGURE 1-32. Gothic Avenue, example of old red sediment that contains bone, Point 1510.

Point 1490 marks a deposit of bone in fine powdery red sediment coated with soot and protected under a small shelf/ledge; the sediment in front has been mined away. The deposit is approximately 80 feet long. Bones protrude from the dirt, but they were not identified or collected. Point 1491 is a similar pocket of bone in primary context with loose bone weathering out; it is about 8 feet from the previously described point and its setting is similar. It is also soot covered and some of the protruding bone is sooty. A sample of the bone-laden red sediment was collected and identified by Colburn. *Myotis leibii* (3 left dentaries, 4 rights, and a rostrum), medium-sized *Myotis* (7 left dentaries, 4 rights, and broken maxillae), *Pipistrellus subflavus* (humerus), and numerous elements of indeterminate bat. At Data Point 1493 bone was eroding out of two pockets in the red sediment that are about 12 inches apart, soot-coated, and protected under a ledge. Taxa identified were *Eptesicus fuscus* (upper molar), *Myotis* cf, *grisescens* (distal humerus), medium-sized *Myotis* (humeri, rostrum, 5 left dentaries and 7 right dentaries), and many elements of unidentifiable bat.

Point 1510 is located on the opposite side of the trail (left) from the previous data points of this type. It is an *in situ* pocket of bone eroding out of old red sediments in an anastomotic hole. Identifiable fauna were as follows: *Eptesicus fuscus* (canines, tibiae, femur), *Myotis grisescens* (left and right dentaries), *Myotis leibii* (3 left and 2 right dentaries, rostrum), *Myotis* cf. *lucifugus* (rostrum), medium-sized *Myotis* (8 left and 4 right maxillae, 16 left and 10 right dentaries, humerus, and innominate of a male), *Pipistrellus subflavus* (2 left dentaries, 1 right), *Nycticeius humeralis* (left dentary with a 3123 count), numerous elements of unidentifiable bats, and a cricetine rodent (fragments of right dentary, right femur, and right scapula).

Finally, the seventh paleontological resource of interest is a deposit of old, red-colored water-lain sediments that contain small amounts of bone, located at Paleo Point 1472 (Figure 1-33). The red sediment is a very tight, intact deposit that is adhering to the wall; old bones are eroding out of the deposit. There is evidence of mining, perhaps for saltpeter based on mattock marks. The exposed fill remnant is approximately 25 ft. long and 3.5 feet high, and its face is quite sooty, especially on portions of raised relief.

FIGURE 1-33. Gothic Avenue, Point 1472, old red sediment adhering to wall.

Loose sediment from the deposit is red-beige in color. The gray sediments that produced bone at other points overlie the intact fill deposit. A sandbag of reddish-beige sediment and bone was collected. At the labs, Colburn water washed it through fine-screen mesh (Figure 1-34). Whole and fragmented bat bones (teeth, auditory bulla, shaft pieces, toes, metacarpals, ribs, skull fragments, vertebrae, sternebrae, dentary, humeri, radius, tibia, clavicles) constitute much of the faunal sample. The bones are brittle, with some being extremely brittle, white, and chalky.

FIGURE 1-34. Gothic Avenue, sample from Point 1472 before and after being screened (photographs by Gary Andrashko, Illinois State Museum).

Two clumps of sediment encasing bones yielded an interesting discovery (Figure 1-35). After water washing at the labs, the bones were identified as a left humerus (distal ¾ with proximal end of the shaft unfused), 2 right humeri (one a distal fragment about ¾ complete with the proximal shaft unfused, and the other a distal fragment >1/2), a proximal epiphysis of a right humerus, and two right femurs. All are attributed to *Tadarida*.

FIGURE 1-35. Gothic Avenue, two clumps of sediment from Point 1472 before washing (photograph by Gary Andrashko, Illinois State Museum).

The skeletal elements were from subadult individuals. It does not appear that the location represents an *in situ* roosting area; it is most likely that the bones were washed in with sediments that constitute the red fill, perhaps at a time when the passages of Gothic Avenue, Blackall Avenue, and Blue Spring Branch were still connected. Other elements were identified as medium-sized *Myotis (*rostrum); multiple individuals of *Eptesicus fuscus* (a very white rostrum, 2 whole right maxillae, fragments of left and right dentaries, scapula, humeri, femur, and radii, one of which was not fully fused); *Lasiurus borealis* (left maxilla); and multiple individuals of *L. cinereus* (radii, one with an unfused distal shaft).

Cyclops Gateway [55 data points: 423, 818, 1521-1573]

Although Cyclops Gateway terminates after 400 feet of rocky passage, it provides alternate access to the lower level Black Snake Avenue. Bird (1837:530) called it Ruined Cave and Rocky Cave – the latter a very apt name. Regarding the connection between the old moniker and the current usage of Cyclops Gateway, Hagan and Sutton (1999) write, "This was formerly Rocky Cave, hence the association with the Cyclopes, one-eyed giants of Greek mythology. The cyclops Polyphemus, from whom Odysseus and his crew barely escaped, dwelt in a rocky cave (Homer; Odyssey)."

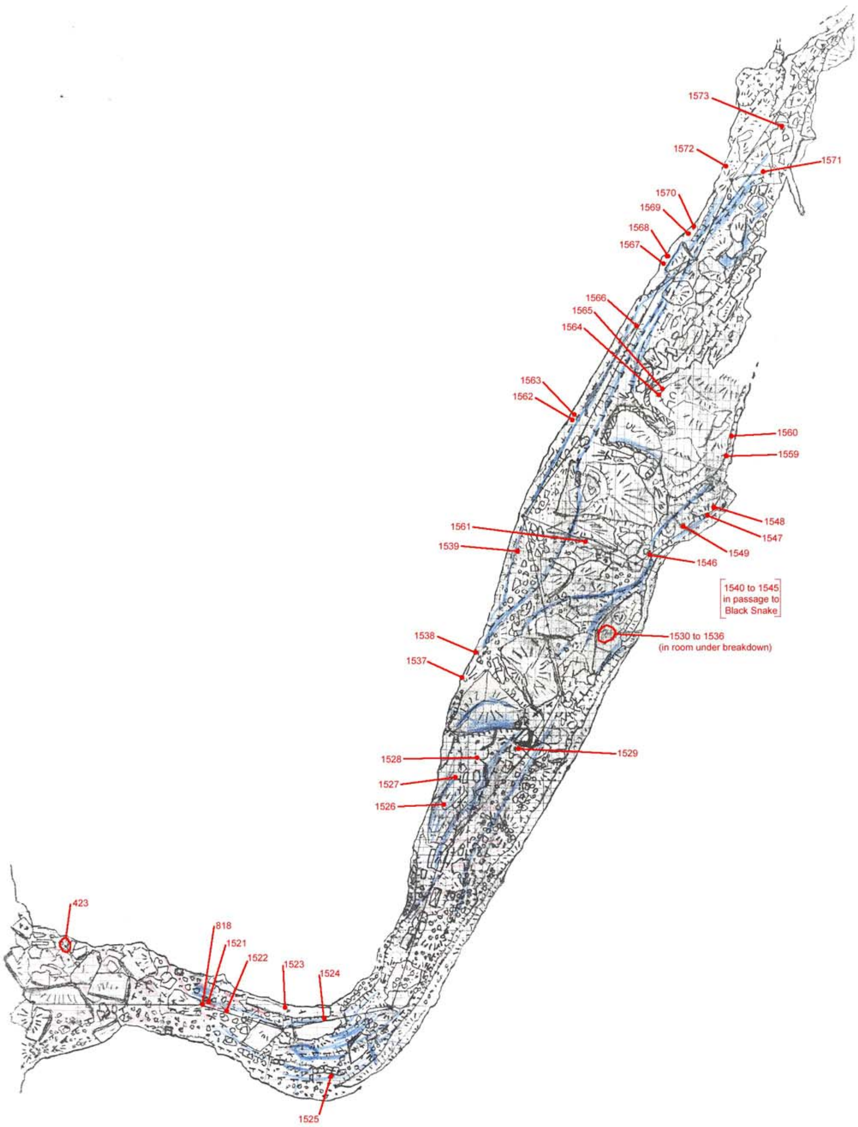

FIGURE 1-36. Side passage: Cyclops Gateway (base map cartography by CRF).

Raccoon scats containing bat bones were found at 40% of the data points in Cyclops Gateway. Soot coated nearly all of the scats, many occurrences were degraded masses of bone, and several communal latrines were located. One scat was full of gastropod shells. No raccoon bones were found.

Six data points yielded mummified bat remains (1 *Lasiurus* borealis, 1 *Myotis lucifugus*, 3 *Pipistrellus* subflavus, and 1 indeterminate bat). Bats identified from skeletal remains were *M.* cf. *leibii*, *M.* cf. *lucifugus* (a sooty skull), *M. sodalis* (7 skulls located at 6 data points), small-sized *Myotis*, medium-sized *Myotis* (most likely *M. sodalis* or *M. lucifugus*), and *P. subflavus*. Scattered bones of indeterminate bats were not very prevalent. One scattered *Neotoma floridana* skeleton and another isolated limb bone shaft were present. Indeterminate mouse bones were found at 5 points, one of which also had *Peromyscus*.

Collections were made at 9 data points. Guano from Point 818 dated to 430 ± 40 RCYBP (CAMS-63099). Raccoon scats collected from 4 points have not been processed. Four data points that had intact red sediments containing bones were sampled (Points 1562, 1565, 1566, and 1572). Each of the collection sites was a remnant of intact deposits still adhering to the cave wall in the mined area at the back of Cyclops. The fine sediments washed easily, the few identifiable bones were of small and medium-sized *Myotis* indeterminate bat, and mouse (found in all four samples).

Figures 1-37 and 1-38 show the remnant sediments that were still adhering to the cave wall long after the area was mined for sediment. Point 1562 (Figure 1-37), on the left wall, was about 12 inches wide, 4 inches high, and 2 inches thick. It appears to be an old surface layer (brownish red in color). Below it is finer, sandier beige-red sediment that was not collected. Myotis and bat dentaries and other small bones were identified.

FIGURE 1-37. Cyclops Gateway: Data Point 1562 bone-bearing sediment before collection.

The sample from Point 1566 was located 2.5 feet above the floor (Figure 1-38). Sediment scraped from the left wall, occurred in small patches (the largest was 3 by 4 inches) that were only 1 inch thick. The sample contained dentaries of medium-sized *Myotis* and several mouse bones.

FIGURE 1-38. Cyclops Gateway: small remnants of bone-bearing sediments adhering to the cave wall at Data Point 1566.

Figure 1-39 shows a sample collected from Point 1572 prior to being screen washed. On the wall, the sample was about 12 inches wide, 5 inches high, and 4 inches thick. Fragments of a bat dentary and scapula and a mouse lower incisor were recovered from the sample.

FIGURE 1-39. Cyclops Gateway: two views of the sediment sample collected from Data Point 1572; shown prior to screen washing. The sample yielded only a lower incisor of mouse and a scapula and dentary of bat.

Protected guano, extensive and heavy roost stain, and many raccoon scats full of bat bones indicate that Cyclops Gateway used to house large populations of colonial bats, probably *M. sodalis*. Based on the soot coating, it appears that the majority of bat usage in Cyclops Gateway predated the time of historic sooting. The extensive, but faded roosting stain near the passage terminus could be much older; however sediment mining has destroyed the deposits below the roost area.

Indian Avenue [7 data points: 495-501]

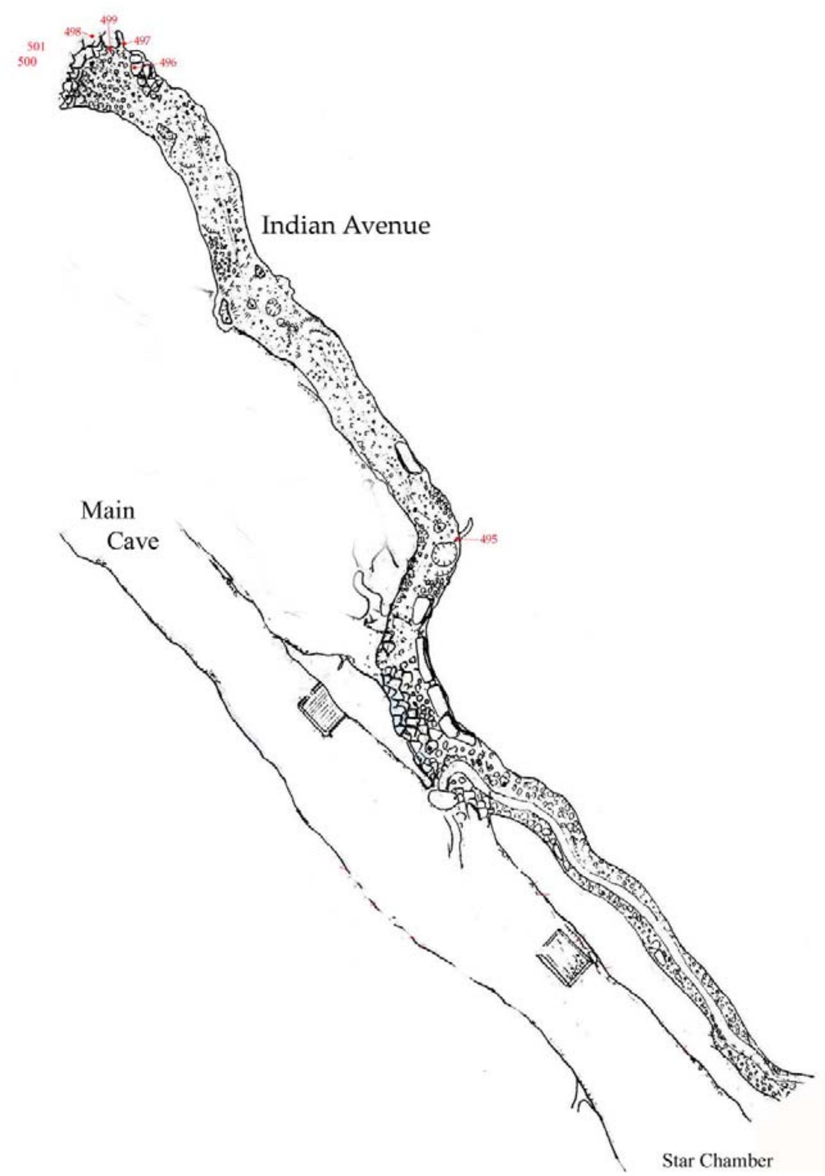

FIGURE 1-40. Side passage: Indian Avenue (base map cartography by CRF).

Indian Avenue is a passage of walking and stoop-walking height. The walls contain many solution tubes and pockets; the ceiling is largely smooth with some channels; and the floor is breakdown with a narrow path of sediment placed down the middle to facilitate walking. The passage terminates in a pile of breakdown where voice and light connections can be made in the vicinity of Giant's Coffin. Some bat guano was observed in the passage and quite a bit, in the terminal breakdown. Bone was located only at the terminal end, although only the area adjacent to the trail and some wall tubes were searched closely.

Of the seven points flagged, five yielded mummified bat remains (1 *Lasiurus borealis*, 1 *Pipistrellus subflavus*, 1 *Myotis sodalis*, and 2 indeterminate vespertilionids). A sand-floored solution tube yielded a mummified pipistrelle and the skeletonized torso and skull of another pipistrelle. Near the base of the breakdown pile is an *Eptesicus fuscus* rostrum and a sooty raccoon scat full of bat bones. The shaft of a squirrel tibia and a partial bat mummy were located in the pile and isolated bat bones were scattered throughout.

Solitary Cave [43 data points: 686-728]

Solitary Cave is accessed through a small crawl in the south wall of the Cataracts and ends beyond the formations of the Fairy Grotto at a place where a man-made dig terminates at a dripping wall and mucky floor. As one travels further into the passage, it becomes increasingly damper and finally wet; at the Fairy Grotto there is a large pool of water and just beyond is a dig with dripping water.

The damp environment and heavy cricket activity are not conducive to good preservation of organic materials and probably account for the paucity of bat guano, rat feces (found in only 2 small pockets), and mummified remains. Three-fourths of the points had indeterminate bat bones. Identified bat taxa were *Eptesicus fuscus*, *Myotis* cf. *grisescens*, *M. leibii*, *M. sodalis*, medium-sized *Myotis* sp., and *Pipistrellus subflavus*. A variety of non-bat taxa were also present: Caudata, Anura, cf. *Mephitis mephitis,* Artiodactyla, *Marmota monax*, *Neotoma* sp., *Peromyscus* sp., mouse-sized rodent, and *Sylvilagus* sp.

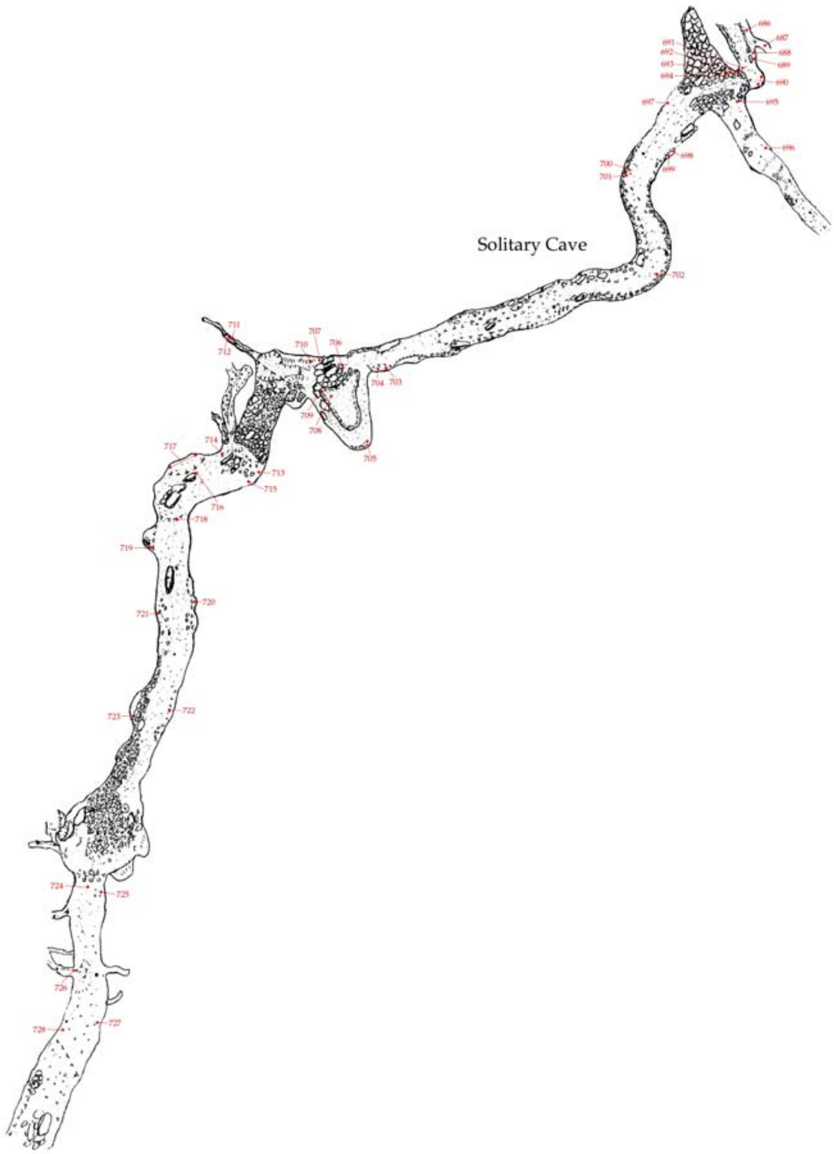

FIGURE 1-41. Side passage: Solitary Cave (base map cartography by CRF).

Black Chambers [74 data points: 1282-1354, 1363]

Black Chambers is a large passage that lies between the Chimneys at the back of Wright's Rotunda and the sandstone collapse at Double Cellars. Of Black Chambers, Hovey (1912:62) wrote, "The black oxide of manganese … swathes the walls and roof in absolute funereal black, while the enormous rocks tumbled about in the wildest disorder make a scene gloomy beyond description." Hovey was correct that Black Chambers seems a gloomy place; the years of accumulated soot that coats everything, the lack of draft that makes it feel warmer, and the silence of being somewhat separated from the Main Cave adds to the atmosphere of lifelessness that pervades the passage.

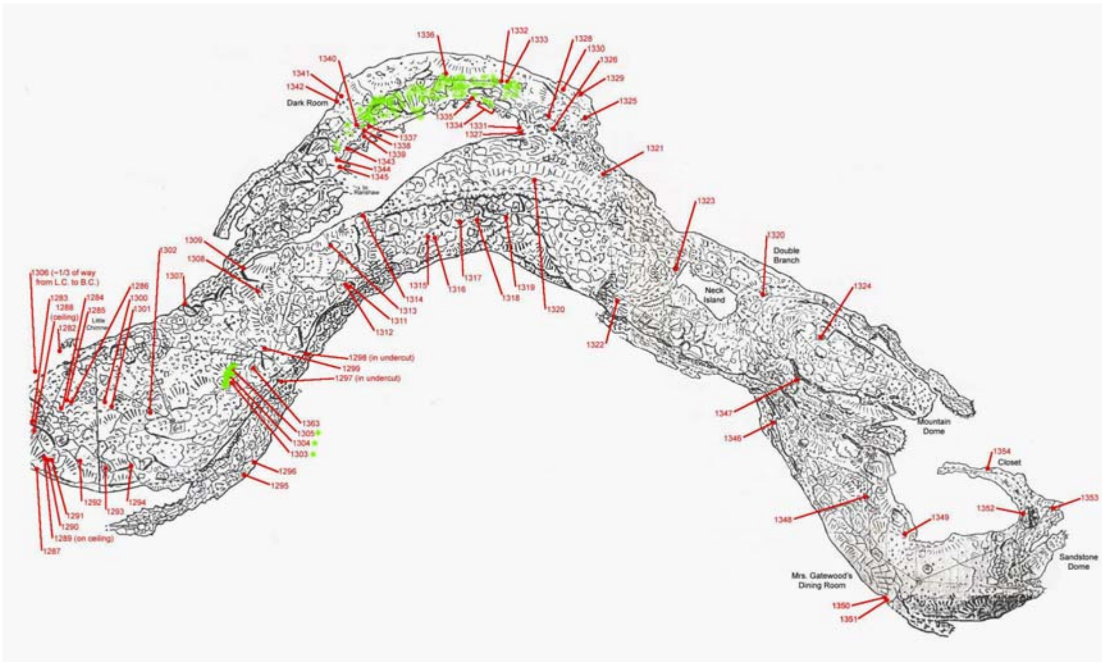

FIGURE 1-42. Side passage: Black Chambers (base map cartography by CRF).

In the summer of 1831, an English traveler, Vigne (1832:51) wrote that the only form of life he saw in Mammoth Cave was a "solitary bat" after climbing beyond one of the chimneys. Perhaps bats were not present in large numbers that summer, but more likely poor lighting hindered Vigne, or, he may have not made close observations. In the winter, Bird (1837:545) reported "we found them [bats] in numbers." Bird's statement is interesting because the skeletal evidence for bats is low and raccoon scat is non-existent. However, pellets of bat guano are ubiquitously scattered throughout. They are a mixture of old and new. Two samples of guano pellets taken from small piles (Points 1299 and 1322) were dated to 460 ± 40 RCYBP (CAMS-83266) and 1,115 ± 40 RCYBP (CAMS-83265), respectively.

The most intriguing bat evidence is the accumulations of dark reddish-brown guano, which is reminiscent of the ancient guano found in Chief City, St. Catherine City, and Wright's Rotunda. The dark brown guano was found at 3 locations in the main portion of Black Chambers and at 5 in the lower leveled Dark Room; none was submitted for radiocarbon dating. The localities in the main area are thin layers of compressed brown guano with adjacent cocoa colored, fluffy fine sediment that is most likely a mixture of guano and sediment:

- Point 1303 thin layer at surface, reddish-brown, granular-looking texture
- Point 1304 thin layer protected under an angled piece of breakdown,
  6 feet downslope from previous point
- Point 1305 thin layer under a rock, 20 feet downslope from previous

The Dark Room is a 250-foot long cut-around that is lower than the main level, the ceiling of the Dark Room being at about the floor level of the main room. Five data points were designated for ancient guano, but in actuality, much of the floor of the Dark Room is covered with a fine cocoa-colored sediment, which most likely is a mixture of sediment and large quantities of trampled bat guano. Could the "Dark Room" be named for the dark coloration caused of the trampled bat guano?

All remains identified to *Lasiurus borealis* were mummified. They occurred at 36% of the data points (27 of 74). Of the red bats, a few were skeletonizing, 14 were moldy, many were still hanging, and most appear to have been males (based on dark red fur). Other mummified bats were *Myotis sodalis* (3 points), *M. lucifugus* or *sodalis* (1), *M.* cf. *septentrionalis* (1), medium-sized *Myotis* (2), cf. *Myotis* (1), and *Pipistrellus subflavus* (6). Interestingly, species found in mummified form were not represented by isolated bones. Bones were identified as *Eptesicus fuscus* (found at 5 data points), medium-sized *Myotis* (1), and *Myotis* sp. (3). *E. fuscus* was represented by bones only. A single dentary fragment was found by a solution tube that had other assorted materials gathered by *Neotoma*. Four of the data points were in the proximity of Sandstone Dome. One of the points has numerous bones and burned cane in dry, gray sediment, limestone flakes, and small rocks that were drifting downward into a crack between a large breakdown block along the right wall and the right wall, itself. Elements of multiple *E. fuscus* were found in this loose sediment. In addition, many elements (claws, phalanges, ribs, metapodials, caudal vertebrae, thoracic vertebrae, innominate, left and right astragali) of a small animal were buried in the loose sediment. No skull or teeth were found, but the right astragalus and left innominate were collected and later identified as

Mustela vison. In the past, more openings in the sandstone breakdown would have made this part of Black Chambers colder and more inviting to *E. fuscus*. A possible *Peromyscus* dentary was found near the breakdown in a sandy-floored solution tube known as the Closet.

Evidence of *Neotoma* activity was recorded at 15 data points and includes: lengthy rodent runs (6 data points) in the upper chamber and in Mrs. Gatewood's Dining Room, areas of feces (3), small larder accumulations (6), and *Neotoma* bones (3). These woodrat runs appear as a reddish-brown, polished patina on many of the large angled slabs. Such polished runs are more extensive here than in any other area of Mammoth Cave. Six data points (Points 1329, 1331, 1334, 1335, 1343, 1345) denote a series of solution tubes and associated ledges along at least 50 feet of the south wall of the Dark Room. Woodrats may have dropped the assorted items as they were being transported in or out of the tubes. The accumulations were not dense, but they were varied. Sediment in the tubes is dark and the bone is orange-red to red-brown, some sediment seems to be a mixture of ancient guano, sediment, and burned cane/soot. Accumulated items included the following:

- Point 1329: woodrat accumulation located against wall on shelf contains fiber, nuts, fungus on nuts.
- Point 1331: Large snake (vertebra with rodent gnaw marks), mouse (lower incisor), *Myotis* sp. (dentary fragment)
- Point 1334: broken bat bones; *Myotis* sp. (rostrum); medium-sized *Myotis* (left dentary fragment); *Eptesicus fuscus* (left dentary fragment); *Marmota monax* (upper right incisor and metapodial); *Neotoma floridana* (lower left incisor, 2 left humeri fragments, 1 lumbar, 1 cervical, 1 unfused distal femur epiphysis, 1 ilial fragment of a juvenile, palate); mouse (left upper and lower incisors); passerine (carpometacarpus)
- Point 1335: *Neotoma* feces and nuts shells
- Point 1343: bone fragments that are dark reddish brown on gray-brown sediment, *Myotis* sp. (fragments of dentaries and maxilla), mouse (incisors)
- Point 1345: accumulation of wood, burned cane, and historic human feces.

The Paleontological Inventory Project visited Black Chambers during the winter (March and December 1999), but no clusters of hibernating bats were observed. In fact the passage felt too warm for bat hibernation. The numerous dead *Lasiurus borealis* – a species not adapted to caves –supports this suspicion. Yet, the guano evidence in the Dark Room indicates that in the past there was intensive and repeated utilization by colonial bats that is not reflected in skeletal evidence. Perhaps the highly active woodrats collected the dead bats. Perhaps raccoons did not have an accessible entrance in close proximity or the usage was in summer, and raccoons were more successful at procuring torpid bats in hibernation. The nearest possible opening to the surface – Sandstone Dome – may have once been a traditional entrance for bats, but it collapsed and excluded the bats. Or, as Sandstone Dome became plugged, it changed the microclimate in the Dark Room making it inhospitable for bats. It is likely that such changes occurred at multiple times in the past; they would have impacted bat usage in the guano-laden area of Wright's Rotunda.

Blackall Avenue [6 data points: 1360-1362, 1518-1520]

Six points were recorded in the 2000-foot long passage of Blackall Avenue. As was the case in Blue Spring Branch, few signs of recent bat usage, pelletized guano, bone, or stain was found. An odd feature on the left side of Blackall Avenue is a narrow, man-made dig into the massive fill. The walls of the dig were thoroughly inspected in the hope of finding *in situ* bone. The only find (point 1362) was a proximal portion of a dentary from a large-sized bat mandible, which was found near the top of the right hand wall, less than 10 feet into the dig. A fragment of bat humerus was found on the dig floor.

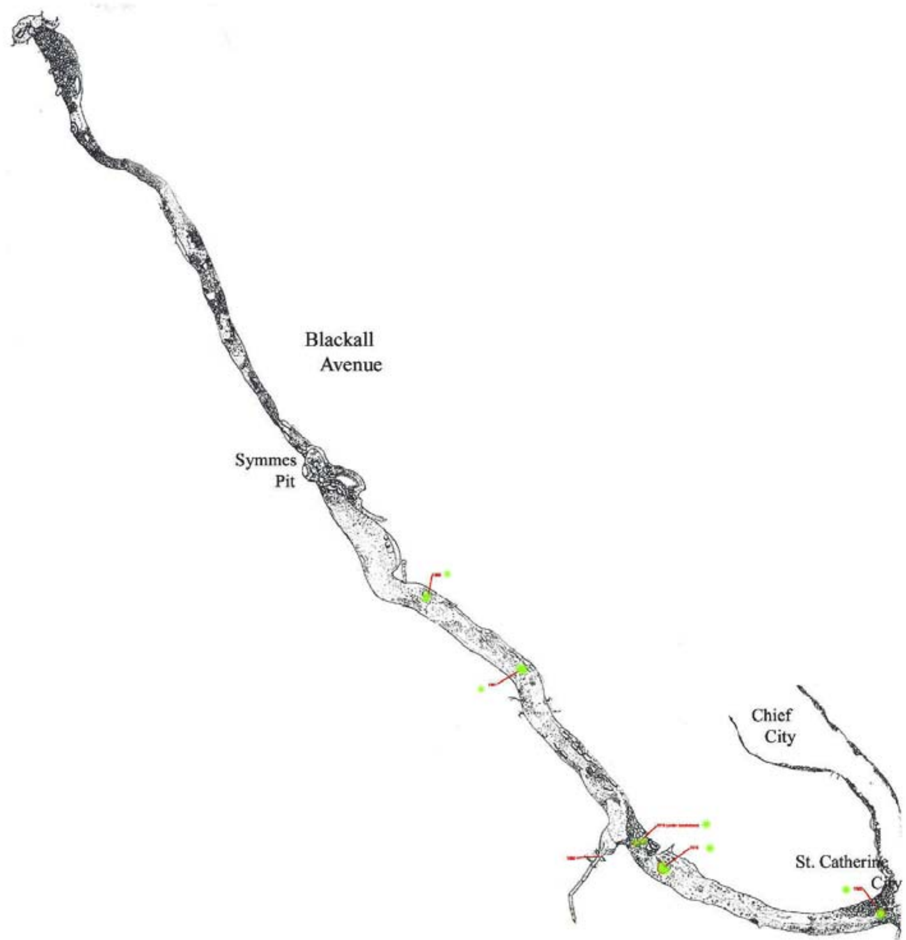

FIGURE 1-43. Ancient upper level passage, high in B-Level: Blackall Avenue (base map by CRF).

A sediment sample was collected, but it yielded no bone. The floor in the rest of Blackall Avenue is very fine silt; the 5 locations are exposures of ancient guano; none has associated bone. The guano deposits, listed below, are tentatively referred to cf. *Tadarida* based on the proximity of known *Tadarida* deposits in Blue Spring Branch and in Main Cave areas:

- Point 1360 denotes 3 smears of ancient guano covering a 3-foot by 12-inch strip
- Point 1361 denotes 2 smears of ancient guano in the center of Blackall Avenue. They are about 15 feet apart and one area has small, flat clumps of dark guano.
- Point 1518 denotes several thin layers of ancient guano visible directly beneath a large breakdown pile. The 2 cm thick layer has at least two white layers within it.

- Point 1519 denotes several exposures of thinly layered ancient guano under small fragments of breakdown. The sediment over the 20-foot by 20-foot area is a fine powdery, light cocoa color, whereas non-guano areas and the sediment underneath the guano are yellow-beige in color. In the vicinity of this point, guano is present in the middle of the passage, but not along the right wall where sediment was mined. It appears that breakdown fell and compressed the thin deposit of guano. No bone was found despite a long, intensive search.
- Point 1520 is located in the trail at the mouth of Blackall Avenue where ancient guano has been scuffed up from just below the surface. Where guano has fallen on pieces of limestone, the limestone has deteriorated and turned white.

Blue Spring Branch [6 data points 1177, 1355-1359]

Only six data points were recorded in the 2500 feet of passage that comprise Blue Spring Branch. The floor consists of breakdown, fine silt, and sand. Signs of recent bat usage were few; there were no accumulations of pelletized guano, little bone, and little stain. What was found, however, is important because all six points in Blue Spring Branch denote areas of ancient guano. The most significant location in Blue Spring Branch is point 1356, a deposit of light, beige-colored guano pellets and identifiable bone found under a 3-foot by 3-foot angled slab of limestone. When a sample of bone was spooned out of the deposit, the pellets readily turned to powder. All of the bone in the collected sample is colored a reddish, medium to dark brown. The following skeletal elements were identified to *Tadarida*: left dentary (nearly whole but missing part of the ascending ramus; with pm1, m1-3), right dentary (whole with p3-4, m1-3), fragments of left and right humeri and radii, femur, right maxilla (with i1, p4, m2-3), and left maxilla and partial palate with p4, m2-3. In addition, it is likely that several rib fragments, vertebral fragments, toe phalanges, numerous whole and broken metacarpals, two loose molars, and an auditory bulla are *Tadarida*.

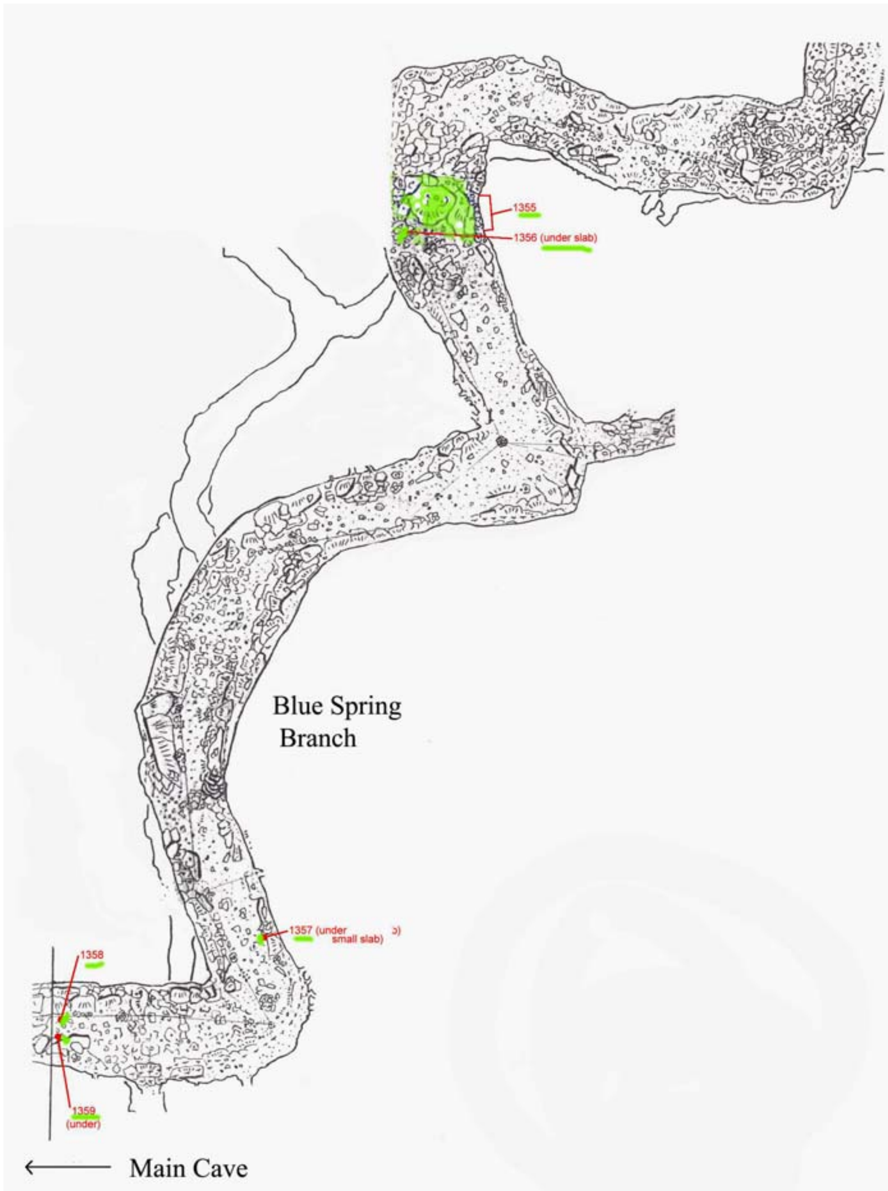

FIGURE 1-44. Ancient upper level passage, high in B-Level: Blue Spring Branch (base map cartography by CRF).

The other 4 locations - points 1177, 1355, 1357, 1358, and 1359 - denote guano deposits without bone. Point 1177 is located about 15 feet inside the entrance, in a crawl that is under the breakdown slabs that go up into Blue Springs Branch; the crawlway has actual cave wall on the right and breakdown on left. Brown sediment that resembles a mix of sediment and disintegrated ancient guano (with no visible pellets or layers nor bone) was conferred to *Tadarida*. At point 1355, darkly colored ancient guano is strongly signaled on top of and underneath pieces of breakdown that form a low rise in a 40-foot by 15-foot area, and light chocolate-colored sediment extends another 15 feet before and beyond the main guano deposit. Some chunks of guano show layering. This large guano deposit is identified as *Tadarida* based on point 1356, which is only 30 feet away. Point 1357 is a deposit of ancient guano found under a large angled slab of limestone; 6 inches of a light brown mixture of fluffy guano and sediment overlie a 1-inch thick deposit of ancient guano and white, soft decomposed limestone. Guano appears to have been trampled by foot traffic. Points 1358 and 1359 are located near the top of the entrance climb into Blue Spring Branch. Point 1358 is a narrow (3 feet long by up to 8 inches wide) smear of exposed ancient guano. Point 1359 signifies 3 chunks of ancient guano found under a slab, well camouflaged by a coating of disturbed surface sediment. It is quite likely that roosting free-tailed bats made the 5 guano deposits that had no associated bone.

TABLE 1-3. Distribution of vertebrate taxa in side passages of Historic Mammoth Cave. Numbers in cells indicate the number of data points at which each taxon was located. Total number of data points found in each section appears in parentheses. * The assignment of one data point number to the guano masses at Lookout Mountain grossly underrepresents aerial spread of the guano and the population of Myotis grisescens that would have produced it.

Taxon	***Houchins' Narrows (121)***	***Little Bat Ave. (34)***	***Lookout Mtn. (152)***	***Bunker Hill to Olive's Bower (96)***	***Corkscrew & Vanderbilt Hall (36)***	***Back-slider's (39)***	***Gothic Ave. (133)***	***Cyclops Gtwy. (55)***	***Indian Ave. (7)***	***Solitary Cave (43)***	***Black Ch. (74)***	***Blackall Ave. (6)***	***Blue Spring Br. (6)***
MAMMALIA													
Scalopus aquaticus				2									
Desmodus stocki						1							
Eptesicus fuscus	21	3	5	3	3	4	9		1	1	5		
cf. *E. fuscus*	1					3	1						
Lasiurus borealis	1		1		1	8	39	1	1		27		
L. cinereus						2	4						
Myotis cf. *austroriparius*							1						
M. grisescens	3		(1) *		1	2	9						
M. cf. *grisescens*	3	2		3		1	2			2			
M. leibii					1	2	5			2			
M. cf. *leibii*	5	5	1		1	2		1		1			
M. lucifugus			1			2	1	1					
M. cf. *lucifugus*	1						2	1					
M. cf. *septentrionalis*											1		
M. sodalis	2	2	1	2			2	6	1	3	3		
M. cf. *sodalis*	1			2						1			
M. sodalis or *lucifugus*											1		
Myotis sp., small-sized	1						1	1					
Myotis sp., medium-sized	13	9	17	24	9	9	17	15		4	3		
Myotis sp.	31	3	4	9	2	3	20	2		3	3		
cf. *Myotis* sp.	3	1		1		2	1				1		

Taxon	***Houchins' Narrows (121)***	***Little Bat Ave. (34)***	***Lookout Mtn. (152)***	***Bunker Hill to Olive's Bower (96)***	***Corkscrew & Vanderbilt Hall (36)***	***Back-slider's (39)***	**Gothic Ave. (133)**	***Cyclops Gtwy. (55)***	***Indian Ave. (7)***	***Solitary Cave (43)***	***Black Ch. (74)***	***Blackall Ave. (6)***	***Blue Spring Br. (6)***
Nycticeius cf. *humeralis*							1						
Pipistrellus subflavus	4		2	10	4	4	10	6	1	1	6		
cf. *P.subflavus*	1		1	2			2	1					
Corynorhinus sp.	1			1									
Vespertilionidae	112	30	133	37	32	24	78	46	4	31	69	1	
Tadarida sp.						1	1						2
cf. *Tadarida* ("ancient" guano)												6	3
Chiroptera, "Ancient" guano							6				8		
Procyon lotor	26	19	32	19	11	3	6	22	1				
Mustela vison											1		
cf. *Mephitis mephitis*										1			
Carnivora	3			1									
Odocoileus virginianus		1											
Artiodactyla										1			
Marmota monax										1			
Sciurus sp.									1				
Tamias sp.	1												
Neotoma floridana	6	2	7	13	8	1	10	2		12	15		
cf. *Neotoma*				2									
Peromyscus sp.				3			4	1		2			
cf. *Peromyscus* sp.				2							1		
Rodentia, mouse-sized	3	1		4		3	3	5		13	3		
Cricetidae								1					
Sylvilagus sp.				1						1			

Taxon	***Houchins' Narrows (121)***	***Little Bat Ave. (34)***	***Lookout Mtn. (152)***	***Bunker Hill to Olive's Bower (96)***	***Corkscrew & Vanderbilt Hall (36)***	***Back-slider's (39)***	**Gothic Ave. (133)**	***Cyclops Gtwy. (55)***	***Indian Ave. (7)***	***Solitary Cave (43)***	***Black Ch. (74)***	***Blackall Ave. (6)***	***Blue Spring Br. (6)***
Homo sapiens					1			1					
Indeterminate mammal	3									2			
AVES													
Gallus gallus		1	1		3		4						
cf. *Gallus gallus*	2												
Passeriformes			1								1		
Unknown bird							1						
REPTILIA													
Colubridae							1						
Crotalus sp.				1									
Serpentes											1		
AMPHIBIA													
cf. *Cryptobranchus* sp.						1							
Caudata							1			1			
Bufo sp.										2			
cf. *Bufo*							1						
Rana sp.							1						
cf. *Rana* sp.										2			
Anura	2			2									
Amphibia						1							
cf. Amphibia										1			
OSTEICHTHYES													
Ictaluridae	1												
cf. *Moxostoma*	2												
Unknown Fish	1												
Fish or salamander						1							
Indeterminate vertebrate	2			1		1							

HISTORIC SECTION INTERPRETATION AND CONCLUSIONS

The Paleontological Inventory Project's intensive search for vertebrate remains in the Historic Section of Mammoth Cave yielded a diverse faunal assemblage that is rich in bat remains. Faunal remains were noted for 1553 data locations/points. This outcome was surprising in light of the fact that humans have conducted a variety of activities in the cave for the past 4,000 years. With the arrival of Euro-Americans 200 years ago, human activities and modifications to the cave escalated and intensified; these made the cave microclimate inhospitable to bats, some purposely excluded bats, drove bats out, and obscured evidence of bat use. Allochthonous vertebrate remains discovered during this study could have resulted from a variety of mechanisms. The animals might have flown or walked into the cave, and then died; carcasses might have been carried in by other animals; whole animals or just their bones could have fallen into (or were washed in) surface openings, fissures, or sinks; and bones might have washed in with fill sediments. Paleontological materials were found in a variety of contexts: on surfaces (floor, breakdown, walls, ceiling), mixed with upper sediments, and buried in old passage fills.

Remains representing more than 40 different animal taxa were located. The majority of remains were from bats; 13 taxa were identified. Of the non-bat taxa, the most frequently encountered were raccoon, woodrat, mice, and domestic chicken. The following animals were identified from bone, but were found infrequently: Old World rat (*Rattus* sp.), dog/coyote (*Canis* sp.), mustelid, domestic pig and/or cow, deer, squirrel, rabbit, phasianid, turkey, screech owl, northern flicker, perching bird, various amphibians, snake, turtle, and fish. Both raccoon and woodrat are known to frequent caves. Bones, footprints and trails, latrines, scattered feces, nests, and larders indicate that rats have roamed over large segments of the study area. It is likely that most of this evidence is derived from woodrats (*Neotoma floridana*) rather than the Old World rat (*Rattus* sp.), which was not well represented. Based on the materials found in the accumulations, the woodrat nests and larders are relatively recent (likely less than 5000 years old). Woodrats occur in the cave at the present time. Mouse remains are not uncommon in the study area. Most probably represent the native white-footed or deer mouse (*Peromyscus* sp.); however, a few were from the introduced house mouse (*Mus musculus*). Obvious non-native species ─ chicken, *Rattus*, pig or cow ─ and probably the *Canis* sp. (dog or coyote) were deposited by humans. Remains from other taxa that were native to the area could be human food debris and/or woodrat treasures. Various small taxa (amphibians, fish, small bird, and rabbit) could have been prey items deposited by other animals. The screech owl was a recent entrant to the cave (it is a fine example of an accidental). The area of the cave between the Acute Angle and the Snow Room contains a number of non-bat remains. Historic food debris near the TB huts consisted of bunched up cloth containing several animal bones.

A question frequently asked about the faunal remains is "How old are they?" While this is a very important question, it is one that is not easily resolved. Traditionally, age determinations are based on rock stratigraphic associations, faunal associations, contextual clues, or the use of absolute dating methods such as radiocarbon, uranium series, and Al/Be ratios. The major problem with materials in a cave is that of time averaging. That is, while much time has passed since many of the animal remains entered the cave record, very little sediment deposition has occurred. Most of the fossil finds do not occur in stratified contexts. Thus, a *Tadarida* bone that we know is associated with guano more than 48,000 years old might be lying on the surface next to a 500 or a 2000-year-old *Myotis* mummy, which in turn might be next to an odiferous *Pipistrellus* mummy that was gathered by a woodrat or is being scavenged by crickets. Low depositional rates coupled with the cave's excellent conditions for preservation of organic remains, mean that a researcher cannot judge age just by looking at a bone or a bat mummy or at its location. Additionally, some of the limestone, sediment, and the faunal remains have a heavy coating of soot. Cane torches used in prehistoric times were a source of the smoke and soot that coat surfaces and objects in the cave. The greatest sources were probably the historic period lamps, which burned various animal oils or kerosene. Thrown cloth torches were another source of soot, and this practice continued on a limited basis into modern times. For these reasons, many materials that lacked a coating of soot could be assessed as "recent," i.e., postdating the 19th and early 20th

centuries. However, bones protected within sediments were also free of soot. Such deposits were found at Rafinesque Hall, The Barrow Pits, Gothic Avenue, Backslider's Alley, Wright's Rotunda, and two stretches of Main Cave (just beyond Gothic Avenue and from Bryan's Pass to Mayme's Stoop). Because it was not possible to radiocarbon date every interesting bone, mummy, or guano deposit we are left with many unanswered questions of the "How old is it?" type. We can state the age of a dated item and discuss that item; but we must be careful about inferring the age of one specimen or deposit based on the age of a nearby specimen.

General statements can be made about the age of the inventoried materials. They range in age from very recent to perhaps greater than one million years in age. Most of the dated material is Holocene in age dating to 10,000 years or less. Fifty samples were submitted for radiocarbon dating. The results from 31 datable items are given in Table 1-5 and demonstrate that Mammoth Cave has been exploited by a changing regime of bat species over a very long period of time. Based on Al/Be dating of quartz in gravels and sands and on context, the vampire bat femur extends the presence of bats in Mammoth Cave back to at least 1 million and perhaps as much as 2 million years.

TABLE 1-5. Radiocarbon dates from the Historic Section of Mammoth Cave.
Abbreviations are as follows:
RCYBP= radiocarbon years before present
EWP = 1995 Earthwatch Paleontology Project
GEOCHRON = Geochron Laboratories, Cambridge, Massachusetts; GX #
INSTAAR = Institute of Arctic and Alpine Research at the University of Colorado at Boulder
LLNL = Lawrence Livermore Laboratories Center for Accelerator Mass Spectrometry, California; CAMS #
SR = Stafford Research Laboratories, Inc., Boulder, Colorado

ISM Data Point #	***Location in cave***	***Material dated***	***Laboratory & lab number***	***Date RCYBP***	***Error***
Point # 828	Houchins' Narrows	Medium-sized *Myotis* 3 humeri	SR & LLNL CAMS-63091	9810	50
Point # 834	Houchins' Narrows	Bat guano	SR	No date	
Point # 842	Houchins' Narrows	*Eptesicus fuscus* 2 humeri	SR	No date	
Point # 853	Houchins' Narrows	Raccoon scat	SR & LLNL CAMS-55908	470	60
Point # 167	Audubon Avenue	Raccoon scat	GEOCHRON GX-24025	345	100
Point #1402	Audubon Avenue	Bat guano	CAMS-83259	550	40

ISM Data Point #	***Location in cave***	***Material dated***	***Laboratory & lab number***	***Date RCYBP***	***Error***
Point # 330 (=EWP LBA #1)	Little Bat Avenue	Bat humerus	Dissolved at INSTAAR	Failed to date	
Point # 369	Little Bat Avenue	Raccoon scat	GEOCHRON GX-24026	110	90
Point # 184	Rafinesque Hall	*Myotis* humerus and large bat humerus	SR	Failed to date	-
Point #1063 (EWP-255)	Rafinesque Hall, left side, from top of guano mass	Guano (probably mix of bat and raccoon)	INSTAAR & LLNL CAMS-27970	290	50
Point #1064 (EWP-256)	Rafinesque Hall, left side, 17 cm below top of guano mass	Guano (probably mix of bat and raccoon)	CAMS-24124	200	60
Point #1065 (EWP-257)	Rafinesque Hall, left side	Guano (probably mix of bat and raccoon)	INSTAAR & LLNL CAMS-27966	280	60
Point #1076 (EWP-269)	Rafinesque Hall, left side	Raccoon scat fragment	CAMS-24123	410	50
Point #1002 (EWP-129)	Lookout Mountain	Medium *Myotis* humerus	INSTAAR & LLNL CAMS-24971	170	50
Point #1019 (EWP-164)	Lookout Mountain, left wall near top	10 dram sample of bat bones in guano mass	INSTAAR & LLNL CAMS-27972	8690	60
Point # 113	Bunker Hill	Wing elements of medium *Myotis* mummy	SR & LLNL CAMS-55909	1,960	40
Point # 127	Bunker Hill	Raccoon scat	CAMS-46215	540	90
Point # 81	Barrow Pit between Bunker Hill & Mushroom Beds	Various bones from floor sediment	SR	Failed to date	------
Point # 35	Vespertilio Hall	Bat guano	SR & LLNL CAMS-46212	100	40
Point # 43	Vespertilio Hall, sample from ceiling	Bat roosting stain on ceiling limestone	SR	No date	
Point # 277	Broadway	Bat guano	CAMS-46214	210	70
Point # 258	Corkscrew	Bat guano	CAMS-46213	1530	50
Point # 1273	Back of Vanderbilt University Hall under rock below A 3	Bat guano, small sample taken from this for AMS dating	Stafford for processing CAMS-83267	8,255	40
Point #1274	Top of Vanderbilt University Hall, at TA 7	~15g of bat guano	GEOCHRON GX-27144	2,090	80
Point #1275	Top of Vanderbilt University Hall just beyond TA 8	~20g of raccoon scat	GEOCHRON GX-27148	920	70
Point # 937	Gothic Avenue	Bat guano pellets	CAMS 83260	450	45
Point #1436	Gothic Avenue	Raccoon scat	CAMS-83261	1,240	45

ISM Data Point #	***Location in cave***	***Material dated***	***Laboratory & lab number***	***Date RCYBP***	***Error***
Point #1465	Gothic Avenue	Ancient guano	Stafford for AMS	No date	
Point #1471	Gothic Avenue	2 bat humeri	Stafford for AMS	No date	
Point #1479	Gothic Avenue	2 bat humeri	CAMS-83262	1,195	50
Point #1493	Gothic Avenue	2 bat humeri	SR & LLNL CAMS-83263	10,690	80
EWP Backslider's #1	Backslider's Alley, right side	Medium *Myotis* humerus	Dissolved at INSTAAR	Failed to date	------
EWP Backslider's #3	Backslider's Alley, left side	*Lasiurus cinereus* humerus	Mostly dissolved at INSTAAR & did not date at LLNL	Failed to date	------
EWP Backslider's #4	Backslider's Alley, left side	cf. *Pipistrellus* humerus	Dissolved at INSTAAR	Failed to date	------
EWP Backslider's #5	Backslider's Alley, right side	Medium *Myotis* humerus	Dissolved at INSTAAR	Failed to date	------
Point # 401	Backslider's Alley (pancake room area)	Untreated bat guano	LLNL CAMS-46216	2,120	80
Point # 384	Broadway just past Gothic Ave., right side sediment sample	2 bat humeri	SR	Failed to date	------
Point # 818.	Cyclops Gateway	Bat guano	SR & LLNL CAMS-63099	430	40
Sparks # 1	Sparks Avenue in Mammoth Cave	Untreated wood found in sandy passage fill; Toomey estimated age to be >35,000 year old	LLNL CAMS-46217	110 radiocarbon date suggests that log may be flood debris	60
Point # 539	Star Chamber	Bat wing elements from mummy	SR & LLNL CAMS-55907	420	50
Point # 557	Star Chamber-Proctors Arcade area	Human paleofeces containing bat bone, plant material was dated	CAMS 66111	2,550	40
Point # 519	Proctors Arcade	Bat wing elements from mummy	SR & LLNL CAMS-55910	700	40
Point # 774	Wright's Rotunda, surface sample from lower breakdown room	29.5 g bat guano pellets	GEOCHRON GX-24446	9,170	130
Point # 774	Wright's Rotunda, surface sample from lower breakdown room	Bat guano pellets	LLNL CAMS-63100	8,460	40

ISM Data Point #	***Location in cave***	***Material dated***	***Laboratory & lab number***	***Date RCYBP***	***Error***
Point #814	Wright's Rotunda	Ancient bat guano (subsample 1)	SR & LLNL CAMS-63092	42,440	720
Point #1299	Black Chambers	Bat guano sample 1.	CAMS-83266	460	40
Point #1322	Black Chambers	Bat guano sample 2	CAMS-83265	1,115	40
Point # 761	Settle's Gorge	Bat guano pellets	SR & LLNL CAMS-63093	>54,000	
Point #1141	Chief City, ledge just beyond	Bat guano pellets	CAMS-83258	7,315	40
Point #1220	Anzer's Hall at Ultima Thule, left wall	Bat bone on ledge	SR & LLNL CAMS-83264	12,400	550

Both natural and human-caused events have changed passage configurations and have had deleterious effects on bat habitat. Colonial species in particular are known to suffer from the ravages of small changes in cave microclimate. As the cave microclimate changed, bats preferentially used different areas. Natural changes that took place include full or partial collapse of sink entrances, plugging of small holes and fissures, and major breakdown within passages. Altered entrance access, modified passage configurations, noise, thrown torches, chemical light sources, and lantern smoke are some of the human caused disturbances. Examples of major human or natural modifications occur in Houchins' Narrows, the Corkscrew, Backslider's Alley, Little Bat Avenue, Vespertilio Hall, Gothic Avenue, Cyclops Gateway, Black Chambers, and Ultima Thule.

Until the Illinois State Museum conducted the inventory in the Historic Entrance Area and the Paleontological Inventory Project, the main evidence for the incredible bat population that once resided in Audubon Avenue was historic observations like that of the English traveler, William Blane:

> The smell caused by such a multitude of these animals was very unpleasant. It would be a curious speculation to calculate how many bushels there were of them; for I imagine that, like Ali Baba's money, they could not be counted in a less compendious manner.
>
> (Blane 1824: 268)

Areas mentioned in the early historical literature as having large numbers of bats were on the popular, high-traffic tour routes. Such areas have been so highly disturbed that there are few physical remains of the bats themselves, and signs like staining and guano can be obscure. For example, no visible remnants remain of the centuries old, undisturbed guano deposits in Audubon Avenue that Hovey (1881: 369) touted would be a boon for a proposed mushroom farm. The primary physical evidence indicating that Vespertilio Hall was an intensively used hibernaculum is the heavy development of roosting stain and corrosion on the ceiling. Less obvious evidences are raccoon scats in branches off of Vespertilio Hall, guano pellets that filtered into the breakdown, and some of the bats collected by Hall that are curated at the United States National Museum.

Despite the high degree of human-caused disturbance and destruction, there are discernable patterns of past bat use. The Paleo Project actually did discover large quantities of bat remains in less traveled portions of the Historic Section and in protected areas. Thirteen bat taxa have been identified based on guano, roosting staining, bones found in raccoon scat, mummified remains, isolated bones, and bones in undisturbed sediment. Evidence for eastern pipistrelles (*Pipistrellus subflavus*) is evenly distributed throughout the cave; this reflects their modern natural distribution. They were more commonly identified from mummies than from bone (this may be due to preservation bias or to differential discovery of their small, delicate bones). Evidence for little brown bat (*M. lucifugus*), Indiana bat (*M. sodalis*), and indeterminate medium-sized *Myotis* is common throughout the cave, but also indicates areas of concentration. Bones of big brown bat (*Eptesicus fuscus*) and small-footed Myotis (*M. leibii*) are very abundant in certain sections of the cave. Although red bats (*Lasiurus borealis*) were usually found as recent mummies in warmer passages, it and the hoary bat (*L. cinereus*) are also represented by bone in Backslider's Alley. The remains of free-tailed bat (*Tadarida* sp.) remains are very abundant in specific segments of the cave. Less ubiquitous bats species are gray bat (*M. grisescens*), northern long-eared bat (*M. septentrionalis*), hoary bat (*L. cinereus*), and big-eared bat (*Corynorhinus* sp.). A single bone fragment represents the extinct vampire bat, *Desmodus stocki*.

Numbers of skeletal remains were not tallied because they could not be used to determine absolute numbers of bats in an area; rather, the fauna provided other types of information. The physical remains of bats (bones and mummified remains) provide taxonomic information and relative taxonomic representation. Location of physical remains, guano, stain, and raccoon scats can be used to interpret relative roost preferences. Bone-filled raccoon scats and mummified remains are evidence that hibernating colonial bats utilized the cave at various times; however, because both are movable, scats and mummies are not necessarily located where the bats roosted. Guano deposits may be the best non-mobile, datable evidence indicating the location of roosting bats, but it is easily destroyed by human activities.

Bat guano is present in a variety of coverage types: from scattered, to a thin veneer, to aggregations. Pellets of guano are ubiquitous, being visible in virtually all undisturbed areas of the cave. As noted in the methods section, guano is so widespread that each deposit could not be mapped individually. Because guano, like other remains, was subject to great disturbance, its absence is not necessarily meaningful. However, the presence of abundant guano is used to identify areas that were either utilized by large numbers of bats or were visited repeatedly, or both. The guano includes material deposited during both winter (insect parts absent) and summer (insect parts present). Aggregated guano is separated into the following four categories:

- Thick accumulations of pellets. They are located in several locations: Vespertilio Hall, the Corkscrew, Vanderbilt University Hall, the distal half of Gothic Avenue, in the pancake room at the end of Backslider's Alley, Cyclops Gateway, Wright's Rotunda, Chief City, and the entrance to Blue Spring Branch.
- Masses of guano representing summer time use by a colonial species (most likely a mixture of bats dominated by *M. grisescens*). Guano masses are located along the left side of Lookout Mountain.
- Ancient guano associated with skeletal elements identifiable to *Tadarida*. Such deposits are located at various places between Bryan's Pass and Maymes Stoop, and in Blue Spring Branch.
- Ancient guano that had no identifiable bone with it or near it. Bone-free ancient guano is located in Black Chambers, Blackall Avenue, Anzer's Hall, and at several places in Wright's Rotunda.

Ceiling and wall stain are generally disturbed in that they have been obscured by smoke and soot, peeled away by rock spalling, and destroyed by Native American mining of gypsum from the walls (although gypsum crust is not the favored roosting medium). Absence of stain cannot be considered significant because only intensive roosting will result in visible levels of staining. Stain intensity increased with the number of bats, the density of roosting, and the length of time a roost was used. Unfortunately, it is not possible to quantify these relationships for past usage; thus, staining provides a *relative* measure of former use intensity. Areas exhibiting heavy bat staining are as follows:

- Little Bat Avenue
- ceiling breakout at Rafinesque Hall
- breakout at Bunker Hill
- passage between Rafinesque Hall and Bunker Hill
- Vespertilio Hall
- Corkscrew
- Vanderbilt University Hall
- distal portion of Gothic Avenue
- on edges of ceiling breakouts and in a small dome in Main Cave
- Cyclops Gateway (which also shows evidence of an old roost at the back)
- Cross Cave

Based on work by Twente (1955) and by Munson and Keith (1984), it is concluded that aggregations of raccoon scat containing bat bones provide two pieces of information. Twente noted raccoon predation on *Myotis velifer* in Kansas and Oklahoma, particularly during hibernation. Munson and Keith surmised that prehistoric raccoon scat contained bones of hibernating *M. lucifugus* or *M. sodalis* from Wyandotte Cave, Indiana. Toomey, Colburn, and Schubert (1998) reached similar conclusions about raccoons in the Historic Entrance area of Mammoth Cave. Thus, raccoon scats are used to indicate areas in Mammoth Cave that were 1) relatively large roosts in which many individual bats could be accessed by raccoons from the floor or from ledges, and 2) wintering sites, because large numbers of bats would have been easily preyed upon while in torpor. Raccoon scats are more prevalent in the Historic Entrance Area than in passages beyond Gothic Avenue, although they are present as far into the cave as Proctor's Arcade. Throughout these areas, the large amounts of raccoon scats are located mainly on ledges, along walls, and in undercuts. These areas provide a measure of protection such that the scats escaped human disturbance. Scats are quite noticeable in the following areas (date for samples in parentheses):

- Houchin's Narrows (470±60 RCYBP)
- Audubon Avenue (340±100 RCYBP)
- Little Bat Avenue (110±90 RCYBP)
- Lookout Mountain (9,000-year-old bat bone mass that may be from degraded raccoon scat)
- The passage between Rafinesque (410±50 RCYBP) and Bunker Hill
- Bunker Hill (scat dated to 540±90 RCYBP and scratches were present)
- between Bunker Hill and into the branches off of Vespertilio Hall
- along walls in Broadway
- Corkscrew
- Vanderbilt University Hall (920± 70 RCYBP)
- Cyclops Gateway

Areas that yielded low incidences of raccoon scats were Gothic Avenue (where a scat was dated to 1240±45 RCYBP), Star Chamber, and Proctor's Arcade. Scat is absent beyond Proctor's Arcade. This phenomenon is unexpected, particularly in Wright's Rotunda and Black Chambers. However, an area near Sandstone Dome may have bones from degraded scat mixed in the gray sediment.

It is reported that Campbell and Cutliff collected mummified bats in the 1930s; however, many are still present in the cave. The Paleontological Inventory Project recorded mummified bat remains at more than 320 data points. These remains include entire animals, partial ones, masses of skin and fur, and skeletonized specimens with some tissue. Some mummified remains have the appearance of being an intact bat, but upon handling it was found that these were so degraded that the fur could be blown off the skeleton, the tissue turned to powder, and the skeleton disarticulated. Because red bats (*Lasiurus* borealis) are not a cave-adapted species, it is surprising to find them in the passages of Mammoth Cave. However, Myers (1960) noted accumulations of dead red bats in Missouri Caves. In Mammoth Cave, mummified red bats are most common in the warm, high-level passages of Gothic Avenue, Backslider's Alley, and Black Chambers; and they are somewhat common between the Rotunda and Acute Angle. *M. lucifugus*, *M. sodalis*, and medium-sized *Myotis*, and *Pipistrellus subflavus* were common throughout the Historic Section. Mummified remains of colonial bats are concentrated in the passage between Star Chambers and Wright's Rotunda. The area of Star Chambers/Proctor's Arcade has the greatest abundance of mummified remains, which are dominated by a mixture of *M. lucifugus* and *M. sodalis*. Beyond Proctor's Arcade and into Wright's Rotunda, *M. sodalis* predominates. Dates on mummified remains in Star Chamber and Proctor's Arcade were 420±50 and 700±40 RCYBP, respectively. A *Myotis* mummy from Bunker Hill dated to 1960 ± 40 RCYBP.

The lines of faunal evidence, when assessed together, indicate that important hibernacula for *Myotis sodalis* and *M. lucifugus* were Audubon Avenue, Little Bat Avenue, Rafinesque Hall, Lookout Mountain, the Bunker Hill area, Vespertilio Hall, Gothic Avenue, Cyclops Gateway, Star Chambers, and Proctor's Arcade. Lookout Mountain may have also been a summer roost for gray bats. Large populations of an undetermined colonial bat once utilized Wright's Rotunda and Black Chambers. Remains of big brown bat and mink suggest that Sandstone Dome may have been open in the past; if so, colonial bats could have accessed Wright's Rotunda and Black Chambers at that time.

Free-tailed bat deposits

The extensive finds of *Tadarida* in Mammoth Cave is very exciting because the modern range of free-tailed bats lies south of the Mammoth Cave region. Davies and Chao (1959) were the first to report on the deposit of ancient guano in Chief City. Originally it was thought to be from *Myotis*. Based on skeletal material associated with the guano, Jegla and Hall (1962) identified the guano as having come from a colony of Brazilian free-tailed bats (*Tadarida brasiliensis*). However, skull elements measure larger than those of *T. brasiliensis*, suggesting that the Mammoth Cave fossils may not be this species. The extinct Constantine's bat (*Tadarida constantinei)* was larger; it was long known only from its type locality, Slaughter Canyon Cave, New Mexico, where Lawrence (1960) first described the species. Deposits of guano and bones from Constantine's bat are still present in that cave and continued to be studied (Morgan 2002). Repenning and Grady (1988) reported a large form of *Tadarida* from Hamilton Cave, West Virginia; they speculated that it might be the extinct Constantine's bat.

The Paleontological Inventory Project identified a mile-long stretch of cave between Bryan's Pass and Mayme's Stoop with discontinuous deposits interpreted to be free-tailed bat guano. Many of the guano deposits in this stretch of cave have associated bones. Areas with thick deposits and high ceilings -- Chief City, Waldach Dome, Hains' Dome -- represent primary roosts of a large *Tadarida* colony. The thick deposits of guano derived from large colonies of free-tailed bat and indicate that the bats were using the areas for long periods of time. Stratified layers of guano occur in Bryan's Pass, Settle's Gorge, and the low-lying passages before and after St. Catherine's City. Free-tailed bat bones were found in close proximity to guano from Bryan's Pass to Waldach Dome, in Blue Spring Branch, and at the beginning of Mayme's stoop. Possibly, the roosts were utilized at different times as cave microclimatic conditions dictated, or the population was very large and used different chambers and adjacent passages. All of these areas have guano deposits that are being trampled because they are adjacent to the tourist trail.

The probable sizes of colonies represented by these deposits suggest cave utilization similar to that observed in modern *Tadarida brasiliensis* in central Texas. Extensive deposits of this size are commonly produced in large maternity roosts. Partially ossified limb elements found in Bryan's Pass and Gothic Avenue are positive evidence supporting the Mammoth Cave's use as a maternity roost. Areas with thinner deposits also represent significant use; either by smaller populations, overflow populations, or less frequently. Examples are areas in Bryan's Pass, Settle's Gorge, Blue Spring Branch, and, possibly, the Blackall Avenue. Post-depositional activities (saltpeter mining, early historic tours, CCC trail work) have severely impact most of these deposits of free-tailed bat guano. A guano deposit closer to Violet City that *may* be free-tailed bat is located in Anzer's Hall. The guano is present as a thin lens (not as the thick, dark deposits found in Chief City) but with no associated bone. Therefore, it has been identified only as ancient chiropteran guano.

The age of the free-tailed bat guano deposits is unknown; and, it has not been established that the various guano deposits are contemporaneous. Previous investigations obtained a radiocarbon determination of >38,000 years BP (W-712; Rubin and Alexander 1960). Results from a Settle's Gorge sample (>54,000 years BP, CAMS-63093) submitted by the Paleo Project indicate, like the previous work, that the age is beyond the limits of radiocarbon dating. However, a few constraints may help pinpoint possible ages. The radiocarbon determination indicates that the deposits are too old to be Late Wisconsin in age. The fact that no water-lain sediments overlie the free-tailed bat deposits (or are even visible) suggests that the guano accumulated well after the final flooding of the Main Cave level. Granger et al. (2001:830) have dated sediments from the level of Main Cave to 2.3 million years old. The biological requirements of *Tadarida* also provide constraints. Present-day *Tadarida* colonies are found in caves far south of Mammoth Cave, which is likely due to the range of cave temperatures required by the colonies. Warmer cave temperatures would have resulted from a warmer mean annual surface temperature (outside the cave). In addition, a warmer regional climate would result in the greater insect populations that would be required to feed the large Tadarida colonies (the modern colony of 20 million Mexican free-tailed bats in Bracken Cave, Texas, eat an estimated 200 tons of insects per night (figures from Bat Conservation International, Inc. website, 2003). Thus, the guano deposits were produced by *Tadarida* colonies that inhabited Mammoth Cave at a time when regional climate and cave temperatures were significantly warmer than present. *Tadarida* could have inhabited the cave during one or more of the interglacial periods. Jegla and Hall (1962) suggested that the guano might be related to free-tailed bat colonies inhabiting the cave during the last interglacial period, the Sangamon Interglacial.

Based on data collected worldwide from ice cores, deep-sea cores, speleothems, and pollen cores from lake sediments, scientists know that the climate oscillates between glacial and interglacial periods. That is, conditions seesaw from a climate cold enough to cause snow to accumulate into masses of ice, to a warm and temperate climate -- similar to our present climate -- that causes glacial ice to melt and sea water level to rise. In addition, scientists have calibrated the various data sets with mathematically predictable variations in the Earth's orbit and rotation to estimate the timing of climatic events reflected in the cores. Thus, paleoclimatologists know that interglacial episodes occurred on a cycle of *roughly* 100,000+ years. Variations in the oxygen isotope record of foraminifera found in deep-sea cores led to the classification of isotopic events (marine oxygen isotope stages) (Imbrie et al. 1984, Shackleton 1967). The Sangamon Interglacial (130,000-75,000 years before present) falls within Marine Isotope Stage 5 (substages 5a-e); the warmest portion being Marine Isotope Stage 5e, which approximates the Eemian Interglacial in Northern Europe and occurred between 130,000 and 115,000 years ago (Kukla et al. 2002, Shackleton et al. 2002). The Sangamon Interglacial is the most recent period during which free-tailed bats could have inhabited the Mammoth Cave region, but it is not the only possible time. Other time periods that may have met the climatic criterion include the following: 300,000-350,000 YBP (Marine Isotope Stage 9); 362,000-423,000 YBP (Marine Isotope Stage 11); 472,000-502,000 YBP (Marine Isotope Stage 13); 540,000-590,000 YBP (Marine Isotope Stage 15); 625,000-645,000 YBP (Marine Isotope Stage 17); and 820,00-900,000 YBP (Marine Isotope Stage 23) (Burckle 1993, Lowe and Walker 1984).

One puzzling area is located in Wright's Rotunda about 1.5 miles from the Historic Entrance. Here, "ancient" guano deposits are extensive and resemble guano ascribed to *Tadarida* at the above-mentioned areas. It radiocarbon dated to 42,440±720 (CAMS-63092). However, no *Tadarida* bone was found and the ceiling is low. It is possible that another colonial bat species, such as *M. grisescens*, produced the guano. Thus, the guano was identified only as ancient Chiroptera guano. Another area with a substantial accumulation of trampled dark brown guano occurs beyond the Wright's area in the Dark Room of Black Chambers. Again no skeletal remains of *Tadarida* were found and the ceiling is very low. The Dark Room contains a large amount of ancient guano; it may have been a *Myotis* roost. Possibly, it too, may have been a *Tadarida* roost, but the passage does not seem to have the preferred configuration.

Resources found in an ancient upper level passage (high B-level) between Double Cellars and Methodist Church

The most unexpected bone deposits in the Historic Section of Mammoth Cave occur in remnants of what was once a continuous upper level passage that ran between Double Cellars and Methodist Church and along the high ceiling of Broadway. Originating in the area of the Double Cellars, it was one of the earliest passageways and was formed in the ancient past, perhaps 2 million years ago or more. The continuity of the passage was broken when water down cut the passage floor (and perhaps some action upward from the passage below) and broke through the ceiling of the Main Cave at three known intersections: St. Catherine City, Gothic Avenue, and the Methodist Church-Broadway junction (eventually forming the high-ceiling canyon known as Broadway) (Palmer 1981). The once continuous passage was also truncated by a valley wall collapse between Blackall Avenue and Gothic Avenue. Remnants of the ancient passage are now manifested as the side passages called Blue Spring Branch, Blackall Avenue, Gothic Avenue, Backslider's Alley, and the upper portions of Methodist Church and Broadway. The passage remnants contain extremely fine-grained sediments, perhaps deposited by slow moving waters during episodes of backflooding as the cave-forming waters moved through lower levels. Table 1-4 summarizes faunal ubiquity in the old passage as a single unit (see Table 1-3 for listing of remains by passage segment).

TABLE 1-4. Faunal ubiquity (number of data points) in the ancient upper level passage.

Taxon	***Ubiquity (N=184)***
MAMMALIA	
Desmodus stocki	1
Eptesicus fuscus	13
cf. *Eptesicus fuscus*	4
Lasiurus borealis	47
L. cinereus	6
Myotis cf. *austroriparius*	1
Myotis grisescens	11
M. cf. *grisescens*	3
Myotis leibii	7
M. cf. *leibii*	2
Myotis lucifugus	3
M. cf. *lucifugus*	2
Myotis sodalis	2
Myotis sp., small-sized	1
Myotis sp., medium-sized	26
Myotis sp.	23
cf. *Myotis* sp.	3
Nycticeius cf. *humeralis*	1
Pipistrellus subflavus	14
cf. *Pipistrellus subflavus*	2
Tadarida sp.	4
cf. *Tadarida* (“ancient” guano)	9
Chiroptera (“ancient” guano)	6
Chiroptera (primarily Vespertilionidae)	103
Procyon lotor	9
Neotoma floridana	11
Peromyscus sp.	4
Rodentia, mouse-sized	6
AVES	
Gallus gallus	4
Unknown bird	1
REPTILIA	
Colubridae	1
AMPHIBIA	
cf. *Cryptobranchus* sp.	1
Caudata	1
cf. *Bufo*	1
Rana sp.	1
Unknown Amphibian	1
Fish or salamander	1
Unknown vertebrate	1

A sizable deposit of *Tadarida* bones associated with ancient guano is located in Blue Spring Branch. In Blackall Avenue no bones were found associated with a small area of trampled ancient guano, which was tentatively attributed to cf. *Tadarida* based on the proximity of known *Tadarida* remains. Blue Spring Branch and Blackall Avenue yielded no other signs of aggregated bat usage beyond occasional scattered elements; however, they were not inspected as closely as other passages. Gothic Avenue was not expected to yield many faunal remains because it had been so heavily trafficked in historic times. Ultimately, Gothic Avenue was inspected closely because it was proving to be rich in faunal resources. The walls of the passage are literally lined with loose, old red sediments that contain thousands of bones, some densely clustered in pockets. Interestingly and unexpectedly, several *Tadarida* bones were found in clumps of dirt taken in a sample collected from a long sediment bank of *in situ* water-lain deposits. In addition, strips of ancient guano were found intermittently along the tourist trail where the floor was scuffed, and layers of ancient guano were found in profile where the trail has been incised below the grey cultural surface sediments. At this time, there is no evidence that the ancient guano and the *Tadarida* bones are associated. A radius fragment of *T. brasiliensis* was found in the anteroom of Backslider's Alley; it appears to have fallen out of the finely laminated silts. Bones from multiple individuals of possible hellbender (cf. *Cryptobranchus* sp.) were found in coarse red sediments in the wall of the man-made crawl. The richness and density of faunal remains indicate that Gothic Avenue received more usage by bats in post-*Tadarida* times than did Blue Spring Branch and Blackall Avenue.

The most surprising discovery in the ancient upper level passage is the femur from an extinct vampire bat (*Desmodus stocki*) found in the anteroom of Backslider's Alley. It appears to have fallen out of the same laminated, very fine, red silty clay deposit that produced the *Tadarida* bone. These fine, red silty clays appear to be *in situ* deposits from slackwater flooding, which are still banked against the walls of the anteroom. Thousands of brittle white bones are sliding down slope from pockets of bone that are eroding out of the loose, fine sediments located along both sides of the anteroom. In a few spots, bat bones are adhering to the ceiling (indicating that fill once extended to the ceiling). A variety of other bat taxa, including *Myotis* and *Lasiurus* were identified from the bone-rich deposits. Radiocarbon dating was attempted on one sample from Backslider's Alley during the 1995 Earthwatch Project, but it failed to date. The reason may be due to degradation of organics or to the presence of sulfur (from gypsum) in the sample. It is possible that these factors are related to a relatively great age for the sample (possibly greater than 40,000 years). Much of the post-cranial material appears to be from vespertilionid bats; however, given the presence of *Desmodus stocki* in the deposits, the material should be closely examined to determine if it other extinct, and/or extralimital species are present.

The implication that vampire bats were in the Mammoth Cave region is very interesting. Its occurrence there is far north of the modern range of vampire bats (*Desmodus rotundus*) in Mexico, Central America, and South America. Modern vampire bats are not adapted to cold climate so their geographic range is limited to areas with winters warmer than 10°C (McNab 1973, 1974). Precise statements about the climatic requirements for the fossil species cannot be made; however, by analogy to the modern species, the presence of a fossil vampire bat probably indicates a time with warmer winters.

The temporal range of fossil vampire bat remains in the United States spans late Pliocene to Late Holocene times (1.9 million to 3,000 years ago). The oldest vampire bat finds are the late Pliocene-aged *D. archaeodaptes* (known only from Florida), which was found in early Irvingtonian contexts (1.9 million years ago) in Florida (Morgan 1991). All other North American remains of vampire bat are of *D. stocki* and date from late Pleistocene (120,000 years ago) to Holocene (3,000 – 5,000 years ago at San Miguel Island, California) contexts (Grady et al. 2002, Ray et al. 1988). *Desmodus stocki* is known from 12 late Pleistocene localities in the U.S., Cuba, and Mexico; 9 of the sites are in the U.S. (California, Arizona, New Mexico, Texas, Florida, and West Virginia). Mammoth Cave is the third most northerly locality, the second most northerly in the eastern U.S., and the only Midwestern locality. Specimens from New Trout Cave (West Virginia) were found in deposits that were 30 cm below material dated to 29,000+/-1700 YBP (Grady et al. 2002).

The exact age of the Backslider's sediments is not known, but they could be as old as 1-2 million years. Sediments, with which the *Tadarida* and *Desmodus* bones are associated, consist of a thick, beige-colored, sandy deposit that fines upward. Near the base of the sandy sediments are layers of coarser sand and gravels. A body of laminated, orange colored silts and clays conformably overlies the sandy deposits. Each of the numerous lamina average approximately 0.5 cm thick. The sandy materials are alluvial sediments deposited in the passage by major (probably base-level) streams during Green River backflooding. Gravels at the bottom of the sandy exposure have been dated to 2.2±0.10 million years (Granger et al. 2001:829, 830); they correlate with the gravels in Methodist Church. The fine grain size suggests that the sediments were deposited during a time when the main base level flow was below the Main Cave level (potentially when flow was at the Blacksnake or Cleaveland Avenue level). The bones occur at the very top of this section. They are found associated with the uppermost sediments, which formerly extended all the way to the ceiling. Patches of sediment and sediment with bone still adhere to the ceiling in places. The presence of bone adhering to the ceiling and the occurrence of bone at the top of sediment banks with very little clearance (3 cm or less) to the ceiling, suggests that the bone was deposited during backflooding. The presence of the possible hellbender in the crawlway helps to support the idea of backflooding from the Green River. Under the scenario of slackwater flood deposition, the *Desmodus* bone was carried by the last backflooding episodes that impacted Backslider's Alley. The age of the sediments is difficult to assess. Obviously, they are younger than the 2.2 million year age of the underlying sandy sediments. If the sandy sediments or uppermost laminated clays in Backslider's Alley derive from backflooding when base stream level was lower at Cleaveland Avenue (Level C), then the age might be circa 1.34 ± 0.15 million years (Granger et al. 2001:829-831). However, because the actual Backslider's Alley sediment deposit in has not been dated, the specimen could be younger. Given that the presence of *Desmodus* indicates a warmer climatic regime, other possible times are the same as those suggested for *Tadarida*, which also required a warmer climate: 130,000-75,000 years before present (Sangamon Interglacial), 300,000-350,000 YBP (Marine Isotope Stage 9); 362,000-423,000 YBP (Marine Isotope Stage

11); 472,000-502,000 YBP (Marine Isotope Stage 13); 540,000-590,000 YBP (Marine Isotope Stage 15); 625,000-645,000 YBP (Marine Isotope Stage 17); and 820,00-900,000 YBP (Marine Isotope Stage 23) (Burckle 1993, Lowe and Walker 1984).

The timings of various flood events, the valley wall collapse, the upper passage break-throughs to the Main Cave passage, and the presence of live *Tadarida*, *Desmodus stocki,* and *Cryptobranchus* are not known. Blue Spring Branch-Blackall avenues may have been open at St. Catherine's City because remains of *Tadarida* are found to all three areas. The collapse between Blackall Avenue and Gothic Avenue had not occurred until after floodwaters deposited *Tadarida* bones in Gothic and Backslider's Alley. The *Tadarida* deposit in Gothic Avenue had been mined and a profile was exposed. The sediments are fine, but the exposed profile does not exhibit the distinct thinly laminated fine silty clays that can be seen in the slackwater deposits (that produced the *Tadarida* and *Desmodus* bones) in Backslider's Alley. Perhaps the area of Backslider's Alley was the terminus for the slow moving backwaters. In addition, the red flood sediments containing cf. *Cryptobranchus* (in Backslider's Alley) more closely resemble the Gothic Avenue *Tadarida* deposit in that they lack the laminated silts of the Backslider's Alley anteroom. However, the past excavation of a crawlway through the passage fill where *Cryptobranchus* was found, has also exposed the presence of calcite rafts, which would have formed on the surface of a quiet pool(s) of water. The remains of *Tadarida, Cryptobranchus,* and *Desmodus* may have been deposited during different episodes of flooding and deposition. Research focused on this issue is needed.

Other Late Pleistocene-Early Holocene bone deposits

Besides the bone deposits in Gothic and Backslider's Alley and the *Tadarida* deposits, there are bone-bearing sediments in other areas. They are usually a mix of fine sediments, small rocks, and bone. They are found in protected areas such as alcoves, on ledges, under rocks, in the cavities formed by limestone blocks and slabs, and in guano and sediment mixtures. This type of deposit was identified in several areas: Houchin's Narrows, the Barrow Pits between Bunker Hill and Olive's Bower, the junction of Audubon Avenue and Rafinesque Hall, Lookout Mountain, along the walls in

Backslider's Alley, in low-lying deposits in Main Cave just beyond Gothic Avenue, along the wall in Ultima Thule, and along the wall in Elisabeth's Dome/Violet City. All of the deposits contain bat bone, usually a mix of several species. Some deposits also contain bones of other small mammals. Often, they form a thin veneer (2-5 cm) of material on top of sediments that lack bone. A slight difference in color sometimes differentiates the upper bone-bearing sediment from the material lacking bone.

The deposits in Main Cave just beyond the intersection with Gothic Avenue are interpreted as representing the sediment floor prior to saltpeter mining and prior to aboriginal use of the cave. The deposits appear to be a slightly turbated zone at the top of the waterlain cave sediments. They are analogous to a soil zone (outside the cave) in surface alluvial deposits. As with a surface soil, it is likely that the faunal material in the cave deposits accumulated over an extended period of time. The remains could have begun accumulating as soon as cave levels ceased being flooded and after an entrance allowed access. Bone submitted for dating failed to date. It is suspected that the material is at least several thousand years old. In the case of the Barrow Pit fill (between Bunker Hill and The Mushroom Beds) two to four thousand years old archaeological materials overlie the deposit.

A small deposit of mixed sediment and bone is located along the left wall at the top of Lookout Mountain. It is extremely bone-rich and looks somewhat like "shredded wheat." The bones are mostly fragmentary, but all appear to be from bats. The deposit may be composed of large amounts of degraded raccoon scats. A small sample from the deposit submitted during the 1995 Earthwatch project on Lookout Mountain returned a date of 8,690 ± 60 RCYBP (CAMS-27972). This deposit has not been adequately sampled to determine what species of bats are represented.

Sediments containing bat bones in Houchins' Narrows are located on ledges and packed into horizontal wall crevices. The deposits indicate that the pre-modification floor level was three to four feet higher than the present floor level. A *Myotis* humerus dated to 9810 ± 50 RCYBP (CAMS 63091).

Another very interesting find in this study is the discovery of several locations with concentrations of *E. fuscus* and *M. leibii* bones. These locations are interesting because the bones occur mixed in sediments and are not the result of having been transported by water. The concentrations of these two species associated with in place sediments indicate areas that were once suitably cold. Locations where they were found in grayish-beige or gray sediments (due to a high percentage of grains of limestone and/or due to contamination from soot, charcoal, and burned cane) are Houchins' Narrows, Rafinesque Hall, Black Chambers near Sandstone Dome, Ultima Thule, Elisabeth's Dome/Violet City. Each of these areas is very close to a collapsed sink and each has highly fractured walls, which may have been caused by their exposure to weathering, influxes of cold air, and perhaps even to freeze-thaw activity. Bat bones from the Ultima Thule deposit were dated to 12,400±550 RCYBP (CAMS-83264).

A possible scenario for Quaternary bat use and deposition

The Paleontology Inventory Project discovered a myriad of vertebrate faunal resources in the Historic Section of Mammoth Cave, which are dominated by bat remains. Here I discuss one possible interpretation of bat use during the Quaternary Period and the deposition of their remains. Obviously it is only one of many possible scenarios. Bats responded to external climate changes by moving in and out of the Mammoth Cave region. They responded to changes in cave microclimate by preferentially shifting to more suitable areas within the cave, moving to different parts of the Mammoth Cave System, or to other caves in the area. The thick limestone strata buffered the cave from the vagaries of the above ground weather (although the cave microclimate would have been influenced by daily and seasonal weather patterns); however, the Mammoth Cave System could not escape major climate changes that occurred regionally and globally. *Desmodus* (vampire bat) and *Tadarida* (free-tailed bat) were taxa that appeared and disappeared with major changes in global climate, and perhaps with regional climate shifts.

The *Desmodus* femur was transported by floodwaters to its final resting place in Backslider's Alley more than a million years ago. Therefore, it is unknown whether the individual had been roosting inside Mammoth or if it came from a different cave. Because only a single individual is represented, we do not know if it belonged to a nearby colony, if it was a vagrant, or if it was another animal's food item. The proximity of a possible *Desmodus* colony is not known because the Mammoth Cave specimen is the second most northerly occurrence east of the Mississippi River and the only midwestern specimen that has been recorded to date.

Large colonies of *Tadarida* utilized the cave at one or more times in the geological past when climatic conditions were more equable and winters were above 50°F (10° C); warmer than the region currently experiences. Climatic conditions would have been suitable during several interglacial periods, the most recent being the Sangamon Episode, circa 130,000-75,000 years BP. Bones from immature individuals suggest the presence of one or more maternity roosts.

Eptesicus fuscus (big brown bat) and *Myotis leibii* (small-footed myotis) utilized the cave by at least 13,000 years ago during the Pleistocene-Holocene transition when climatic conditions were warmer than glacial times, but were colder than today. Dated remains indicate that conditions *may* not have been warm enough for hibernating colonial *Myotis* until after about 10,000 years ago because, thus far, no *Myotis* (*M. sodalis, M. lucifugus,* or *M. grisescens*) material older than this has been dated. (*Myotis* bones in Backslider's Alley appear to be much older; and, if they are associated with the same sediments as the *Desmodus*, then they are from a past interglacial period and are considerably older). Multiple lines of evidence indicate that important hibernacula for *M. sodalis* (Indiana bat) and *M. lucifugus* (little brown bat) were Audubon Avenue, Little Bat Avenue, Rafinesque Hall, Lookout Mountain, the Bunker Hill area, Vespertilio Hall, Gothic Avenue, Cyclops Gateway, and Star Chambers/Proctor's Arcade. Lookout Mountain may have also been a summer roost for *M. grisescens* gray bats. Wright's Rotunda and Black Chambers were major roosts for large populations of an undetermined colonial bat, possibly gray bats or even free-tailed bats.

MANAGEMENT CONCERNS in the HISTORIC SECTION

Important faunal resources were discovered during the course of the Paleontological Inventory Project conducted by the Illinois State Museum. These discoveries intersect with management concerns because the National Park Service must balance resource preservation with its various public missions. Resources that are judged to be of significance are inherently resources that must be addressed in management strategies for tourist routing, trail maintenance, electrical work, after-hours trips, environmental monitoring, cave restoration work, resource preservation, education, etc.

Significant paleontological resources

Thirty-three spots in the Historic Section are deemed to be paleontologically significant; therefore, they are the most deserving of protection, avoidance, and future research. The important of the faunal remains are listed below and a map showing the general location of each follows the list (Figure 1-45).

1. Houchins' Narrows: *in situ* deposits of sediment contain bat bones behind and under fractured limestone along walls that pre-date human presence in the cave; bat bones AMS dated to 9,810 ± 50 years BP.
2. Little Bat Avenue: ceiling stain indicates that in the past, the passage was an intensively used *Myotis* hibernaculum.
3. Rafinesque Hall: loose, bone-bearing sediments pre-date saltpeter mining activities; taxa indicate that this area was a cold spot in the past.
4. Lookout Mountain: accumulations of guano are evidence for past use by roosting gray bats.
5. Lookout Mountain: sediment along the left wall at the top of Lookout Mountain yielded circa 9000-year-old bone.
6. Rafinesque Hall: stain on stepped edges of breakout dome provides evidence that the area was heavily used as summer roost or hibernaculum site.
7. Bunker Hill: heavily used roost or hibernaculum site as signaled by the stain on stepped edges of breakout dome. Paleontological material is still present on the surface as evidenced by the nearly 2,000-year-old *Myotis* mummy.

8. Barrow Pits between Bunker Hill and Vespertilio Hall: *in situ* deposits of sediment contain bat bones below prehistoric cultural layer.
9. Vespertilio Hall: the dome was one of the most intensively used *Myotis* hibernacula in the past.
10. Vanderbilt University Hall: the site of a former roost; sample of Bat guano radiocarbon dated to 8,255 ± 40 years BP; a raccoon scat containing bat bone dated to 2,090 ± 80 years BP.
11. Backslider's Alley: loose, bone-bearing sediments pre-date saltpeter mining activities.
12. Backslider's Alley: vampire bat (*Desmodus stocki*) femur may be as old as 1-2 million years.
13. Backslider's Alley: Remains of hellbender found in sediment profile by 1930s era man-made crawlway; remains are possibly of similar age to vampire bat, 1-2 million years old.
14. Gothic Avenue: loose, bone-bearing sediments pre-date saltpeter mining activities located along both side walls of passage near ceiling; they are protected by being off of tourist trail.
15. Gothic Avenue: *in situ* deposit with 2 bones of free-tailed bat (*Tadarida* sp.) exposed in area mined possibly by saltpeter activity.
16. Gothic Avenue: several spots of accumulated ancient guano are cut through by tourist trail (no identifiable bone associated).
17. Gothic Avenue: roosting stain signals former bat roost near end of passage; a veneer of guano pellets is also present.
18. Right side of Main Cave, just beyond the junction with Gothic Avenue: *in situ* bone-bearing sediments pre-date human presence in the cave and are exposed by saltpeter mining and trail building activities.
19. Cyclops Gateway: very old bat hibernaculum is located at back end of the passage; extensive mining of sediments is visible, it probably removed evidence of guano and bone.
20. Cyclops Gateway: remnant *in situ* deposits of sediment containing bone adhere to cave wall at trail level.
21. Star Chamber and Proctor's Arcade area: numerous soot-covered mummified bats are lying on surface.
22. Star Chamber/Proctor's Arcade area: human paleofeces, with an AMS date of 2,550 ± 40 years BP, contain bat bones.

23. Wright's Rotunda: *in situ* stripes of ancient guano (species unknown) are exposed in test holes dug by Davies and Chao located behind the pillars; no associated bone.
24. Wright's Rotunda: small area with accumulated bat guano, but no associated bone; deposit has been trampled; relative age of deposit is judged to range from old to ancient.
25. Wright's Rotunda: accumulations of pelletized old guano (no identifiable bone associated) are present; produced conventional date of 9,170 ± 130 and AMS date of 8,460 ± 40 years BP.
26. Wright's Rotunda: multiple examples of ancient guano occur beneath surface sediments in left hand passage leading to Black Chambers.
27. Wright's Rotunda: large area with accumulation of ancient guano has an *appearance* similar to guano attributed to free-tailed bat (*Tadarida* sp.) found in Chief City; however, it has no associated bone so it could be from gray bats; some of the deposit is intact, protected under a breakdown slab, but most has been trampled; intact deposit produced an AMS date of 42,440 ± 720 years BP.
28. Black Chambers: ancient guano accumulations (no identifiable bone associated) indicate large roost used by colonial bats in the Dark Room passage.
29. Black Chambers: accumulations of pelletized guano (no identifiable bone associated) indicate that conditions were more conducive to roosting in the past; two different accumulations returned AMS dates of 460 ± 40 years BP and 1,115 ± 40 years BP.
30. Black Chambers: loose gray-colored sediment with burned cane, bones from multiple *Eptesicus fuscus*, and elements of *Mustela vison* are present; the relative warmth of Black Chambers now attracts *Lasiurus borealis*, but an opening in nearby Sandstone Dome could have provided suitable habitat for *E. fuscus* and an entrance for bats to access the now documented roosts in Black Chambers, Wright's Rotunda, and points beyond.
31. Bryan's Pass: *in situ* deposits of guano and bones of free-tailed bat (*Tadarida* sp.) are present; evidence of immature *Tadarida*.
32. Settle's Gorge: *in situ* deposits of *Tadarida* guano; *Tadarida* bones are present
33. Chief City: many *in situ* deposits include guano and bones of free-tailed bat, *Tadarida* sp.; the tour route passes through ancient guano deposits.

34. Chief City to St. Catherine City: *in situ* strata of *Tadarida* guano, and *Tadarida* bones are present in disturbed sediments.
35. Blackall Avenue: ancient guano accumulation (no identifiable bone associated) presumed to be extension of *Tadarida* deposits observed in Blue Spring Branch.
36. Blue Spring Branch: Deposits of *Tadarida* guano and bones are present.
37. Waldach Dome: guano and bones of *Tadarida* are present.
38. Hains' Dome: substantial amount of *in situ* deposits of guano most likely of *Tadarida* are present; no bone of this or any other species was found that might be associated with the guano.
39. Anzer's Hall/ Mayme's Stoop area: *in situ* strata of compressed ancient guano (no identifiable bone) are located beneath large slabs of ceiling breakdown.
40. Anzer's Hall: Concentration of *Myotis leibii* and *Eptesicus fuscus* bones suggest that in the past, the area was a cold spot or was near a former entrance.
41. Ultima Thule: isolated free-tailed bat (*Tadarida* sp.) humerus found in a crawlway that was dug through the breakdown rocks that forms Ultima Thule; may be result of transport by woodrat or may be from a nearby pocket of bone.

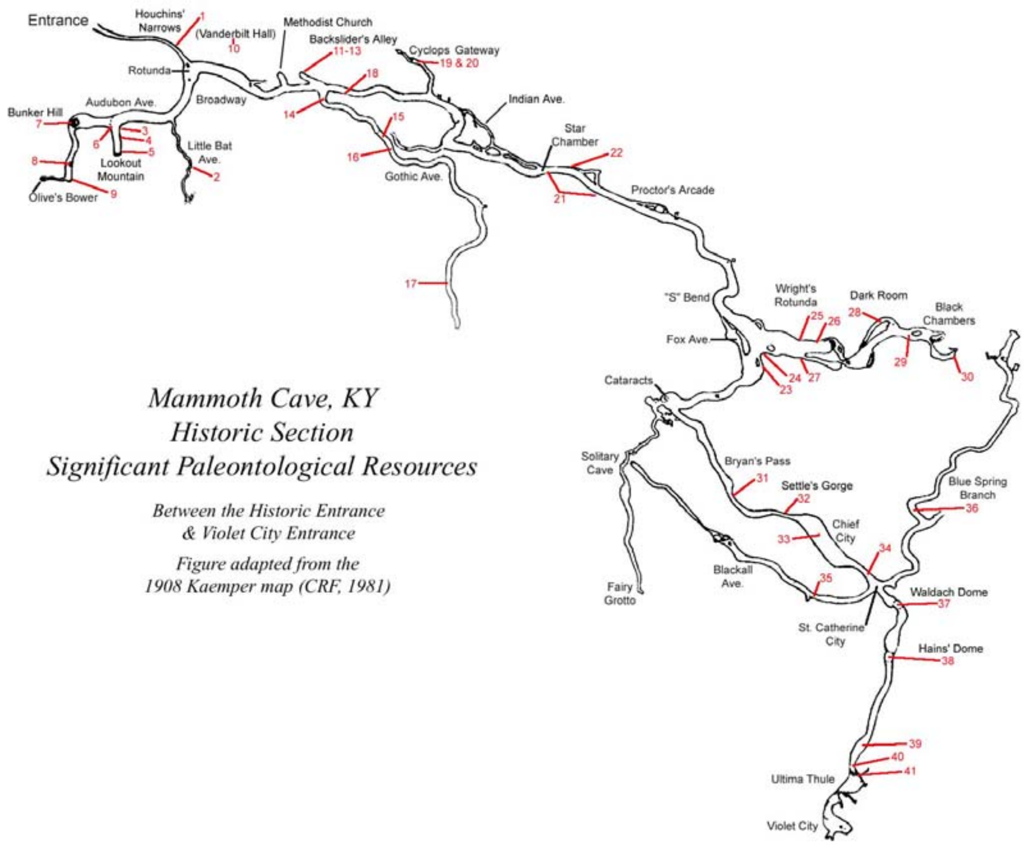

FIGURE 1-45. Locations of the most important paleontological resources found in the Historic Section of Mammoth Cave, between the Historic Entrance and the Violet City Entrance. (Map adapted from Max Kaemper's 1908 map, which was redrawn by Diana Daunt and the Cave Research Foundation in 1981).

Future Research in the Historic Section

Use of surface surveys to locate fossils in Mammoth Cave that are strictly Pleistocene, or even early Holocene, in age is difficult to nearly impossible due to time averaging. Because of the excellent preservation conditions and lack of sediment accumulation in Mammoth Cave, surface materials can reflect multiple time periods. Even remains collected from non-impact areas such as breakdown interstices and cavities can be a mixture of ancient and modern. Radiocarbon dating can give us an age range for only the dated specimen (and its deposit if found *in situ*), but the resulting date does not necessarily apply to adjacent bones. Unfortunately, radiocarbon analysis is too expensive to date every interesting bone. Although many samples were submitted for radiocarbon dating, the lack of dates for a number of the forty-one significant resources has been frustrating, and an admitted shortfall of the Paleontological Inventory Project. Obtaining more radiocarbon dates will be vital to creating a reconstruction of Kentucky's paleobiological history. Important areas in the cave for which dates were obtained in combination with taxonomic data, and their designated context (e.g., roost, raccoon latrine, etc.) indicate areas that have high potential for productive research in the future. Examples of faunal remains that should be dated are the compressed ancient guano in Black Chambers, the loose ancient guano in the Dark Room, and the bones near Sandstone Dome.

Further research is necessary to gain a fuller understanding of the areas targeted as being paleontologically significant, and their relationship to the rest of the Mammoth Cave system. Focused research will provide information for a better reconstruction of former surface environments and past climatic changes. Salts Cave is a prime example of an important site for future paleontological inventory and monitoring. Future studies would also benefit from an increased use of environmental monitoring equipment. We know that human activities and modifications within the cave and on the surface have changed both passage and entrance configurations, which in turn have influenced airflow and cave microclimate. We know that humans, intentionally and inadvertently, wreaked havoc on bat colonies through direct destruction of bats, exclusion, and disruption of roost fidelities. We know that traditional hibernacula used in the past are now too warm to be hibernation sites. Future studies may be able to discern the roles played by humans, regional climate changes, and global events. For example, no investigation has explored the potential influence of the Little Ice Age (circa 1400 to 1850s) on Mammoth Cave hibernacula.

Remains of colonial bats were found throughout the cave, but intensive use of preferred roosts appears to have ceased by the late 1800s to early 1900s (could this disappearance have been influenced by a slight cooling, by the ever-increasing human presence, a combination, or will we be unable to discern a cause? The microclimates of roost areas need to be studied and they should be considered in roost restoration plans. Star Chamber, Proctor's Arcade and Bunker Hill were preferred hibernacula for *Myotis lucifugus* and *M. sodalis*; mummified remains from these three areas dated to 700 ± 40, 420 ± 50, and 1960 ± 40 RCYBP, respectively. *M. sodalis* preferentially used areas between Proctor's Arcade and Wright's Rotunda. These areas would be good targets of further study to determine if more information about past bat usage can be obtained.

Bones and deposits from the ancient upper level passage between Double Cellars and Methodist Church are highly significant paleontologically, and the passage has great potential for producing additional finds. Of particular paleontological interest are *Tadarada* bones in Blue Spring Branch; the site of the old sediment mine and the ancient guano stripes in Gothic Avenue; and, the bone pockets, the finely laminated silts, and the coarser flood deposits in the crawlway in Backslider's Alley. All of these deposits need not only protection, but also additional study. Several small excavations might yield data with which to better assess the diversity and distribution of bone in the deposits. The sequence of flooding and backflooding and the deposition of the various sediment fills need to be outlined. Also, a sample of bat remains adhering to the ceiling in Backslider's Alley should be collected and analyzed more fully to determine if any additional extinct or extirpated species are represented. The nearly 9000-year-old bone assemblage at the top of Lookout Mountains needs to be adequately sampled and evaluated for bat taxa. A potentially rich avenue for future research would be a study focused on raccoon scats, samples of which could be processed, dated, and evaluated for identifiable bat skulls. The *Tadarida* bones need to be studied further to determine if they are *T. brasiliensis* or perhaps the extinct species, *T. constantinei*. Additional skulls may need to be collected to obtain an adequate sample size for measurements. If it is determined that the *Tadarida* remains are *T. brasiliensis*, then another avenue for research would be determining if they can be distinguished to *T. b. mexicana* (the migratory subspecies that is so well-known from Texas and New Mexico) or *T. b. cynocephala*, a non-migratory subspecies (which some researchers have suggested is a separate species) that lives in the southeastern U.S. (Davis and Schmidly 1997). During the course of this project, I identified faunal remains recovered during archaeological subsurface testing conducted by Dr. George Crothers. The assemblage provided evidence about the prehistoric surface of the cave floor; however, paleontology was not actually included as part of the analysis of such sub-surface testing. Future archaeological reconnaissance of subsurface features should include a faunal analyst to examine subsurface remains retrieved through shovel probes.

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CHAPTER 2
Paleontological Reconnaissance in Colossal Cavern

INTRODUCTION

In the late 1800s, Colossal Cavern became one of the cave region's tourist attractions. The discovery of the Woodson-Adair entrance and the first rope drop in the 125-foot deep pit Colossal Dome has variously been credited as early as circa 1890 to James Henry Lee, Pike Chapman, and William Garvin (Hagan and Sutton 1999). The cave was located under farmland then owned by Dr. L. W. Hazen, who showed it for a few months. In 1896, the Louisville and Nashville (L & N) Railroad Company bought the cave from Dr. Hazen and quickly proceeded to develop the cave as a commercial cave. L & N turned the cave into a more user-friendly experience -- buying additional land, widening passages, building stairways and boardwalks, and blasting open the user-friendly artificial entrance (Figures 2-1 and 2-2) that is still used as the main entrance to Colossal. By 1896, L & N was showing Colossal; the highlight was Colossal Dome, described by Hovey (1912:129) as "the grandest room in all this region of silence and of night."

FIGURE 2-1. Early photograph of artificial main entrance to Colossal Cavern used since 1896, from Hovey's 1912 guide to Mammoth Cave.

FIGURE 2-2. The main entrance in 2001.

Another early access point was through the Hazen Entrance (Figure 2-3). Subsequent to the building of the new entrance, the railroad company had closed other entrances to "prevent intrusion by undesirable parties for the purpose of spoliaton [sic]" (Hovey 1903:23316). Hazen, Bed Quilt, and Woodson are Colossal Cave entrances that appear on a 1940 list of blasted entrances (Anonymous 1940).

FIGURE 2-3. Hazen entrance in 2001.

In Hovey's day, Colossal was known to connect with Bedquilt Cave. Although Colossal was infrequently visited by 1910 and closed by the 1920s (Thompson and Thompson 2003:88), it has continued to interest cave explorers and biologists. In 1960, explorers found a connection between Colossal Cave and Salts Cave; in 1961, between Colossal/Salts and Unknown/Crystal Cave; and in 1972, between the Flint Ridge Cave system and Mammoth Cave (Brucker and Watson 1976).

In 1903, Hovey saw crickets, beetles, flies, and eyeless crayfish, but he had the impression that the "fauna and flora of this cavern were scanty as compared to Mammoth Cave." However, his non-mention of bats does not mean that they were not using the cave. A number of studies since Hovey do mention bats. In summer 1912, W. W. Vothers took *Pipistrellus subflavus* in Colossal Cave. In 1929, Bailey captured several specimens of *Myotis lucifugus* (in late summer), *M. sodalis* and *P. subflavus* (in late fall). The Vothers and Bailey specimens are curated at the U.S. National Museum (Smithsonian Institution 1996). Bailey (1933:453) reported that "small numbers" of *M. lucifugus* were found in Colossal in late September, but that by mid-November they occurred in "great abundance." In November he also had seen large numbers of *M. sodalis* and a few *M. leibii*. All together, he counted about 5000 hibernating bats in Colossal in November of 1929, half of which he thought were *M. lucifugus* (Bailey 1933:454). In December of 1934, Claude Hibbard (1935) observed hibernating myotis and pipistrelles. At that time he recorded the air temperature to be 46^{o} F and the water, 44^{o} F. Hibbard (1935) noted in his diary that on July 29, the entrance to Colossal Cave was being measured for a new gate in order to "allow the entrance of bats in that cave;" and, a few days later, "the entrance was being opened and a new gate installed to allow passage of bats in and out of the cave" (31 July entry). New gate installation was completed on August 5th. A few days later, Hibbard visited Colossal with Dr. Pohl and Mr. Holland to study its blind cave fish (Hibbard's diary entry for 8 August) -- a search of the streams produced no blindfish, but "blind crayfish were common." In January 1953, Colossal Cave housed 6000 hibernating *M. sodalis*, but sometime thereafter, the "original entrance collapsed and became filled with rubble" and the disposition of the colony is unknown (MacGregor 1991:368). In a progress report of his ongoing bat study, John Hall (1958) estimated as many as 4050 hibernating myotis bats (with as many as 1680 *M. sodalis*) and 45 pipistrelles in 1957. In the fall of 1969, Keefer (1969) estimated that there were only about 300 myotis (50-100 were *M. sodalis*), and, in winter 1971, at most 1250 *Myotis* (700-750 were *M. sodalis*) in the cave (Keefer 1971). The number of Indiana bats wintering in Colossal declined throughout the 1980s; a February 1991 count placed their numbers at only 556 individuals (MacGregor 19991:368).

In 1979, a CRF crew collected a *Neotoma floridana* skeleton from the K survey passage in the Bedquilt section (Wilson 1980).

RESULTS AND DISCUSSION

The Paleo Project visited the main passage at the historic entrance of Colossal Cave on short excursions. In 2000 Toomey and Colburn accompanied a crew conducting a winter bat count in Grand Avenue and Bicycle; but no fossils were found. In August 2001, Colburn and Olson examined the historic entrance area and a dugout crawlway. Assorted bat bones were found in the crawl and a *Pipistrellus subflavus* skeleton was located in a puddle of water near a stream.

The Hazen entrance (see Figure 2-3, above) -- one of the original entrances reported to have been blasted shut -- was examined by Colburn and Olson in 2001. Hazen appears on a 1940s list of blasted entrances (Anonymous 1940). A search of the entrance passage, a series of three shafts, and a narrow ledge above one of the shafts yielded few bones. Limb elements of *Eptesicus fuscus* were found in a 30-foot deep shaft. Interestingly, though, we did discover that this area of Colossal is a cold trap. On a hot August afternoon, the temperature in the shafts was a cool 46.6^{o} F -- about 10^{o} F cooler than the average for Mammoth Cave. Much of the Hazen area exhibited the highly fractured limestone walls characteristic of areas that have undergone freezing and thawing.

Colossal Cavern has been a surprise in that the Paleo Project found only isolated and scattered elements of bats, but no significant fossils or signs indicative of large bat colonies or of prolonged bat usage. Despite Hovey's notation of Colossal's poor showing of flora and fauna, and despite the lack of a bat-friendly gate for some unknown period of time prior to 1935, the absence of abundant animal remains is quite unexpected in light of the reports that Colossal held sizable populations of Indiana and little brown bats in the 1950s. One explanation for the paucity of bones may be poor preservation due to dampness of the main passage. Another is that the Paleo Project's small-scale investigation of the cave was not adequate to detect bone localities; for example Colossal Dome was not examined.

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CHAPTER 3
Dead Bat Avenue

INTRODUCTION

In mid-January of 1998, Colburn and Toomey inventoried paleontological remains in Dead Bat Avenue. They accompanied a re-survey trip conducted by Scott House, Bob Osburn, and George Bilbrey. Our attention was drawn to Dead Bat Avenue by Tommy Brucker who remembered seeing numerous dead bats during the original CRF survey. Two aeolian sediment piles (Figure 3-1) lie in Turner Avenue, outside the entrance to Dead Bat Avenue. They appear to have been formed when sediment was forced out of Dead Bat Avenue through the horizontal slots under the breakdown, perhaps from the force of air currents created by massive ceiling collapse. Just beyond the entrance (Figure 3-2) is a room with formations of delicate, long, fibrous crystals. The passage is a low wide crawl that is approximately 1,000 feet in length (Figure 3-3).

FIGURE 3-1. Two aeolian sediment piles in Turner Avenue.

FIGURE 3-2. "X" marks the entrance to Dead Bat Ave.

FIGURE 3-3. Two photographs showing the low nature of the passage in Dead Bat Avenue.

Disturbed sediments running down the center of the sandy passage indicate the path of the original survey. The inventory for bones was conducted from this path with no off-trail searching.

RESULTS

Fourteen data points were recorded from which four vertebrate taxa were identified.
Table 3-1 shows their distribution. In this small sample, *Pipistrellus subflavus* is the most common bat represented among the remains. The *Myotis lucifugus* was located outside the

TABLE 3-1. Location of vertebrate taxa in Dead Bat Avenue, numbers in column headings are Paleo Data Points.

Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Myotis lucifugus	x													
M. leibii					x									
M. septentrionalis									x					
Pipistrellus subflavus		x	x	x			x				x	x		
Vespertilionidae								x		x			x	x
Neotoma floridana						x				x				

entrance to Dead Bat Avenue on a pile of sediment in Turner Avenue. *M. leibii* was identified on the basis of dentition and a right dentary measurement of 9.5 mm. A mummified bat at Paleo Data Point 9 was identified as *M. septentrionalis* from its very long ears and lack of nose ornamentation. Its measurements (forearm length, 3.7 mm; tibia length, 14.1 mm; and length of ear, 9 mm) indicate that it was a small individual. Although adult forearm measurements range between 34-38 mm, and, ear lengths range from 14 to 19 mm (Caceres and Barclay 2000), the desiccated nature of the Dead Bat Avenue specimen may account for the shortened ear length. Clearly though, as Figure 3-3 shows, the ears are long.

***FIGURE 3-3. Paleo Data Point 9 is a mummified* Myotis septentrionalis.**

M. septentrionalis is considered to be rare in Kentucky. In 1963, Barbour and Davis (1974:73) captured more than 12,000 bats at Mammoth Cave National Park, but "fewer than half a dozen were *M. keenii*" [*M. septentrionalis* was once considered a subspecies of *M. keenii*]. Its tendency to hibernate in deep crevices of caves may cause it to be missed during winter bat counts. The Paleontology Project also found a mummified specimen of this species in Main Cave.

DESCRIPTION of DATA POINTS

- Data point 1-- Lying on one of the aeolian sand beds at the entrance is a mummified *Myotis lucifugus*. Calcar not keeled, forearm=36.4 mm, fungus covered, ears present, lacks feet except for metatarsals on left foot. Probably fell from the ceiling and onto the pile or was placed on the pile

- Data point 2-- right side. Pipistrelle found in alcove across from entrance and above passage

- Data point 3-- left side. Pipistrelle: fungus covered, long sharp tragus, wing membrane very dark, forearm=32.6 mm

- Data point 4-- left side. Pipistrelle: covered with pink fungus, long sharp tragus, wing membrane very dark, forearm=31.1 mm

- Data point 5-- left side. Concentration of bones from a single skeleton of a *Myotis leibii*. Present are a scapula, femora, humerus, radius, assorted wing elements, pelvis, skull fragment, tibia, 2 dentaries, and other limb elements scattered within 5 feet. 1 piece of bat guano. Right dentary=9.5 mm, radius=29.8 mm, humerus=20.4 mm, femur=13.0 mm, tibia=12.5 mm

- Data point 6-- left side of trail. *Neotoma floridana*: bones of a subadult scattered 3 feet linearly, most in an area more than 1 foot long and 6 inches wide. Most of the bones are present (humeri, femora, tibiae, pelvis, mandible, incisors, vertebrae, ribs); tail vertebrae are missing.

- Data point 7-- right of trail. Skeleton of an individual *Pipistrellus subflavus*. Present are the right dentary=8.9mm, radius=33.0mm, humerus=21.1 mm, and a femur fragment.
- Data point 8--right of trail. A bat skeleton in two clumps, with tissue adhering, subadult. Femurs, tibiae, pelvis, and lower vertebrae at lower

point on slope. Skull and upper body parts upslope about 8 inches away.

- Data point 9-- left side. A bat mummy with ears that look long and have a very long pointed tragus, calcar without keel, no lumps on nose. Lying on ventral side with legs, totally dessicated, no fungus is present. Forearm=33.7 mm, tibia=14.1 mm, ear=9 mm

- Data point 10-- scattered bones of a very young *Neotoma floridana*. Pelvis elements unfused, scapula, ulnae, femur, radius, foot phalanges, ribs, vertebrae, and a hunk of tissue. One bat radius among woodrat bones = 36.1 mm.

- Data point 11-- right side of trail. Mummy of a pipistrelle, forearm=31.9 mm

- Data point 12-- right side of trail. Mummy of a pipistrelle, some fungus, tail pulled over its head, wings outspread. Forearm=33.7 mm

- Data point 13-- right side of trail. Bat mummy (species not identified) stretched out and lying on ventral side. Forearm=34.4 mm

- Data point 14-- right side about 35 feet past DB16. Bat bones: radius fragment, humerus=21.8 mm

RECOMMENDATIONS

Because Dead Bat Avenue is visited infrequently, its paleontological resources are safe. No recommendations are made.

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CHAPTER 4
Marshall Avenue in Lee Cave

INTRODUCTION

On June 22, 1998, Colburn and Toomey (Illinois State Museum) conducted a search for paleontological remains in Marshall Avenue while on a trip into Lee Cave with Richard Zopf, Rick Olson, Art Palmer, and Peg Palmer. Situated in Joppa Ridge, near the southern boundary of Mammoth Cave National Park, Lee Cave was explored some 4,000 years ago by early Native Americans, entered by T. E. Lee in 1897 (he left his signature at the bottom of the 50 foot entrance shaft), and *rediscovered* in modern times in 1968 (Freeman et al. 1973, Kennedy and Watson 1997, Watson 1997). Soon after its rediscovery, the cave caught the attention of the Cave Research Foundation Archaeological Project, which has been working in Mammoth Cave National Park since 1963. Between 1968 and the 1990s, archaeologists have investigated Marshall Avenue and its artifacts to collect information about the early Native American visitors. Marshall Avenue is a 7,000-foot long section of large trunk passage entered at the western end via a 50-foot shaft and truncated at the eastern end by terminal breakdown. Smaller, lower level passages can be reached from Marshall Avenue. More than 7 miles of passageways have been mapped in the Lee Cave system. Archaeological debris consists of cane torch (including some very long segments), burned torch fragments, charcoal, grass torch ties, stoke marks, and rock cairns. Results from the radiocarbon dating of burned cane indicate that Late Archaic period peoples explored Lee Cave circa 2150 BC $\pm$65 (Freeman et al. 1973:125, Kennedy and Watson 1997:8). The Amerindians are thought to have entered Marshall Avenue from the eastern end via an entrance that was later closed by the terminal breakdown.

RESULTS AND DISCUSSION

Because Lee Cave is archaeologically sensitive, the Illinois State Museum's search for animal remains was restricted to already disturbed areas on and adjacent to the trail in Marshall Avenue of Lee Cave. The terminal breakdown was combed fairly thoroughly for bones. Within the confines of this limited search, only 15 Paleo Data Points were recorded in Marshall Avenue, probably due to the trampled nature of the trail area.

Remains of six different taxa and bones of indeterminate bats were identified. Table 4-1 shows the distribution of the remains.

TABLE 4-1. Data point location of various taxa in Lee Cave.

Taxon	***Data Point #***														
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***
cf. *Eptesicus fuscus*														X	
Myotis lucifugus										X					
Myotis grisescens			X		X	X	X	X	X		X	X			X
Pipistrellus subflavus	X	X		X											
Vespertilionidae						X								X	
Neotoma floridana													X		
Odocoileus virginianus													X		

During their early visits, Cave Research Foundation members noted signs of woodrat activity and found a mummified woodrat in Marshall Avenue (Freeman et al. 1973). The Paleo Project located a woodrat larder containing nutshells, and a large fragment of deer ilium with rodent gnaw marks was found along the left wall of the passage near the bottom of the terminal breakdown pile (Paleo Data Point 13, Figure 4-1). The Paleo Project crew did not see the mummified woodrat.

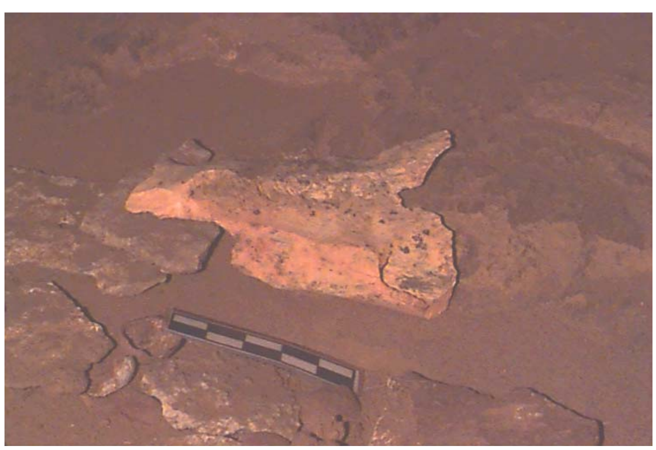

FIGURE 4-1. Paleo Data Point 13 in Marshall Avenue, fragment of deer pelvis with rodent gnaw marks found among woodrat debris.

A big brown bat (cf. *Eptesicus fuscus*) was tentatively identified from a humerus. Three Paleo Data Points are mummified remains of pipistrelles. Freeman et al. (1973) had noted finding a desiccated pipistrelle. Data Point 10 yielded a mummified *Myotis lucifugus*. *M. grisescens* was represented by a live colony, a skull, several measurable limb bones, and guano. The early surveyors remarked on seeing live bats: "about 20 *Myotis* spp." in the summer and "several dozen hibernating *Myotis lucifugus*" in November (Freeman et al. 1973:120).

In the past, someone labeled two desiccated chunks of organic matter (Points 7 and 8, both located near survey station K30, Figure 4-2) as "FECE" and used flagging tape to demarcate another area near K28 that has clumps of organic matter (Paleo Data Point 11, Figure 4-3). Labels indicate that the chunks were probably mistaken for human

FIGURE 4-2. Desiccated bat guano at Paleo Data Point 8, near K30.

FIGURE 4- 3. Desiccated bat guano at Paleo Data Point 11, vicinity of K 28.

paleofeces. In fact, Kennedy and Watson (1997:8) lamented that paleofecal material found in Lee Cave dated younger than the torch material; they commented, "upon close examination, the Lee Cave specimens do not appear to be of human origin." Furthermore, Watson (1997:218) wrote, "A sample of organic substance found in the center of the passage at K29 was given to [Richard] Yarnell for identification because at first it was thought to be paleofecal matter; it is not paleofecal matter, but a positive identification has not yet been made."

These mysterious organic substances are clumps of desiccated bat guano, not human paleofeces. The Illinois State Museum submitted a chunk of the bat guano from Paleo Data Point 9 (Figures 4-4 and 4-5) for radiocarbon dating. The guano dated to

1630 $\pm$ 40 RCYBP (CAMS 63101). Paleo Data Point 9 is located at survey station K29 -- the same location where the archaeologists found their mysterious substance.

FIGURE 4-4. General view of location with desiccated bat guano at Paleo Data Point 9, near K29.

FIGURE 4-5. Closer view of the desiccated bat guano at Paleo Data Point 9.

The desiccated guano is probably from past summer-time roosts of *Myotis grisescens*, a species that currently resides in the cave. In fact, Paleo Data Point 3 designates an active cluster of bachelor grays roosting on the ceiling with an associated guano pile below. Paleo Data Point 6 yielded a skull and several humeri and radii of *M. grisescens*. The skull (Figure 4-6) has a very well developed sagittal crest; the following measurements were taken: greatest length of skull = 16.1 mm, condylo-basal length = 15.5 mm, I-M^3 = 7.5 mm, M^3-M^3 = 6.4 mm, interorbital breadth = 4.4 mm, braincase breadth = 7.7 mm, and occipital height = 5.4 mm. Two bat humeri of *M. grisescens* were submitted for dating, but dates could not be obtained from the bone.

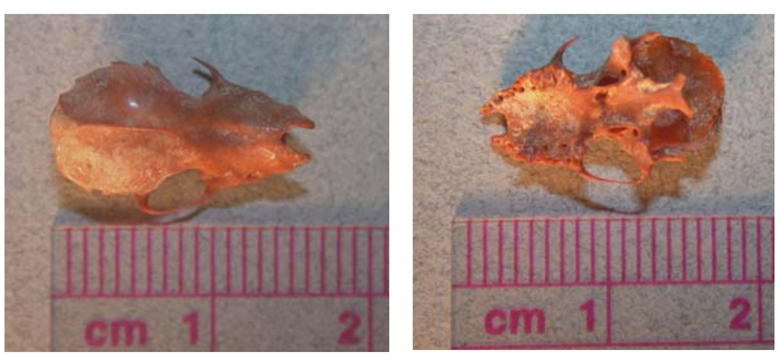

FIGURE 4-6. Dorsal and ventral views of the gray bat skull found at Paleo Data Point 6, between K33 and K34.

LEE CAVE PALEO DATA POINT DESCRIPTIONS

- Paleo Data Point 1, to left of trail, near station J34.
  Pipistrellus subflavus
  Mummified pipistrelle to left of trail, fur scattered (probably by crickets), stoke marks to right circa 10 feet above the dusty floor. Fur is tricolor, wings dark, forearm=34.5 mm.

- Paleo Data Point 2, to right side past station J50.
  Pipistrellus subflavus
  Torn apart pipistrelle mummy. Dark wings, scattered tri-colored fur, torso missing, wings and part of skull are present.

- Paleo Data Point 3, to right of trail on ceiling
  Small cluster of *Myotis grisescens* on ceiling about 17 feet above floor. Guano pile below.

- Paleo Data Point 4, to right of trail
  Pipistrellus subflavus
  Mummified pipistrelle on pedestal of red sediment lying on back. Circa 30 feet past K80 and 25 feet before K79.

- Paleo Data Point 5
  probable *Myotis grisescens*
  Darker sediment (chocolate-gray colored) on a rise of breakdown in a trench in Marshall Avenue. Looks like mixture of trampled guano and sediment.

- Paleo Data Point 6, to left of trail, 15 feet past K34 and 33 feet before K33.
  Vespertilionidae
  Myotis grisescens
  Area approximately 10 foot long and 5-foot wide along loose sediment slope. Numerous bat bones and skull sticking out of dusty sediment under a rock. Dark spot that is possibly guano. 4 left humeri (24.4 mm, 24.9 mm, 25.8 mm, 24.8 mm), 3 right humeri (24.1 mm, 25.4 mm, 24.7 mm), femur=14.9 mm, 2 left radii (41.9 mm, 42.1 mm), 2 right radii (40.9 mm, 41.7 mm). Skull lying on surface (different than one under rock) of *Myotis grisescens:* greatest length of skull = 16.1 mm, condylo-basal length = 15.5 mm, I-M3=7.5 mm, M3-M3=6.4 mm, interorbital breadth = 4.4 mm, braincase breadth = 7.7 mm, occipital height = 5.4 mm. Collected skull and 2 humeri. The lab was unable to get a radiocarbon date from the humeri.

- Paleo Data Point 7, just along right of trail, just before K30
  probable *Myotis grisescens*
  Large chunk of compressed guano, dark charcoal in color located under a rock. Labeled "FECE".

- Paleo Data Point 8, to right of trail, past K30
  probable *Myotis grisescens*
  Lump of compressed bat guano, located behind a slab labeled "FECE", under a step down block.

- Paleo Data Point 9, to right of trail, circa 15 feet before K29.
  probable *Myotis grisescens*
  In situ bat guano deposit/chunk located under/between breakdown blocks. Collected a sample of chunk of in situ bat guano, dated to 1630±40 BP.

- Paleo Data Point 10, to right of trail, circa 7 feet past K28.
  Myotis lucifugus
  Mummified *Myotis lucifugus*, complete, lying on belly. Fur two-toned, belly grayish and lighter than brownish back, long toe hairs, no keel on calcar, right forearm=37.9 mm.

- Paleo Data Point 11, to right of trail, up on top of sediment behind/up hill from station K28.
  probable *Myotis grisescens*
  3 clumps of bat guano that have been marked off with tape. Burned and unburned cane and salts mixed in sediment.

- Paleo Data Point 12, to right of trail, circa 5 feet downslope from point 11, behind station K28.
  probable *Myotis grisescens*
  Churned up sediment with dark brown peaks.

- Paleo Data Point 13, along left wall past L5.
  Neotoma floridana
  Odocoileus virginianus
  Deer ilium with rodent gnaw marks in a woodrat larder with nut shells.

- Paleo Data Point 14, left wall to left of station L5.
  cf. *Eptesicus fuscus*
  Vespertilionidae
  Bat bones in sediment or on sediment. Located along same wall as point 13 but about 20-30 feet before it. Sediments are thinly laminated, water lain, fine sand and silt. Bat bones are not running

with grain of sediments but are angled across and exposed on the slope. However some sediment covers the bones, sediments may have oozed downslope. cf. *Eptesicus fuscus* humerus=28.5 mm (marked with a pencil painted red). There is another pocket of bat bones about 2 feet to left and 5 inches higher than the first pocket.

- Paleo Data Point 15, right side of trail just before station K23 and after LK4.
  probable *Myotis grisescens*
  Several (about 8) clumps of compressed guano (some more than 6 inches long and 4 inches in diameter).

RECOMMENDATIONS

A thorough search of the entire passage would have produced more remains, but at the expense of damaging archaeological specimens. If work is to be conducted in the future, a search limited to the area along the passage walls would be the most likely to yield bones and additional information and disturb the resources the least. At present, the resources in Lee Cave have a low likelihood of being impacted due to limited visitation.

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CHAPTER 5
Wilson Cave Reconnaissance

INTRODUCTION

Most researchers enter Wilson Cave, located on the north side of the Green River, for the purposes of surveying, mapping, and exploring. Since the 1950s, researchers have noted hibernating *Myotis sodalis* (now classified as an endangered species), faunal remains, and bat staining in the passages of Wilson Cave. For example, in late November 1957, John S. Hall (1958) counted 530 *M. sodalis* in a partial exploration of Wilson. In addition, he saw 13 *Pipistrellus subflavus*, but no *M. lucifugu*s nor *Eptesicus fuscus*. Keefer (1971) saw only pipistrelle and big brown bats during his February 1971 visit. In March 1997 a Cave Research Foundation (CRF) crew found a cluster of hibernating *M. sodalis* in the historic upper level passage of the C survey, where they recorded a temperature of 5.5^{o} C near station C8, and saw faunal remains in various areas of the cave (Toomey 1997).

On February 13, 1999, CRF team members Mona Colburn, Janice Tucker, Rick Olson, and Steve Thomas traveled into Wilson. The purpose was twofold: Steve Thomas (Mammoth Cave National Park, then with Kentucky Fish and Wildlife) wanted to survey the cave for the presence of the endangered Indiana bat, and Colburn (Illinois State Museum) was to make a reconnaissance of paleontological resources (intended to be preliminary to conducting an actual inventory). The ultimate destination was an area named the Hiberdomes, where Thomas wanted to identify and count the bats known to winter there.

RESULTS AND DISCUSSION

Access to the various passages in Wilson Cave was made via an entrance pit (Figure 5-1). At the time of our trip (February 1999), the temperature was 0^{o} C in the pit, where six live pipistrelles were hanging. Remains of six taxa and bones of indeterminate bats were recorded at seven areas in Wilson Cave on the 1999 trip (Figure 5-2). Colburn collected samples of bone from Paleo Points 2, 3, 5, and 6; she later identified samples at the Illinois State Museum laboratory in Springfield.

FIGURE 5-1. Entrance to Wilson Cave.

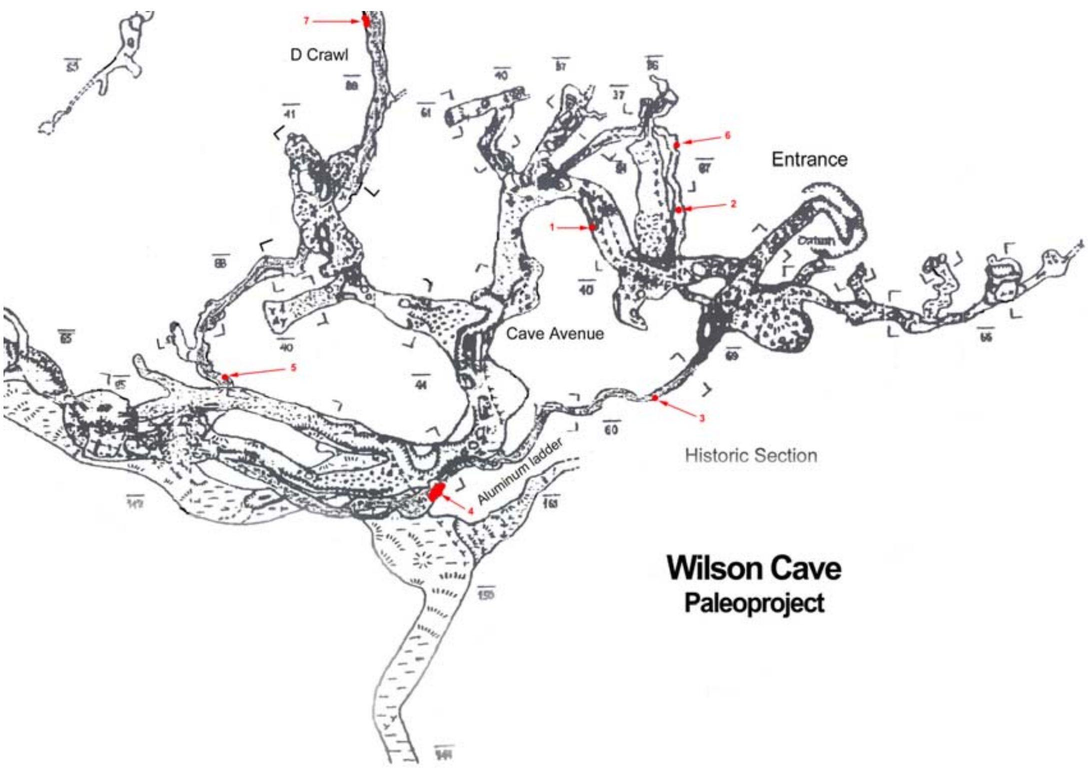

FIGURE 5-2. Wilson Cave: Map of approximate distribution of vertebrate remains (base map cartography by Dave West of the Cave Research Foundation).

The vertebrate taxa that have been identified in various areas of Wilson cave are listed in Table 5-1. On a March 17, 1997 CRF trip, Toomey, Fry, and Hendrickson took biological inventory in portions of the C, D, and W surveys. Their observations in the W crawl, near W12, have been included as Data Point 8 (not shown on Figure 5-2). At this location, they found woodrat debris, abundant bones of myotis, indeterminate bat, *Microtus* sp., *Rana* sp., and *Terrapene* sp. (Toomey 1997). The floor is a rich brown organic mixture and is littered with plant materials that are in various stages of decomposition. The debris has fallen from woodrat nests and larders above.

TABLE 5-1. Locations of vertebrate remains in Wilson Cave. Numbers refer to the assigned Paleo Data Point and letters in parentheses are the CRF survey designation. The W survey is included as Point 8.

Taxon	***1 (C)***	***2 (A)***	***3 (D)***	***4 (D)***	***5 (D)***	***6 (D)***	***7 (L)***	***8 (W)***
Rana sp.								x
Serpentes			x					
Terrapene sp.								x
Myotis lucifugus		x				x		
Myotis sodalis		x						
Myotis sp.		x						x
Pipistrellus subflavus	x							
Vespertilionidae	x	x	x	x	x	x	x	x
Microtus sp.								x
Neotoma floridana				x		x		x
Procyon lotor					x			

On the 1999 trip, we investigated about 180 feet of the upper level C survey (Figure 5-3). Steve Thomas recorded a temperature of 5.6^{o} C and counted a single cluster of 65 Indiana bats circa station C9, a single gray bat about 10 feet from the cluster, and lone pipistrelles and big brown bats scattered throughout the passage.

FIGURE 5-3. Entrance to the C survey.

The floor of the C survey is lightly littered with bat bones, including a skull of *Pipistrellus subflavus.* In addition, we could see 0.5-1 inch deep accumulation of bat bones in dime-sized drip holes in the floor.

The A survey is a lower level narrow canyon that is about 88 feet long (Figure 5-4). Pipistrelles and big brown bats were hibernating in this area. In a migrating shaft in the vicinity of A5, bat bones occur in a thin layer on the floor and are caught on ledges. Bones have accumulated in small divots where water tends to pool. Bat staining is present on the walls, and, near the passage terminus, staining is present on the ceiling (circa station A16).

FIGURE 5-4. The A survey.

Figure 5-5 shows the bone samples that were collected from the floor of a shaft in the A survey (Point 2): a fragment of bone from large-sized bird, bat radii (left = 38.3 mm;

rights = 38.3 mm, 36.9 mm, and 1 broken), and 4 bat skulls. Skull measurements are given in Table 5-2.

FIGURE 5-5. Bones from Point 2 in Wilson Cave.

TABLE 5-2. Bat skulls recovered from Wilson Cave Paleo Point 2 in the A survey.

Taxon	***GLS***	***CBL***	***I-M3***	***M3-M3***	***IOB***	***BB***	***OD***	***Sagittal crest***
Myotis lucifugus	14.7	13.9	6.3	6.0	4.3	7.4	5.3	no
M. sodalis	14.4	13.8	6.7	5.7	3.7	6.9	5.0	yes
M. sodalis			6.3	5.5	3.9			yes
Myotis sp.			6.4	5.4	3.9			no

In total, we traveled about 550 feet of passage in the D survey (Figure 5-6) and another 50 feet in the Hiberdomes. We observed hibernating pipistrelles and big brown bats in the D passage. Bat guano is dispersed throughout the passage and the walls exhibit bat staining. Several bones, encrusted with light gray calcium carbonate,

FIGURE 5-6. Entrance to D survey.

were collected from a small shaft at station D6 (temperature was 3.7^{o} C). The bones are indeterminate bat (left radius=37.4 mm, 38.0, 37.7 mm; right radius=36.0 mm; and the anterior half of a skull that is unidentifiable due to the mineral crust) and two mineral encrusted vertebrae of a colubrid-type snake. Some bat bone and woodrat debris consisting of feces, nuts, and wood, cover the floor of a larger shaft at the base of an aluminum ladder (before the crawlway). Near the entrance to the crawl (Figure 5-7), a piece of raccoon scat was collected; later examination showed that it contained no bone, but was full of fur.

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FIGURE 5- 7. Entrance to crawlway in D survey, near location of raccoon scat.

In the crawlway segment of the D survey beyond the ladder (at least from D5 to D21), bat bones are abundant in the sediment. The bone is best preserved in the protected areas that occur along the walls, under overhangs, and under rocks. A *M. lucifugus* skull and woodrat feces were found along the crawlway. However, skulls are not abundant or they are hard to detect. Two bones collected at D16 are left radii (37.4 mm and 35.3 mm) of indeterminate bat.

In a small pit/room above the Hiberdomes (near the rigging point at L5 for the descent into the Hiberdomes) there are bat staining on wall prominences and lots of broken bat bones in the mud floor. Steve Thomas descended into Hiberdomes (wet and 8.7^{o} C), where he counted 19 pipistrelles and an estimated 178 little brown bats.

Biological inventories show that Wilson Cave is the wintering site of sizable populations of the endangered Indiana bat, and two preliminary paleontological investigations searches show that that it has been utilized by a variety of bats for a long time. Only a future intensive inspection can determine the longevity of use. Admittedly, the search for fossil remains has been abbreviated, but in light of the new passages being explored in the ongoing CRF survey efforts, Wilson Cave has the potential to yield important fossils in the future. For the time being, the best management practice is to maintain the care that CRF expeditions already exercise when traveling through Wilson.

DESCRIPTION OF WILSON CAVE PALEO DATA POINTS

- Paleo Data Point Wil 0001
  In C survey, the historic upper passage.
  Pipistrellus subflavus
  Vespertilionidae
  Floor is lightly littered with bat bones, bone can be seen 1/2-1 inch deep, in dime-sized drip holes in the floor, including 1 pipistrelle skull.
  Photograph 1) passage entrance to C survey

- Paleo Data Point Wil 0002
  A Survey. Migrating shaft.
  Vespertilionidae
  Migrating shaft with bat bones in a thin layer on floor and caught on ledges. Aggregations of bones in small divet where water puddles. 3.5 ^{o} C.
  Further down passage around station A-16 Olson saw roosting stain on ceiling. Collected bones from floor of shaft in A survey.
  Photograph 2) view of entrance to A survey.
  Photograph 3) general view of accumulation of bat bones that resemble shredded wheat.

- Paleo Data Point Wil 0003
  D Survey. Survey station D6, in a migrating shaft.
  Vespertilionidae
  Colubridae
  In migrating shaft at D6. Bone accumulations that appears to be sooty or sediment coated. 3.7 ^{o} C. [Live pipistrelle and big brown bat in passage before D5]
  Collected sample identified by Colburn on 7-18-2003:

All bones are encrusted with calcite.
Bat: left radius=37.4 mm, 38.0 mm, 37.7 mm
Bat: right radius=36.0 mm
Bat: anterior half of a skull, not identifiable due to mineral crust.
Colubridae: 2 vertebrae, mineral encrusted.
Photograph 4) general view of entrance to D survey
Photograph 5) general view of bat bones on floor

- Paleo Data Point Wil 0004
  D Survey. In migrating shaft.
  Neotoma floridanus
  Vespertilionidae
  Photo: In D survey. Abundant woodrat debris and some bat bones at bottom of ladder.

- Paleo Data Point Wil 0005
  D Survey. In migrating shaft.
  Procyon lotor
  Vespertilionidae
  At beginning of crawl in D survey past the ladders.
  Collected sample identified by Colburn on 7-18-2003:
  The fragment of scat collected turned out to contain no bone, but was full of fur.
  Photograph 6) shot of opening to crawl.

- Paleo Data Point Wil 0006
  Vicinity of D16.
  Vespertilionidae
  Myotis lucifugus
  Neotoma floridanus
  Abundant bat bones in sediment along wall. *Myotis lucifugus* skull and woodrat feces in crawlway part of passage.
  At D16 collected sample
  Collected sample (2 bones) identified by Colburn on 7-18-2003:
  Bat: Left radius=37.4 mm, 35.3 mm
  Photograph 7) Bones along wall vicinity of D16.
  Photograph 8) Bones along wall vicinity of D16.

- Paleo Data Point Wil 0007
  L5 rig point for descent into Hiberdomes.
  Vespertilionidae
  Bat stain on wall protruberances. Bat bone in stiff mud on floor of small room just before rigging point at L5. Clump of mud with bones fragmented and aligned as in coon scat (no scat observed though).

[Steve Thomas descended into Hiberdomes while the rest of the crew waited in small room above. He observed 19 pipistrelles and an estimated 178 little brown bats. Heard squeaking bats.
Wet and temperature was 8.7 ^{o} C.]

- Paleo Data Point Wil 0008
  [This number has been assigned to W-12, located in the crawl of the W survey, information gleaned from trip notes on file with CRF and NPS; trip taken on March 17, 1997 CRF by Toomey, Fry, and Hendrickson (see Toomey 1997)]
  Vespertilionidae
  Myotis
  Microtus
  Rana
  Terrapene
  Neotoma
  Rich brown organic sediment floor degraded vegetable matter from pack rat roosts above. Some plant macroremains -- walnut, acorn, and wood
  Abundant bone including bat, *Myotis*, *Microtus*, Rana, *Terrapene, Neotoma*.
  Very abundant material -- needs further work.

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Keefer, Scott D. 1971. "Observations on bat colonies in Mammoth Cave National Park 13, 14, 15 February 1971." Report and letter dated April 28, 1971 to Edwin L. Rothfuss, Chief of IRM, Mammoth Cave National Park, 3 pages. On file at Mammoth Cave National Park.

Toomey, Rickard S. Toomey, III. 1997. [CRF trip notes on biological inventory of portions of Wilson Cave on March 17, 1997.] On file with the Cave Research Foundation.

CHAPTER 6
Dixon Cave

INTRODUCTION

Dixon Cave is a 1,000-foot long section of trunk passage that is up to 40 feet wide and 65 feet high; its mouth is about 1500 feet from the Historic Entrance of main Mammoth Cave. Today, Dixon stands alone, but in the past it was joined to Mammoth Cave, perhaps via Houchins' Narrows. At an unknown time in the past, collapse of the valley wall severed the connection near the top of the Historic Entrance stairs. Little can be gleaned about how bats and Native Americans used Dixon in prehistoric times because 200 hundred years ago Dixon became what is likely the most disturbed cave in Mammoth Cave National Park. Disturbance began in 1798 when Valentine Simons began mining nitrous dirt from Dixon and Mammoth. In the effort to help meet the War of 1812's demand for gunpowder, mining grew greatly in scope of production and in the amount of damage created. Angelo George (1994:43) writes the following about the "herculean effort" in Dixon: "over 30,875 tons of breakdown rock was removed from the front half of the cave and stacked in the back half! Part of the goal in Dixon Cave was to intercept the clay filled floor of the cave. An objective that never occurred." Nitrate-rich sediments were mined from anastomotic tubes in the walls, from under the breakdown on the floor, and from cracks in the walls of Dixon. Mining evidence includes well-trafficked ledges that were used to access higher wall levels, pick marks on the walls, and "working bays" (areas along the wall where breakdown was moved to expose a section of wall, creating large pits circa 10-40 feet across and 3 to 17 deep in the cave floor) (George n.d. p.6-7). The floor is covered with uniform sized breakdown cobbles, the sloping sides of the so-called working bays are composed of these cobbles, the bays or quarried pits are separated by ridges of these cobbles; a well-traveled path atop the central-most ridge of piled breakdown and cobbles that winds down the middle of the passage is the only flat surface in the cave (other than the narrow, discontinuous ledges along the left and right walls). George (1994:43) refers to the moving of more than 30,875 tons of rock (that's nearly 62 million pounds) as the miner's "herculean effort." Miners piled and stacked rock from the front half of the passage into the back half of the cave, resulting in a 20-foot differential in floor heights, and creating a shoulder-width trough (called the "Miners Causeway" by Duane DePaepe [George n.d. p. 7]) that passes up the middle of the piled rock.

METHODS AND RESULTS

The Illinois State Museum Paleontological Inventory Project worked in Dixon in the summers of 2000 and 2001. Fieldwork was always conducted in the summer months because Dixon is closed for bat hibernation from September to May. Field methods followed those discussed in the Project Methods section. Because Dixon Cave was so disturbed and rearranged, we did not expect to find extremely old deposits *in situ*. In an effort to find them, every nook and cranny was searched. Examples of the contexts in which remains were found are shown in Figures 6-1 through 6-4.

FIGURE 6-1. Flagging faunal remains at base of saltpeter mining spoil pile (photograph by Ann and Peter Bosted).

FIGURE 6-2. Under breakdown.

FIGURE 6-3. In a mining bay/pits.

FIGURE 6-4. On ledges and in wall cracks and tubes.

The Paleontological Inventory Project recorded vertebrate faunal remains at 324 data points. Figure 6-5 shows the distribution of the data points throughout the passage.

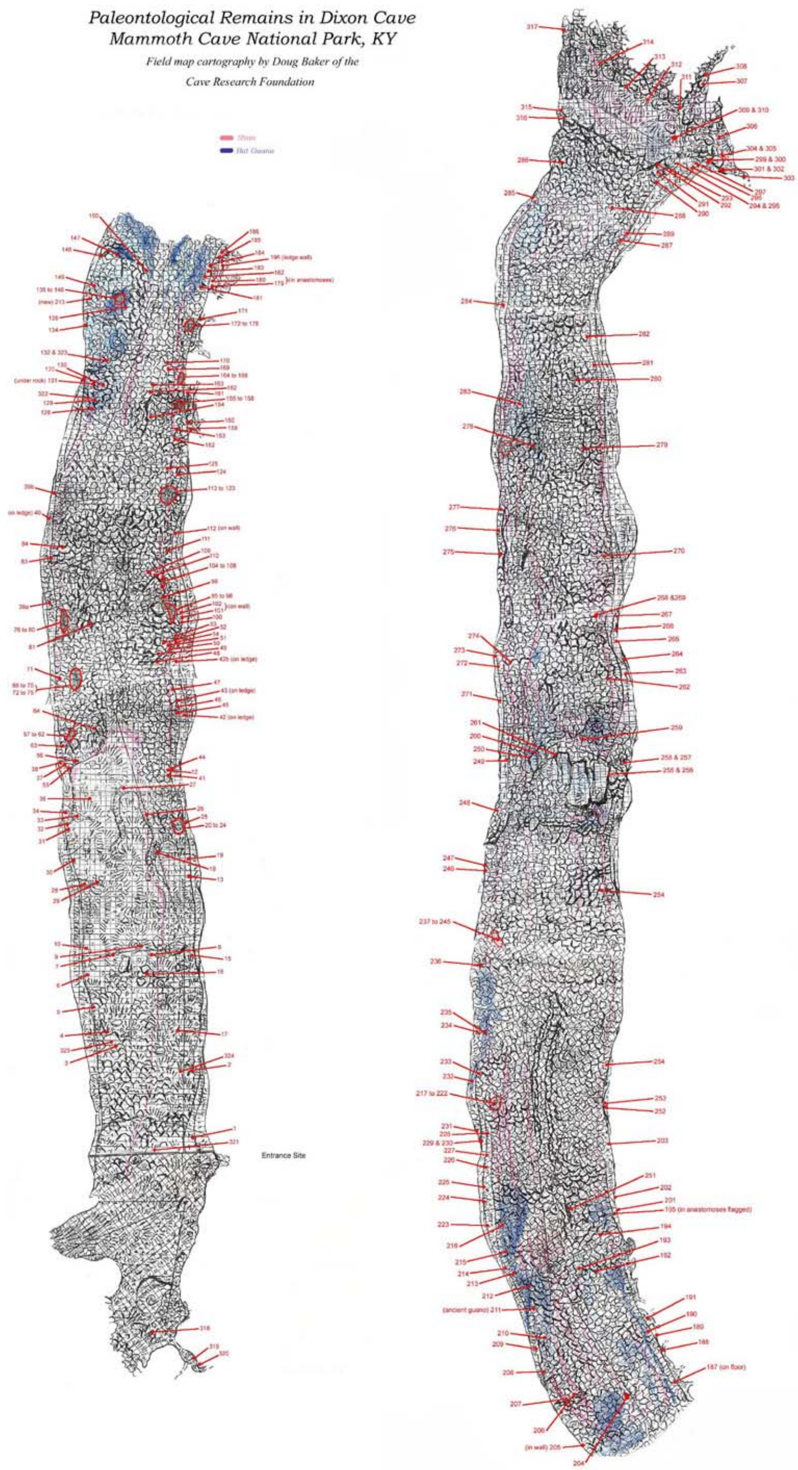


FIGURE 6-5. Map of Dixon Cave showing distribution of data points (red dots).

Bat staining and guano are prevalent (there are active bat roosts in the cave). Faunal remains are dominated by bat bones and body parts with tissue (often referred to as mummified). For example, Data Points 21 through 24 represent four pockets of bat bones and partial mummies around a piece of breakdown (Figure 6-6 through 6-8).

FIGURE 6-6. Data points 21-24 are located around breakdown block.

.

FIGURE 6-7. Example of bat bones (Point 24).

FIGURE 6-8. Example of partial bat mummy (Point 85).

Two samples were radiocarbon dated (Table 6-1).

TABLE 6-1. Radiocarbon samples submitted from Dixon Cave.

Dixon Cave, Data Point number	*Material dated*	*Laborator& Lab number*	*14C years before present*	*Error*
ISM MACA Paleo Dixon #39	~24 g raccoon scat	GEOCHRON GX-27147	470	± 60
ISM MACA Paleo Dixon #82	~29.5g bat guano	GEOCHRON GX-27145	1380	± 70

Seventeen samples with bone were collected and identified at the Illinois State Museum's Research and Collections Center in Springfield, Illinois. Figures 6-9 through 6-11 shows the sediment sample collected from Data Point 100. After screen washing in water, some samples like that from Point 100 (Figure 6-12), prove to be poor, but others, like that from Point 310 (Figure 6-13), contain abundant bone.

FIGURE 6-9. Sediment with bone was collected from wall crack at Point 100.

FIGURE 6-10. Sample from Data Point 100 before being washed.

FIGURE 6-11. Sample after screen washing.

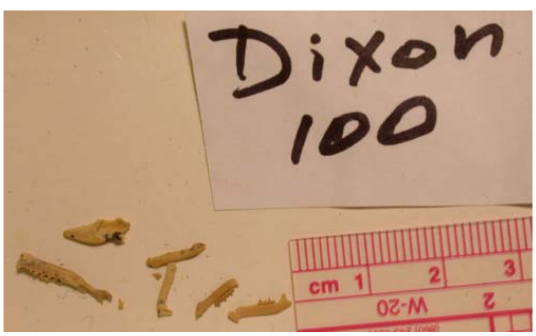


FIGURE 6-12. Bones sorted from Point 100 sample.

FIGURE 6-13. Sample from Point 301 before washing, and bones recovered after washing and sorting.

In total, 32 different vertebrates were identified from Dixon Cave; the scientific names and corresponding common names are given in Table 6-2. Table 6-2 also presents the percent ubiquity for each species, that is, the number of data points where a certain taxon was found.

TABLE 6-2. Vertebrate faunal remains found in Dixon Cave. Percent ubiquity based on 324 data points (this number excludes the point that denotes active gray bats).

Scientific name	*Common name*	*# data points*	*Percent Ubiquity*
Osteichthyes	Unidentified fish	2	0.6
Amphibia			
Salamandridae	Unidentified salamander	3	0.9
Bufo sp.	Toad	2	0.6
Anura	Frog or toad	8	2.5
Reptilia			
Terrapene sp.	Box turtle	3	0.9
Testudines	Unidentified turtle	2	0.6
Sauria	Unidentified lizard	1	0.3
Colubridae	Coluber-type snake	1	0.3
Serpentes	Unidentified snake	1	0.3
Aves			
Gallus gallus	Chicken	1	0.3
Strigiformes	Owl	1	0.3
Aves	Small to medium-sized bird	2	0.6
Mammalia			
Didelphis virginiana	Opossum	2	0.6
Blarina brevicauda	Short-tailed shrew	2	0.6
Sorex sp.	Indeterminate shrew	1	0.3
Corynorhinus sp.	Big-eared bat	2	0.6
Eptesicus fuscus	Big brown bat	47	14.5
cf. *E. fuscus*	Possible big brown bat	2	0.6
Myotis cf. *austroriparius*	Possible southeastern myotis	1	0.3
Myotis grisescens	Gray bat	5	1.5
M. cf. *grisescens*	*Myotis*, possibly gray bat	3	0.9
Myotis leibii	Small-footed bat	30	9.3
M. cf. *leibii*	*Myotis*, possibly small-footed bat	2	0.6
Myotis lucifugus	Little brown bat	12	3.7
M. cf. *lucifugus*	*Myotis*, possibly little brown bat	3	0.9
Myotis sodalis	Indiana bat	38	11.7
M. cf. *sodalis*	*Myotis*, possibly Indiana bat	15	4.6
Medium-sized *Myotis* sp.	Indeterminate medium-sized *Myotis*	84	25.9
Myotis sp.	Indeterminate *Myotis*	38	11.7
cf. *Myotis*	Possible mouse-eared bat	5	1.5
Pipistrellus subflavus	Eastern pipistrelle	24	7.4
Vespertilionidae	Indeterminate vespertilionid bat	206	63.6
Canis sp.	Dog or coyote	1	0.3

Scientific name	***Common name***	***# data points***	***Percent Ubiquity***
Procyon lotor	Raccoon	82	25.3
cf. *P. lotor*	Possible raccoon	1	0.3
cf. *Mephitis mephitis*	Possible striped skunk	1	0.3
Lynx cf. *rufus*	Probable bobcat	1	0.3
Carnivora	Indeterminate carnivore	1	0.3
Sus scrofa	Domestic pig	1	0.3
Odocoileus virginianus	White-tailed deer	2	0.6
O. virginianus or *Sus scrofa*	Artiodactyl, most like deer or pig	1	0.3
Glaucomys volans	Flying squirrel	1	0.3
Marmota monax	Woodchuck	2	0.6
Peromyscus sp.		9	2.8
Microtus ochrogaster (& *Microtus* sp.)	Prairie vole (& vole)	1	0.3
Rodentia (small taxa)	Mouse-sized rodent	10	3.1
Neotoma floridana	Eastern woodrat	49	15.1
cf. *N. floridana*	Possible eastern woodrat	1	0.3
Sylvilagus floridanus	Eastern cottontail rabbit	2	0.6
Mammalia, medium-sized	Indeterminate medium-sized mammal	2	0.6
Mammalia, large-sized	Indeterminate large mammal	1	0.3

Bats dominate the faunal assemblage. Remains of *Procyon lotor* (scat) and *Neotoma floridana* (feces, larders, and bone) were the most commonly found of the non-bats animals. Woodrats are currently active in the cave as attested to by chewed up orange pin flags and a woodrat mummy that went missing (Figures 6-14 and 6-15).

FIGURE 6-14. Entire woodrat skeleton with tissue found was in 2000, Data Point 210 (photograph by Gary Berdeaux).

FIGURE 6-15. Only the tail remained in 2004.

A possible owl pellet (in two pieces) was found at point 44 (Figure 6-16). The pellet may have been deposited inside the cave, or, a woodrat may have transported them. The pellet pieces were not dismantled; fur, wing and finger bones, and skulls of multiple bats are visible in them. One piece contains an isolated dentary of a medium-sized *Myotis* and two skulls with attached mandibles (cf. *Myotis*, embedded in fur, and *M.* cf. *lucifugus*). The other pellet fragment has two skulls that are exposed, both assigned to *Myotis* cf. *lucifugus*. The backs of the skulls are broken.

FIGURE 6-16. Two fragments of a possible owl pellet that contains bones of multiple bats.

Figure 6-17 illustrates the ubiquity of all taxa, except indeterminate vespertilionids (see Table 6-2, above, for the ubiquity of each species) (graph made using SigmaPlot by SPSS, Inc., 2001).

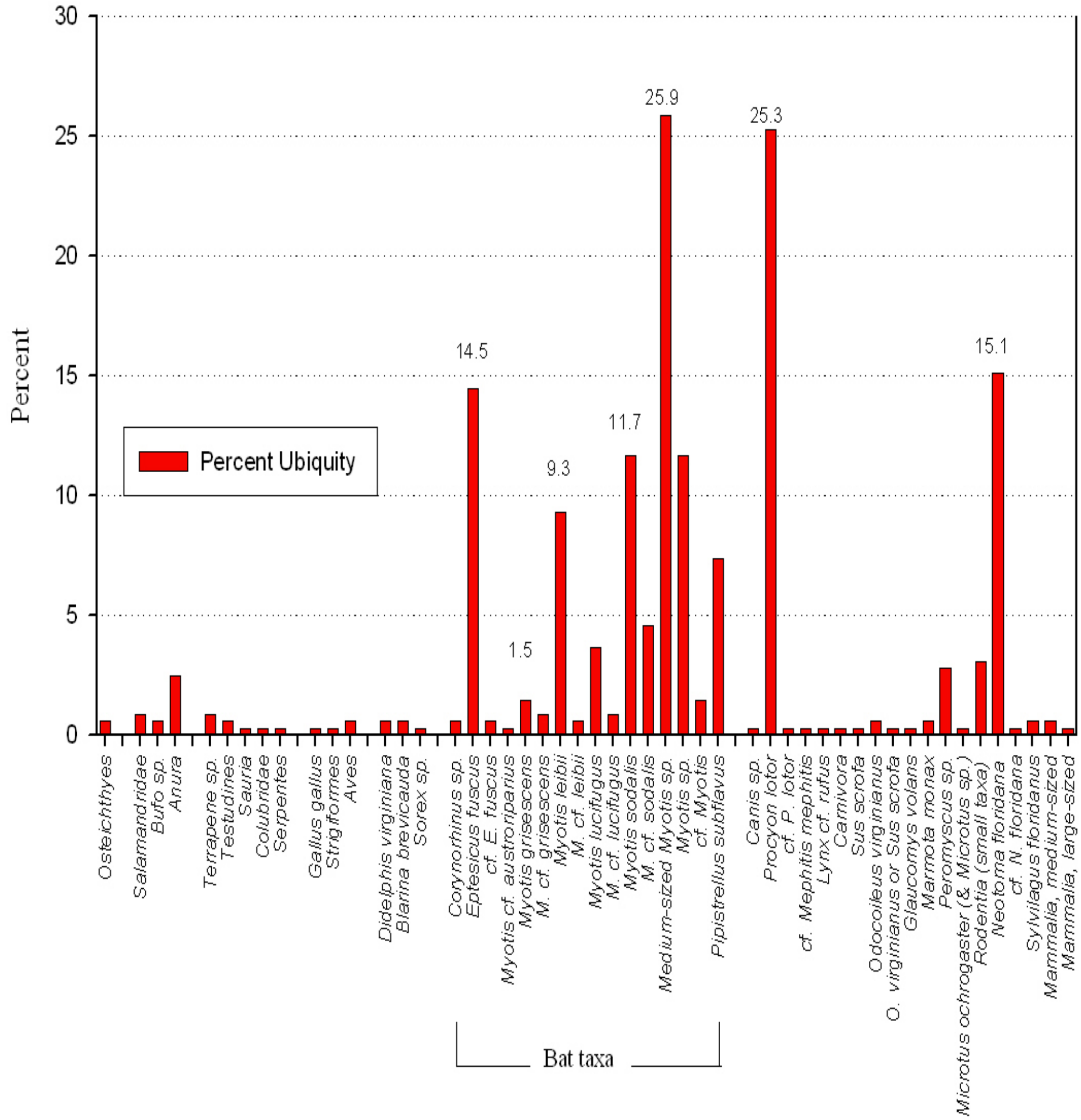


FIGURE 6-17. Percentage of data points (total number of data points = 324) that yielded remains of specified vertebrate taxon (percent indeterminate vespertilionids not graphed).

The paleontological study found *Myotis* bats to be the most prevalent and, also, the most ubiquitous, taxon. Thirty-nine percent of the data points yielded bones attributed to *Myotis* (Table 6-3). Of the fraction that could be either positively or tentatively identified to a species, *M. sodalis* and *E. fuscus* were the most ubiquitous.

TABLE 6-3. Rank order of bat taxa in Dixon Cave according to ubiquity. n = number of data points yielding specified taxon. Ubiquity based on 324 data points that yielded vertebrate remains.

Rank order	*Taxon*	*n*	*% Ubiquity*
1	Indeterminate *Myotis* (includes medium-sized *Myotis*, n=84, and *Myotis* sp. + cf. *Myotis*, n=43)	127	39.2
2	*Myotis sodalis* (includes *M.* cf. *sodalis*)	53	16.4
3	*Eptesicus fuscus* (includes cf. *E. fuscus*)	49	15.1
4	*Myotis leibii* (includes *M.* cf. *leibii*)	32	9.9
5	*Pipistrellus subflavus*	24	7.4
6	*Myotis lucifugus* (includes *M.* cf. *lucifugus*)	15	4.6
7	*Myotis grisescens* (includes *M.* cf. *grisescens* and cf. *M. grisescens*; excludes point that is currently active guano area)	8	2.5
8	*Corynorhinus* sp.	2	0.6
9	*Myotis* cf. *austroriparius*	1	0.3

Bat skull elements and dentaries were measured using dial calipers. The following measurements were taken for skull elements: greatest length of skull (GLS), condylobasal length (CBL), distance between front of maxilla (excluding incisor) and M3 (I-M3), breadth across the M3s (M3M3), interorbital breadth (IOB), maximum breadth of the braincase (BB), occipital depth (OD). Distinguishing species of *Myotis* based on skulls takes into consideration measurements (especially of the IOB and BB), shape of the cranium, and presence or absence of a sagittal crest; assessing the latter can be somewhat subjective. Skull measurements are listed in Table 6-4 (at the end of this chapter). Total dentary length was measured on 82 dentaries associated with skulls, and on 222 loose dentaries (i.e., those not clearly associated with a skull). When dentaries occurred in pairs, the measurement from only one of the sides was used. Taxonomic assignment of dentaries was based on tooth count, total length, and on robustness of the horizontal ramus and teeth. The measurements for dentaries found in association with skulls are in Table 6-4 and the measurements of loose dentaries are given in Table 6-5 (also at the end of this chapter).

Figure 6-18 presents bar graphs (produced with SigmaPlot software) for all measurable dentaries (loose and associated) for a given taxon (taxonomic category includes both positive and conferred, "cf.", identifications). For known pairs, only a left or a right measurement was included in the data set. The box represents data that lie between the 25th and 75th percentile, and the upper most horizontal line is the 90th

percentile (dots are outliers). An interesting outlier is the left dentary of a very young (well under a month old) bat, tentatively assigned to cf. *Myotis* (Data Point 292). The dentary is approximately 8.5 mm long and has unerrupted teeth in the ramus (Figure 6-19 and 6-20).

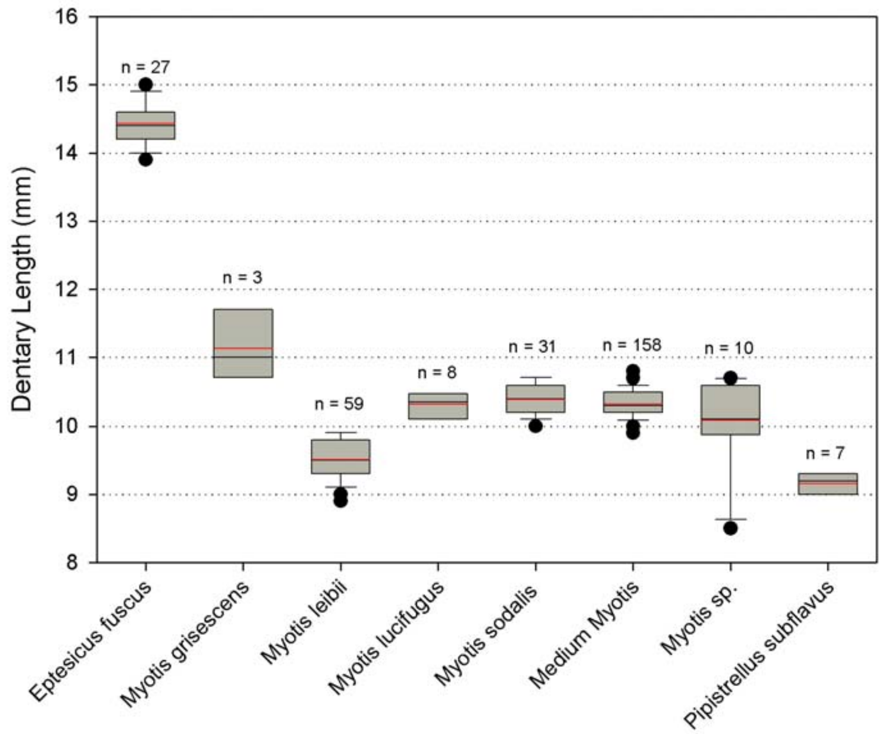
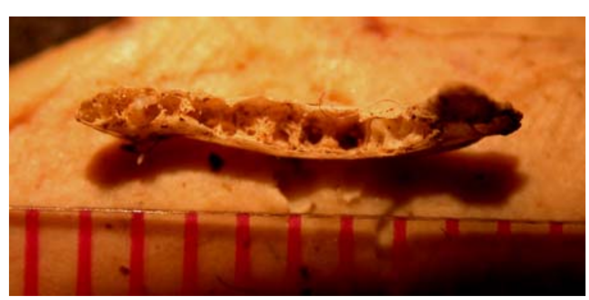


FIGURE 6-18. Dixon Cave bat dentaries. Inside the box, red line is the mean and black line is the median.

***FIGURE 6-19. Dixon Cave, Point 292, labial view, right dentary of juvenile bat, cf.* Myotis.**

***FIGURE 6-20. Dixon Cave, occlusal view, right dentary of juvenile, cf.* Myotis.**



DISCUSSION AND CONCLUSIONS

Since the 1800s, it was apparent that Dixon Cave has been an important bat hibernaculum. In the early 1890s, Hovey visited Dixon Cave. He and Ed Bishop, his guide, "sallied forth one cold March morning" with the daffodils in bloom and 4 inches of snow on the ground; inside the cave they found the roof to be "appropriated by myriads of hibernating bats, clinging in great clusters like swarms of bees" (1893:189-190). This phrase was an often-used expression in old descriptions, but it aptly describes hibernating *Myotis sodalis* and *M. lucifugus*.

On July 24, 1934, Claude Hibbard (Assistant Naturalist) made his first visit to Dixon and found several scattererd *Pipistrellus subflavus* covered with condensation and about 350 *M. sodalis* in two clusters and scattered (he collected 2) (Hibbard 1935:9). On that day he recorded the temperature at the ceiling as 46^o F and at the floor, 56^o (where in the cave is unknown). In mid-August, he saw about 300 *M. sodalis* (Hibbard 1935:11). Later in late October, he saw "a large number" of *Myotis sodalis* … 3 *Myotis lucifugus*, and *P. subflavus* and a few *Eptesicus fuscus* (Hibbard 1935:20). In early November he saw "hundreds" of *M. sodalis* with a few *M. lucifugus* hanging amongst them, one M. leibii, and numbers of *P. subflavus* and *E. fuscus* (Hibbard 1935:22).

In 1929 Vernon Bailey (with the U.S. Bureau of Biological Survey), Leonard Giovannoli (with the Kentucky Geological Survey), and Florence Bailey inventoried the animal life of the Mammoth Cave region as part of a U.S. Department of Agriculture Bureau of Biological Survey project (before it was abolished). At the time of their April 22, 1929 visit they found a few hundred bats in Dixon Cave, but were told by their guide that in the winter there had been thousands of bats. Bailey wrote the following about Dixon Cave:

- *Pipistrellus subflavus* were still hibernating in "considerable numbers"(<100) at the back of Dixon where the temperature was 52^o F, but none were present in the "big room nearer the entrance" (p. 450)

- *Myotis* were hanging in the main passage

- *Myotis lucifugus* found in "small numbers" in late April and in mid-November in "great abundance" with an estimated 1,000 individuals hanging mainly on the ceiling and some hanging on the walls and singly (p. 453, 454)

- A "few hundred" *Myotis sodalis* were seen in late April, but on November 15 "at least 1,000" were on the ceiling (p. 457)

- In July 1929, a *M. grisescens* (although not recognized as such at the time) was collected in Dixon Cave (p. 459)

- Based on the collection of "several full-grown young of the year," Bailey concluded that Dixon was one of the "breeding as well as wintering caves" for *M. sodalis* (p. 457).

Giovannoli collected specimens of *Myotis grisescens*, *M. lucifugus, and M. sodalis* in July 1929 and Bailey collected *M. sodalis* from Dixon in September and November; these specimens are curated at the U.S. National Museum (Smithsonian Institution 1996). In addition, Bailey recorded the temperature near the back of Dixon as 52^{o} F in April.

In 1928, the year before Bailey's work at Mammoth Cave, *Myotis sodalis* had been recognized as a species separate from *M. lucifugus* when Gerrit Miller described and named it based on a type specimen from Indiana's Wyandotte Cave. Bailey (1933) makes several interesting statements regarding *M. sodalis* in Dixon Cave in his 1929 research. Bailey (1933: 457) indicated that on April 22, 1929, *M. sodalis* were "hanging to the roof near the back of the cavern in bunches or rows of a dozen to fifty together or scattered out by twos and threes over the ceiling, fully torpid…."

In the 1950s, Hibbard, Hall, and Davis, studied bats in Dixon and other caves in the Park. In early February 1957, Hall and Davis (1957) found *Eptesicus fuscus* (entrance area), *Myotis sodalis* (ceiling of main passage), *Pipistrellus subflavus* (end of passage), and *M. sodalis* (end of passage). Hall (1958a, 1958b) surveyed bats in Dixon during each of the 4 seasons in 1957-1958: February, April, June, and November of 1957 and February 1958. The species that he saw were *M. sodalis* (highest estimated populations ranged between 4000-4500 for April and November), *M. lucifugus* (200 in February 1957), *M. grisescens* (1 in June), *E. fuscus* (5 in November), and *P. subflavus* 250 in April) (Hall 1958a). Although their numbers fluctuated greatly in April and November, *M. sodalis* was by far the majority population on each of Hall's visits to the cave. At the end of November 1957, Hall (1958a) banded 17 *M. sodalis*.

A survey of live bats conducted by Wayne Davis (1963) at Dixon Cave for 16 days between July 30 and September 15 of 1963 netted the following species: *M. sodalis* (6354), *M. lucifugus* (6616), *P. subflavus* (450), *E. fuscus* (145), *M. grisescens* (129), *L. borealis* (53), *M. subulatus* (22), *Nycticeius humeralis* (4), and *M. keenii* (3). Species netted inside the cave during the day (versus night time captures, which took place in the cave mouth and outside on the tourist trail) were *M. sodalis*, *M. lucifugus*, *M. grisescens*, and *P. subflavus*. Daytime captures inside the cave, netted twice as many *M. sodalis* (5183) as *M. lucifugus* (2440) (however, night time netting caught 1171 and 4176, respectively). Ninety-seven percent of the *M. grisescens* were captured during the day inside the cave.

Hall, Wilson, and Keefer did bat counts in the 1960s and into the early 1970s. Hall and Wilson conducted four years of survey in the early 1960s, banding 159 *M. grisescens* and concluded that the population of Dixon consisted of wandering groups of no more than 100 males that stayed in the cave for only one or two days (Hall and Wilson 1966). In the fall of 1969, Keefer (a zoology student at Southern Illinois University) estimated that Dixon Cave housed 4,000 *M. sodalis* (Keefer 1969) and in mid-February of 1971 there were an estimated 4,000-5,000 with no clusters larger than 200 and no activity sites (Keefer 1971). (Keefer' reports did not list any numbers for *M. lucifugus*.) In a report that focused on nitrates and saltpeter mining, Carol Hill (1979:9) noted that there was a small bat colony, with a guano pile below it, hanging at the end of Dixon, but the species was not specified, nor was the time of year.

Between 1982 and 1987, numbers for hibernating *M. sodalis* were overestimated (ranged between 16,550 and 30,000) but became more accurate when counts were made using a spotting scope beginning in 1993 (MacGregor (2004, personal communication).

Numbers of wintering *M. sodalis* were estimated at 9,150 in 1993; however, since then numbers steadily fell into the 7000s, then 5000s, and in 2003 were down to 3600 (Wethington 2004, personal communication). Between 1995 and 2003 estimated numbers for hibernating *M. lucifugus* are low (ranging from 30-160 individuals) (Wethington 2004, personal communication).

Apparently, many of the early researchers (1971 and before) identified *M. sodalis* as the species hanging at the end of Dixon in the fall through winter months. Hall's research seems to place *M. sodalis* at the back of Dixon in all seasons of the year: The active *M. sodalis* in Dixon in mid-April of 1957 (the only species Hall noticed to be active), was an influx of 2500 individuals that arrived from the outside the cave and departed after a couple of days (Hall 1958a). In the last week of February 1958, Hall (1958b) counted 200 active *M. sodalis* and 2000 torpid. He wrote:

> Near the end of Dixon Cave is a spot where *Myotis sodalis* were observed to form active clusters in April, June, and November. A pile of guano at this point attests to the presence of active bats roosting here. In November, a small group of active *Myotis sodalis* were seen on the ceiling directly over the pile of guano. These were, most likely, bats which had awakened from hibernation and came to this spot while they were active. In April [17, 18, 19] there was still a near maximum population in hibernation in Dixon Cave, but at dusk large numbers of bats were seen flying into the cave and forming a cluster, at the active spot at the back, of about 2500 *Myotis sodalis*. These were not the ones that were hibernating in the cave. This large cluster then left the cave before dawn.
>
> (Hall 1958a:8-9)

In a May 1957 letter to the Park, Hall made a point of saying that the active species [in April] was "*Myotis sodalis* and not *Myotis grisescens*" (Hall 1957). Female *M. sodalis* are known to rouse in late March-April and leave the cave for summer sites; some individuals engage in mating behavior in late April before leaving the cave.

During visits to the cave in the summers of 2000, 2001, and 2002, we saw 50-100 bats clustered at the end of Dixon (most appeared to be *M. grisescens,* Figure 6-21) and several *Pipistrellus* hanging in isolation. Thus, it is very interesting that in June, Hall (1958a) noted 1) only a single *M. grisescens* in his 1957 bat counts for the month of June;

and, 2) *M. sodalis* to be the species at the activity spot. However, according to MacGregor (2004, personal communication), the bat colony at the back of Dixon Cave in the summer is actually a mix of *Myotis* species (mostly *M. lucifugus*, and a few *M. grisescens, M. austroriparius*, and *M. sodalis*).

FIGURE 6-21. Dixon Cave, summer cluster of Myotis at the back of Dixon Cave.

As all of these examples show, Dixon has been important habitat for both summer and winter bat populations. It is hard to believe that in the 1930s E. R. Pohl proposed opening the collapsed western end of Dixon so that visitors would be able to view both the new opening and the Historic Entrance from a single vantage point and so that visitors could go on a self-guided tour (Hibbard 1935:59, Pohl 1935). The bizarre plan included installing chicken wire over the entrance in order to exclude bats from returning to the hibernaculum while the back end of the cave was being opened; the reopening of Bat Cave was seen as a sufficient alternative for the bats. Hibbard (1935:59) objected to the plan unless "a large number of the caves now suitable for bats be opened before the Dixon Cave is opened." Among the then closed caves were Ganter and Bat. After discussions centered on how such an opening would detrimentally affect bats utilizing Dixon Cave, the plan caved-in.

As studies of live populations have shown, Dixon has been an important summer and winter roosting venue for several species, especially *Myotis*. Although Dixon Cave may be the single most disturbed cave in the Park, faunal evidence is consistent. Remains of indeterminate *Myotis* (this category includes remains identified as medium-sized *Myotis, Myotis* sp., and cf. *Myotis*) were the most widespread and ranked first in ubiquity. However, the paleontological remains do not reflect the same rank order of species netted by in Davis' 1963 study wherein *M. lucifugus* and *P. subflavus* were more common than *E. fusc*us (see figures in the Introduction). In fact winter bat counts and netting studies have found Dixon to be an important hibernaculum and swarming locale not only for *M. sodalis*, but also for *M. lucifugus*. Many studies mention seeing or capturing *E. fuscus* and *M. leibii*. For example, Hall and Davis (1957) saw *E. fuscus* hanging near the entrance and Davis (1963) commented that most *M. subulatus* were netted about a foot above the cave floor. Among the identifiable bats, bones of *E. fuscus* and *M. leibii* ranked second and third in ubiquity (but not in number of individuals). *E. fuscus* and *M. leibii* are well-known for hibernating in cold areas. Bailey (1933) recorded a temperature of 52^{o} F at the back of Dixon in April of 1929. Using an inexpensive digital thermometer, the Paleontological Inventory Project recorded temperatures in the high 40s ^{o} F at numerous places along the floor.

Because Dixon Cave is protected from public entry by a bat gate and because it receives infrequent visitation, the faunal resources are safe from impact. Faunal remains that have potential to be extremely old are exposed only in a couple of the mining pits and are protected under breakdown and in the interstices.

TABLE 6-4. Dixon Cave: measurements (in millimeters) for bat skulls and associated dentaries. Location indicates the data point number and left (L), right (R), or center (C), in passage. Condition abbreviations: M= mummified, T=tissue adhering, S=skeletanized, F=fur. Measurements taken on skull: total length (incisor to articular condyle) of dentary (TL), greatest length of skull (GLS), condylobasal length (CBL), first incisor to M3 (I-M3), breadth from M3 to M3 (M3s), interorbital breadth (IOB), breadth of braincase (BB), occipital depth (OD).

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
Corynorhinus sp.	0083 L	L maxilla					5.5					
Corynorhinus sp.	0301 R	rostrum					6.1	6.2	3.8			
Eptesicus fuscus	0011 L				19.4	18.1	8.0	7.9	4.4	8.3	6.3	
E. fuscus	0022 R	mummy	M		19.3	18.5	8.2	8.0	4.8	9.2	6.1	
E. fuscus	0025 R	palate					8.5	8.0				
E. fuscus (male)	0028 L		S, T	L=14.1, R=14.1	19.4	17.8	8.0	8.0	4.6	8.8	6.3	
E. fuscus	0056 L	mummy	M	L=14.4			8.4	8.2				
E. fuscus	0061 L	skull	T, F	R=14.5			8.0	8.5				
E. fuscus	0077 L	skull		R=14.8	20.3	18.9	8.5	8.1	4.7	9.3	6.2	
E. fuscus	0083 L						8.3	8.2	4.5			
E. fuscus	0101 R						8.5	8.3	4.7			
E. fuscus	0101 R						8.0	8.4	4.4			
E. fuscus	0101 R	rostrum					Not measurable					
E. fuscus	0102 R	R maxilla										
E. fuscus	0142 L	skull & dentary	T, F	L= 15.0	20.4	19.0	8.4	8.3	4.7	9.1	6.4	
E. fuscus	0156 R	mummy	M		19.7	18.3	7.8	7.5				
E. fuscus	0187 R		M, moldy	L=14.6, R=14.6								
E. fuscus	0196 R	palate						8.0				
E. fuscus	0199 R	mummy	M			18.0	8.0	8.0				
E. fuscus	0274 L	mummy	M		19.9	18.8	8.1	7.9				
Myotis cf. *austroriparius*	0320 R	skull					6.4	5.6	3.9			
Myotis grisescens	0021 R				15.2	14.5	6.8	5.8	4.4	7.7	5.2	present
M. grisescens	0021 R			R=10.7		14.5	6.6	6.1	4.5	7.3		present
M. grisescens	0268 R	mummy	M	L=11.7	16.2	15.4	7.3	6.1	4.1	7.8	6.0	present
Myotis leibii	0025 R	skull					5.8	5.3	3.6			absent
M. leibii	0083 L	skull			12.9	12.5	5.7	5.1	3.5	6.8	4.2	absent

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
M. leibii	0083 L	skull	Damp & mushy				5.7					absent
M. leibii	0083 L	maxilla					Not measurable					
M. leibii	0083 L	skull	T		13.3	12.7	5.9	4.9	3.6	6.9	4.4	absent
M. leibii	0083 L	rostrum					5.9	5.3	3.3			
M. leibii	0101 R	skull			13.8	13.0	6.2	5.2	3.5	6.7	4.1	
M. leibii	0118 R	skull				12.8	5.9	5.2	3.6	6.7		
M. leibii	0124 R	mummy	M, moldy	mandible broken			6.0	5.2				
M. leibii	0184 R	skull			13.6	13.0	6.0	5.1	3.6	3.6	4.1	
M. leibii	0194 R	mummy	M	R=9.5	13.4	12.8	6.0	5.1	3.6	6.8	4.3	
M. leibii	0200 R	skull			13.6	13.0	6.1	5.0	3.6	6.6	4.1	
M. leibii	0200 R	rostrum					6.2					
M. leibii	0200 R	palate					6.3	5.3				
M. leibii	0234 L	rostrum					6.0	5.2				
M. leibii	0102 R	skull					5.6	5.3	3.3			
M. leibii	0272 L	mummy	M	L=9.2	13.3	12.6	6.0	5.3	3.6	6.7	4.2	absent
M. lucifugus	0051 R	skull	T, F		14.4	13.8	6.5	5.7	4.2	7.2	4.9	wide suture
M. lucifugus	0078 L	mummy	M, S	L=10.1	14.4	13.9	6.3	5.8	4.1	7.4	5.1	absent
M. lucifugus	0108 R	mummy	M	L=10.4	14.7	14.3	6.7	5.7	4.0	7.3	5.1	absent
M. lucifugus	0125 R		T, S, no fur, moldy	mandible, not measured	14.8	14.0	6.3	5.6	4.3	7.5	5.4	absent
M. lucifugus	0196 R	skull					6.8	5.8	4.0			absent
M. lucifugus	0197 R	mummy	M, moldy	R=10.7	15.0	14.2	6.5	5.7	4.3	7.7	5.3	absent
M. lucifugus	0198 R	mummy	M, moldy	R=10.4	14.7	14.2	6.7	5.5	4.2	7.3	5.1	absent
M. lucifugus	0202 R	mummy	M, moldy	R=10.5	14.5	13.8	6.5	5.7	4.1	7.2	5.1	absent
M. lucifugus	0259 R	mummy	M	R=10.3	14.6	14.1	6.5	5.6	4.3	7.6	5.1	absent
M. lucifugus	0285 L	skull		L=10.1	14.2	13.7	6.2	5.8	4.4	7.3	4.9	absent
M. lucifugus	0301 R	skull			14.3	13.4	6.2	5.5	4.3	7.3	~4.7	absent
M. cf. *lucifugus*	0012 L	skull			14.5	14.1	6.5	5.3	4.2	7.0	4.8	poor
M. cf. *lucifugus* (male)	0036 L	mummy	T, no fur	R=10.1	13.9	13.6	6.2	5.3	4.0	6.8	5.3	wide suture

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
M. cf. *lucifugus*	0044 R	skull							3.9			absent
M. cf. *lucifugus*	0044 R	skull							3.9			absent, wide
M. cf. *lucifugus*	0044 R	skull					6.4	5.4	3.9			absent
Myotis sodalis	0006 L	skull	T		14.8	14.5	6.9	5.9	4.0	7.1	5.1	present
M. sodalis	0021 R	mummy	T		14.4	14.1	6.5	5.5	3.9	6.9	4.7	present
M. sodalis	0021 R	mummy	T		14.6	14.2	6.5	5.8	4.1	7.3	5.2	present
M. sodalis	0021 R	mummy	T		14.1	13.8	6.4	5.7	3.9	6.8	4.9	present
M. sodalis	0022 R	mummy	T		14.5	14.4	6.6	5.9	4.1	7.0		present
M. sodalis	0022 R	mummy	T		14.4	13.7	6.4	5.9	4.0	7.2	5.2	present
M. sodalis	0022 R	mummy	T		14.2	13.8	6.6	5.5	4.1	7.0	4.9	present
M. sodalis	0023 R	mummy	M		14.5	14.0	6.7	5.9	4.1	6.8		present
M. sodalis	0026 R	mummy	T		14.4	13.7	6.4	5.5	4.2	6.8	4.8	present
M. sodalis	0026 R	mummy	T				6.4	5.6	4.1	7.1		present
M. sodalis	0026 R	mummy	T		14.2	13.7	6.3	5.7	4.1	6.9	4.8	present
M. sodalis	0036 L	skull	T			14.0	6.5	5.5	3.8	6.8	4.6	present
M. sodalis	0036 L	skull	T		14.1	13.7	6.4	5.6	4.1	7.1	4.7	present
M. sodalis	0036 L	skull	T		14.5	14.1	6.4	5.7	3.8	7.0	5.1	present
M. sodalis	0036 L	skull	T		15.1	14.5	6.8	5.5	4.0	7.1	5.0	present
M. sodalis	0036 L	skull	T	10.1	14.4	14.0	6.4	5.5	4.0	7.2	4.9	present
M. sodalis	0036 L	skull	T		14.3	13.8	6.3	5.4	4.0	6.8	4.7	present
M. sodalis	0036 L	skull	T		14.5	14.2	6.5	5.5	4.0	--	5.0	present
M. sodalis	0036 L	skull	T	R=10.1	14.3	13.9	6.2	5.3	4.0	6.9	5.0	present
M. sodalis	0036 L	skull	T		14.5	14.2	6.7	5.6	4.0	7.0	5.0	present
M. sodalis	0036 L	skull	T		14.5	14.2	6.6	5.8	4.1	7.0	5.0	present
M. sodalis	0036 L	skull	T	R=10.3	14.7	14.1	6.8	5.9	4.1	7.1	4.9	present
M. sodalis	0036 L	skull	T		14.3	13.9	6.4	5.5	3.9	6.9	4.7	present
M. sodalis	0036 L	skull	T	R=10.5	14.7	14.1	6.6		4.0		4.8	present
M. sodalis	0037 L	mummy	M		14.8	14.2	6.6		3.9	6.8	5.2	present
M. sodalis	0037 L	mummy	M, F	L=10.3	14.5	13.9	6.4	5.3	3.8	7.1	4.8	present
M. sodalis	0037 L	skull	S		14.7	14.2	6.5	5.7	3.9	7.0	5.1	present
M. sodalis	0037 L	skull	F		14.6	14.2	6.3	5.5	3.9	6.9	5.2	present
M. sodalis (male)	0040 L	mummy	M, moldy	L=10.7	15.0	14.0	6.5	5.5	3.8	7.1	5.3	present
M. sodalis	0046 R	skull			14.8	14.2	6.7	5.7			5.0	present

Taxon	*Location*	*Element*	*Condition (M, S, T)*	*Dentary TL*	*GLS*	*CBL*	*I-M3*	*M3s*	*IOB*	*BB*	*OD*	*Sagittal Crest*
M. sodalis	0052 R		T	not measured	15.1	14.5	6.9	5.4	4.1	6.7	4.8	present
M. sodalis	0058 L	mummy	M	R=10.7	14.9	14.6	6.2	5.9	3.8	7.0	5.0	present
M. sodalis	0062 L	mummy	M, F	R=10.3	15.7	14.2	6.7	5.8	4.0	7.2	5.2	present
M. sodalis	0062 L	mummy	M	L=10.5			6.5	5.8	4.1			present
M. sodalis	0062 L	mummy	M	R=10.2	14.1	13.6	6.5	5.7	4.0	6.9	4.8	present
M. sodalis	0065 L	mummy	M	L=10.6	14.7	14.1	6.6	5.6	3.9	7.0	4.7	present
M. sodalis	0071 L	mummy	M	L=10.2	14.4	14.0	6.6	5.8	4.1	7.1	5.0	present
M. sodalis	0086 R	mummy	M	L=10.2			6.4	5.7	3.9	6.9		present
M. sodalis	0087 R	skull	M, T, F	R=10.6			6.5	5.7	4.0			present
M. sodalis	0091 R	mummy	M	L=10.4			6.5	5.6	3.8			present
M. sodalis	0103 R	mummy	M	10.6			6.8	6.0	4.0	7.0		present
M. sodalis	0104 R	mummy	M	10.5	14.9	14.4	6.6	6.0	3.9	7.2	5.2	present
M. sodalis	0107 R	mummy	M	L=10.5			6.5	5.7	3.9			present
M. sodalis	0128 L	skull	S				6.7	5.7	4.0			present
M. sodalis	0128 L	skull	T	R=10.6	14.8	14.3	6.6	5.6	3.9	7.0	5.2	present
M. sodalis	0128 L	skull	T, F	R=10.5	14.8	14.3	6.5	5.8	3.9	7.1	4.9	present
M. sodalis	0135 L	mummy	M		15.3	14.4	6.7	5.5	3.9	6.8	4.8	present
M. sodalis	0139 L	mummy	M, F	R=10.2	14.4	13.9	6.3	5.4	3.8	6.7	4.8	present
M. sodalis	0140 L	mummy	M, F		14.1	13.5	6.4	5.2	4.0	6.9	5.0	present
M. sodalis	0141 L	skull	M, F		13.9	13.5	6.3	5.4	3.9	6.9	4.9	present
M. sodalis	0141 L	skull	M, F	L=10.0	13.4	13.2	6.4	5.4		6.8	4.9	present
M. sodalis	0162 R	mummy	M		14.0	13.5	6.5	5.3	3.8	6.8	4.9	present
M. sodalis	0162 R	mummy	M				6.6	5.5	3.8			present
M. sodalis	0179 R	mummy	M	L=10.3	14.3	13.8	6.4	5.5	3.8	6.8	4.8	present
M. sodalis	0183 R	mummy	M		14.5	14.0	6.5	5.5	3.9	7.1	5.5	present
M. sodalis	0192 R	mummy	M		14.3	13.8	6.5	5.8	3.8	7.0	4.9	present
M. sodalis	0221 L	mummy	M	R=10.0	14.6	13.9	6.6	5.5	3.7	6.8	5.0	present
M. sodalis	0221 L	mummy	M	L=10.6	15.1	14.6	6.7	5.7	4.0	7.0	4.9	present
M. sodalis	0223 L	mummy	M	L=10.4			6.7	5.7	4.0			present
M. sodalis	0237 L	skull	T	R=10.3	14.5	14.2	6.5	5.5	4.0	7.0	4.8	present
M. sodalis	0252 R	mummy	M, moldy	R=10.3	14.7	14.0	6.7	6.0	4.1	7.4	5.2	present
M. sodalis	0300 R	skull	S		15.0	14.3	6.6	5.7	4.0	7.1	5.1	present
M. sodalis	0313 C	skull	S				6.3		3.8			present
M. sodalis	0319 L	skull	S		14.3		6.5		3.9			present

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
M. sodalis	0320 R	skull	S				6.0	5.6	3.9			present
M. cf. *sodalis*	0017 R	skull			14.7	14.2	6.6	5.5	4.0	7.2	5.2	short
M. cf. *sodalis*	0021 R	mummy	T		14.5	14.1	6.6	5.8	4.2	7.1	5.1	present
M. cf. *sodalis*	0021 R	mummy	T		14.5	13.9	6.4	5.8	4.2	7.2	5.2	present
M. cf. *sodalis*	0021 R	mummy	T		14.3	14.1	6.3	5.7	4.2	6.9	5.0	present
M. cf. *sodalis*	0022 R	mummy	T			13.8	6.5	5.6	4.2	6.8	5.1	present
M. cf. *sodalis*	0022 R	mummy	M	R=10.7	14.6	14.3	6.7	5.8	4.2	7.2	5.2	present
M. cf. *sodalis*	0023 R	mummy	M		14.5	14.1	6.7	6.1	4.2	7.1	5.0	present
M. cf. *sodalis*	0023 R	mummy	M		14.7	14.3	6.7	5.9	4.3	7.1	4.9	present
M. cf. *sodalis*	0023 R	mummy	M		14.5	14.0	6.5	5.7	4.3	7.2	5.3	present
M. cf. *sodalis*	0024 R	mummy	M		14.5	14.3	6.5	6.1	4.2	7.2	4.8	present
M. cf. *sodalis*	0024 R	mummy	M		14.5	13.9	6.6	6.0			5.2	present
M. cf. *sodalis*	0027 R	skull			14.1		6.3	5.9	4.2	~7.2		present
M. cf. *sodalis*	0036 L	skull	T			14.1	6.4					present
M. cf. *sodalis*	0036 L	skull	T		14.2	13.3	6.3	5.8				present
M. cf. *sodalis*	0042 R	skull	S				6.6	5.7		4.0		present
M. cf. *sodalis*	0105 R	mummy	M	R=10.7	14.7	14.2	6.5	5.8				present
M. cf. *sodalis*	0141 L	skull	F			14.0	6.6					present
M. cf. *sodalis*	0162 R	mummy	M	L=10.3, R=10.4			6.6					present
M. cf. *sodalis*	0192 R	mummy	M				6.5	5.7	4.1			present
M. cf. *sodalis*	0221 L	mummy	M		~14.1	13.7	6.4	5.6				present
M. cf. *sodalis*	0245 L	skull	S				6.4					slight
Medium-sized *Myotis*	0015 R	L maxilla					6.2					
Medium-sized *Myotis*	0021 R	mummy	T	L=10.2		14.1	6.5	6.2	4.0			
Medium-sized *Myotis*	0022 R	mummy	T			14.0	6.4	5.7				
Medium-sized *Myotis*	0023 R	mummy	M			13.8	6.3	5.6				
Medium-sized *Myotis*	0026 R	mummy	T		~14.5	14.2	6.4	5.5	4.3		4.9	
Medium-sized *Myotis* (not long-eared)	0037 L	mummy	M		No measurements taken							
Medium-sized *Myotis*	0037 L	skull	F	L=10.4			6.7		4.0			
Medium-sized *Myotis*	0037 L	palate	F				6.6	5.8				
Medium-sized *Myotis*	0038 L	rostrum	S				6.2					
Medium-sized *Myotis*	0038 L	rostrum	S	L=10.5			6.7					

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
Medium-sized *Myotis*	0039 L	maxilla	S		Not measurable							
Medium-sized *Myotis*	0042 R	R maxilla	S				6.4					
Medium-sized *Myotis*	0061 L	mummy	M				6.6	5.6				
Medium-sized *Myotis*	0064 L	skull	S				6.5	5.7				
Medium-sized *Myotis*	0079 L	mummy	M	L=10.7			6.5	5.7				
Medium-sized *Myotis*	0083 L	skull	S				6.3	5.8				
Medium-sized *Myotis*	0083 L	rostrum	S				6.2					
Medium-sized *Myotis*	0083 L	rostrum	S				6.4	5.7				
Medium-sized *Myotis*	0083 L	rostrum	S				6.7	5.6				
Medium-sized *Myotis*	0083 L	rostrum	S				6.6	5.6				
Medium-sized *Myotis*	0084 L	mummy	M	R=10.8			6.7	5.4				
Medium-sized *Myotis*	0087 R	skull	M, T, F				6.8	5.8				
Medium-sized *Myotis*	0095 R	skull	M, T, F	R=10.6	Did not expose skull due to very dry tissue							
Medium-sized *Myotis*	0096 R	mummy	M	L=10.3								
Medium-sized *Myotis*	0099 R	mummy	M, moldy	L=10.5								
Medium-sized *Myotis*	0101 R	skull	S		14.1	13.7	6.3	5.3	3.8	6.9	5.2	broken
Medium-sized *Myotis*	0101 R	skull	S				6.2	5.4	3.7			
Medium-sized *Myotis*	0101 R	skull	S				6.4	5.2				
Medium-sized *Myotis*	0101 R	rostrum	S				6.7	5.4				
Medium-sized *Myotis*	0101 R	rostrum	S				6.3					
Medium-sized *Myotis*	0101 R	maxilla	S				6.6					
Medium-sized *Myotis*	0101 R	maxilla	S				6.3					
Medium-sized *Myotis*	0102 R	rostrum	S				6.5	5.7				
Medium-sized *Myotis*	0102 R	rostrum	S				6.0					
Medium-sized *Myotis*	0102 R	rostrum	S				5.9					
Medium-sized *Myotis*	0102 R	L maxilla	S				6.6					
Medium-sized *Myotis*	0102 R	L maxilla	S				6.7					
Medium-sized *Myotis*	0102 R	R maxilla	S				6.6					
Medium-sized *Myotis*	0102 R	R maxilla	S				6.5					
Medium-sized *Myotis*	0106 R	mummy	M	L=10.3								
Medium-sized *Myotis*	0107 R	skull	T				6.5	5.4	4.1	7.1		poor
Medium-sized *Myotis*	0109 R	mummy	M	L=10.5	Did not expose skull due to very dry tissue							
Medium-sized *Myotis*	0111 R	rostrum & dentary	T	R=10.1			6.5	5.4				
Medium-sized *Myotis*	0116 R	skull			14.6	13.9	6.5	5.5	4.1			

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
Medium-sized *Myotis*	0117 R	mummy	M	R=10.5		14.0	6.6					
Medium-sized *Myotis*	0119 R	mummy	M				6.7	5.7				
Medium-sized *Myotis*	0128 L	mummy	M			14.0	6.4	5.3				
Medium-sized *Myotis*	0128 L	skull	S				6.3					
Medium-sized *Myotis*	0130 L	L maxilla	S				6.5					
Medium-sized *Myotis*	0153 R	mummy	M, S	L=10.3			6.5	5.7	4.0			
Medium-sized *Myotis*	0154 R	mummy	M, S, mold	L=10.3			6.5	5.7				
Medium-sized *Myotis*	0160 R	mummy	M	R=10.6		14.4	6.8					
Medium-sized *Myotis*	0162 R	mummy	M				6.5					
Medium-sized *Myotis*	0164 R	mummy	M	L=10.5								
Medium-sized *Myotis*	0164 R	skull	S	L=10.7		14.7	6.7	5.4				
Medium-sized *Myotis*	0166 R	mummy	M				6.3					
Medium-sized *Myotis*	0174 R	mummy	M	L=10.3			6.6					
Medium-sized *Myotis*	0175 R	mummy	M				6.4	5.4				
Medium-sized *Myotis*	0176 R	mummy	M	L=10.3	Not measurable							
Medium-sized *Myotis*	0177 R	mummy	M, moldy	R=10.6								
Medium-sized *Myotis*	0180 R	palate	S				6.5	5.8				
Medium-sized *Myotis*	0180 R	palate	S				6.5	5.6				
Medium-sized *Myotis*	0180 R	palate	S		Not measurable							
Medium-sized *Myotis*	0182 R	palate	S				6.5					
Medium-sized *Myotis*	0184 R	R maxilla	S				6.4					
Medium-sized *Myotis*	0184 R	palate	S				6.6	5.6				
Medium-sized *Myotis*	0186 R	palate	S				6.6	5.6				
Medium-sized *Myotis*	0189 R	palate	S				6.3	5.7				
Medium-sized *Myotis*	0196 R	skull	S	R=10.1	14.5	13.8	6.2	5.4			5.1	
Medium-sized *Myotis*	0196 R	skull	S			13.9	6.5	5.6				
Medium-sized *Myotis*	0196 R	palate	S				6.6	5.5				
Medium-sized *Myotis*	0196 R	palate	S				6.6	5.6				
Medium-sized *Myotis*	0196 R	palate	S				6.6					
Medium-sized *Myotis*	0196 R	R maxilla	S				6.5					
Medium-sized *Myotis*	0196 R	R maxilla	S				6.7					
Medium-sized *Myotis*	0196 R	R maxilla	S				6.6					
Medium-sized *Myotis*	0196 R	L maxilla	S		Not measurable							
Medium-sized *Myotis*	0219 L	mummy	M	L=10.3			6.3	5.5				
Medium-sized *Myotis*	0231 L	R maxilla	S				6.4					

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
Medium-sized *Myotis*	0231 L	L maxilla	S				6.5					
Medium-sized *Myotis*	0267 R	rostrum					6.3					
Medium-sized *Myotis*	0293 R	L maxilla	S				6.5					
Medium-sized *Myotis*	0293 R	L maxilla	S				6.8					
Medium-sized *Myotis*	0293 R	L maxilla	S		Not measurable							
Medium-sized *Myotis*	0293 R	R maxilla	S				6.5					
Medium-sized *Myotis*	0301 R	skull	S				6.2	5.7	3.9			
Medium-sized *Myotis*	0301 R	palate	S		Not measurable							
Medium-sized *Myotis*	0301 R	rostrum	S		Not measurable							
Medium-sized *Myotis*	0301 R	L maxilla	S				6.6					
Medium-sized *Myotis*	0301 R	L maxilla	S				6.5					
Medium-sized *Myotis*	0301 R	L maxilla	S				6.5					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.5					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.2					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.4					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.7					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.6					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.6					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.4					
Medium-sized *Myotis*	0301 R	R maxilla	S				6.5					
Medium-sized *Myotis*	0301 R	rostrum						5.6				
Medium-sized *Myotis*	0304 R	L maxilla	S				6.7					
Medium-sized *Myotis*	0320 R	rostrum	S				6.3	5.6				
Medium-sized *Myotis*	0320 R	rostrum	S				6.6					
Medium-sized *Myotis*	0320 R	L maxilla	S				6.8					
Medium-sized *Myotis*	0320 R	L maxilla	S				6.5					
Medium-sized *Myotis*	0320 R	L maxilla – 5 partials	S									
Medium-sized *Myotis*	0320 R	R maxilla	S				6.5					
Medium-sized *Myotis*	0320 R	R maxilla	S				6.8					
Medium-sized *Myotis*	0320 R	R maxilla	S				6.6					
Medium-sized *Myotis*	0320 R	R maxilla	partial with P2 offset									
Medium-sized *Myotis*	0320 R	R maxilla	3 partials									
Medium-sized *Myotis*	0323 L	mummy	M, recent		14.5							present

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
Myotis sp.	0010 L				Not measurable							
Myotis sp.	0023 R	rostrum					6.8	5.9				
Myotis sp.	0024 R	rostrum		L=10.2	Not measurable							
Myotis sp.	0026 R	mummy	T	L= 9.9	13.8	13.7	6.3	5.4	4.3	7.0	4.8	present
Myotis sp.	0031 L	L maxilla										
Myotis sp.	0031 L	palate					6.3	5.6				
Myotis sp.	0036 L		T				6.4					present
Myotis sp.	0036 L	skull, P2& 3 crowded & medial	T		14.6	14.2	6.5	5.5	4.2	7.1	4.8	present
Myotis sp.	0036 L	mummy	M				6.3	6.0				broken
Myotis sp.	0036 L		T	skull	13.4	13.1	6.1	5.4	3.8	6.6	4.6	present
Myotis sp.	0036 L	mummy	M	L partial	No measurements							
Myotis sp.	0037 L	rostrum	T	R=10.7			6.8	6.1				
Myotis sp.	0047 R	palate	S					5.5				
Myotis sp.	0057 L	mummy	M	R=10.6			6.8	6.1				
Myotis sp.	0074 L	mummy	M	R=10.6			6.5			7.4	5.1	present
Myotis sp.	0083 L	maxilla	S				6.6					
Myotis sp.	0083 L	maxilla	S				6.5					
Myotis sp.	0083 L	rostrum	S				6.0					
Myotis sp.	0083 L	rostrum	S		No measurements							
Myotis sp.	0083 L	maxilla	S		No measurements							
Myotis sp.	0101 R	skull	S				6.8	5.8				
Myotis sp.	0102 R	R maxilla	S		No measurements							
Myotis sp.	0102 R	R maxilla	S		No measurements							
Myotis sp.	0102 R	palate	S		No measurements							
Myotis sp.	0131 L	rostrum	S		No measurements							
Myotis sp.	0131 L	rostrum	S		No measurements							
Myotis sp.	0131 L	R maxilla	S		No measurements							
Myotis sp.	0131 L	R maxilla	S		No measurements							
Myotis sp.	0171 R	palate	S				6.2	5.3				
Myotis sp.	0182 R	mummy	M	L=9.8 & R=9.8, p2 & p3 crowded, but not gracile								
Myotis sp.	0225 L	L maxilla	S		No measurements							
Myotis sp.	0298 R	rostrum	S		Not measurable							

Taxon	***Location***	***Element***	***Condition (M, S, T)***	***Dentary TL***	***GLS***	***CBL***	***I-M3***	***M3s***	***IOB***	***BB***	***OD***	***Sagittal Crest***
Myotis sp.	0301 R	L maxilla	S, 13 partials		No measurements							
Myotis sp.	0301 R	R maxilla	S, 24 partials		No measurements							
Myotis sp.	0307 R	L maxilla	S, 1 partial		No measurements							
Myotis sp.	0307 R	R maxilla	S, 5 partials		No measurements							
Myotis sp.	0307 R	rostrum	S		No measurements							
cf. *Myotis*	0044 R	skull & mandible in owl pellet			Not removed, no measurements							
Pipistrellus subflavus	0038 L	mummy	M				5.2	5.2				
P. subflavus	0038 L	mummy	M		12.4	12.0	5.2	5.1	3.5	6.3		
P. subflavus	0043 R	mummy	M		13.2	12.1	5.3	5.1	3.5	6.7	4.7	
P. subflavus	0049 R	mummy	M		12.8	11.8	5.2	5.2	3.7	6.8	4.4	
P. subflavus	0057 L	mummy	M	R=8.9			5.6	5.4				
P. subflavus	0059 L	mummy	M		12.5		5.5		3.8			
P. subflavus	0089 R	rostrum	T				5.8					
P. subflavus	0144 L	skull	T		12.5	11.8	5.3	5.0	3.6	6.4	4.9	
P. subflavus	0180 R	skull			12.9	12.2	5.5		3.5	6.7	4.5	
P. subflavus	0266 R	mummy	M	R=9.2	13.1	12.0	5.4	5.3	3.7	6.6	4.8	
P. subflavus	0278 L	mummy	M	R=9.0	12.2	12.9	5.5	5.0	3.8	6.6	4.4	
P. subflavus	0286 L	mummy	M	L=9.3	13.3	12.5	5.5	4.9			4.8	
P. subflavus	0324 L	mummy	M, moldy	R=9.3								

TABLE 6-5. Dixon Cave: loose dentaries (i.e., not associated with a skull) that could be identified to genus level or better (L=left, R= right). Total length is given in millimeters. Location indicates data point number and left (L), right (R), or center (C), in passage.

Taxon	*Location*	*Left dentary*	*Right dentary*
Eptesicus fuscus	0011 L	13.9	14.0
E. fuscus	0019 R	Partial, unknown side	
E. fuscus	0025 R		14.4
E. fuscus	0030 L	1 partial	
E. fuscus	0034 L	14.3	14.1
E. fuscus	0083 L	14.0 + 1 juvenile or very small individual (nm)	1 partial
E. fuscus	0100 R	1 partial	1 partial
E. fuscus	0101 R	14.5	14.5 + 1 partial
E. fuscus	0102 R	14.2	14.2
E. fuscus	0128 L	14.4	
E. fuscus	0191 R		14.6
E. fuscus	0196 R	14.8, 14.9	14.9, 14.3, 14.3, 14.7, 14.3
E. fuscus	0224 L		14.4
E. fuscus	0236 L	14.5	
E. fuscus	0320 R	1 partial	
E. fuscus	0325 L	2 partials	
Myotis grisescens	0131 L	broken but > 11mm	
M. cf. *grisescens*	0171 R	11.0	
Myotis leibii	0026 R/C	9.5	
M. leibii	0042 R	9.5	
M. leibii	0083 L	9.0, 9.7, 9.3, 9.2, 9.0, 9.2 + 4 partials	9.4, 9.3, 9.6, 9.2, 9.0, 9.4, 9.4, 9.3 + 3 partials
M. leibii	0101 R	9.5 + 1 partial	9.5
M. leibii	0102 R	8.9, 9.1 + 1 partial	9.1, 9.5, 9.1
M. leibii	0127 L	1 partial	9.3
M. leibii	0131 L	9.8, 9.9	
M. leibii	0148 L		Not measured
M. leibii	0152 R		9.8
M. leibii	0171 R	9.3	
M. leibii	0182 R	9.7	
M. leibii	0196 R	9.5	
M. leibii	0200 R	9.2, 9.5	
M. leibii	0227 L	9.2	
M. leibii	0231 L	9.4, 9.7, 9.8	
M. leibii	0233 L		9.8
M. leibii	0234 L		9.2
M. leibii	0279 R		1 partial
M. leibii	0281 R		9.8
M. leibii	0296 R		9.7
M. leibii	0301 R	9.4, 9.8, 9.9, 9.9, 9.9, 9.7, 9.9	9.9, 9.9
M. leibii	0304 R	9.9	
M. leibii	0307 R	9.8	9.5
M. leibii	0320 R	9.7, 9.8, 9.9	9.5, 9.6
M. cf. *leibii*	0100 R	3 partials	
M. cf. *leibii*	0131 L	2 partials	
Medium-sized *Myotis*	0018 R/C	1 partial	

Taxon	***Location***	***Left dentary***	***Right dentary***
Medium-sized *Myotis*	0023 R	10.5, 10.4, 10.3, 10.3	
Medium-sized *Myotis*	0023 R		10.6, 10.4, 10.0, 10.5, 10.4
Medium-sized *Myotis*	0026 R/C	10.3	
Medium-sized *Myotis*	0031 L	10.2, 10.4, 10.0, 10.5 + 7 partials	
Medium-sized *Myotis*	0031 L		10.1 + 1 partial
Medium-sized *Myotis*	0036 L		10.6
Medium-sized *Myotis*	0036 L	10.5	
Medium-sized *Myotis*	0037 L	10.6	
Medium-sized *Myotis*	0039 L	10.3	10.4, 10.3
Medium-sized *Myotis*	0042 R	10.1, 10.8 + 2 partials	10.1 + 3partials
Medium-sized *Myotis*	0044 R	10.3, 10.0	
Medium-sized *Myotis*	0050 R		10.7
Medium-sized *Myotis*	0083 L	10.3, 10.1, 10.3, 10.1 + 5 partials	10.3 + 1 partial
Medium-sized *Myotis*	0102 R	10.1, 10.0	10.3, 10.4
Medium-sized *Myotis*	0128 L	10.7	10.5, + L & R pair w/ R=10.3
Medium-sized *Myotis*	0131 L	9.9, 10.2 + 1 partial	10.0, 10.2 + 1 partial
Medium-sized *Myotis*	0141 L	10.5	
Medium-sized *Myotis*	0148 L	10.4, 10.3	
Medium-sized *Myotis*	0158 R	10.5	10.5
Medium-sized *Myotis*	0161 R		1 partial
Medium-sized *Myotis*	0162 R		10.0 + 1 partial
Medium-sized *Myotis*	0171 R	10.3, 10.3 + 2 partials	10.1, 10.2, 10.3 + 1 partial
Medium-sized *Myotis*	0180 R	1 partial	10.5 + 4 partials
Medium-sized *Myotis*	0184 R	1 partial	10.5, 10.4, 10.5, 10.6 + 1 partial
Medium-sized *Myotis*	0185 R		10.4
Medium-sized *Myotis*	0186 R		10.2
Medium-sized *Myotis*	0189 R	L & R pair partials	
Medium-sized *Myotis*	0190 R	L & R pair w/ L=10.5	
Medium-sized *Myotis*	0196 R	10.0, 10.5 + 16 partials	10.3, 10.3, 10.2, 10.3, 10.3, 10.4, 10.5, 10.6, 10.8, 10.1, 10.3, 10.7, 10.3, 10.3 + 9 partials
Medium-sized *Myotis*	0200 R	1 partial	
Medium-sized *Myotis*	0201 R	1 partial	2 partials
Medium-sized *Myotis*	0229 L	10.4	
Medium-sized *Myotis*	0231 L	10.4 + 4 partials	10.1 + 8 partials
Medium-sized *Myotis*	0256 R	10.2, 10.4, 10.3	
Medium-sized *Myotis*	0265 R		10.3
Medium-sized *Myotis*	0269 R		10.1 + 1 partial
Medium-sized *Myotis*	0271 L	10.4	
Medium-sized *Myotis*	0273 L		10.5
Medium-sized *Myotis*	0279 R		1 partial
Medium-sized *Myotis*	0289 R		10.4
Medium-sized *Myotis*	0293 R		10.3
Medium-sized *Myotis*	0296 R	10.6 + 1 partial	10.2
Medium-sized *Myotis*	0297 R	1 partial	10.6
Medium-sized *Myotis*	0298 R	10.6 + 1 partial	10.2 + 1 partial
Medium-sized *Myotis*	0301 R	10.2, 10.4, 10.1, 10.1, 10.1, 10.4, 10.2	10.2, 10.1, 10.0, 10.7, 10.3, 10.0, 10.2, 10.2, 10.3
Medium-sized *Myotis*	0304 R	10.2	10.2, 10.5

Taxon	***Location***	***Left dentary***	***Right dentary***
Medium-sized *Myotis*	0307 R	10.3, 10.3, 10.0	10.2, 10.3, 10.2
Medium-sized *Myotis*	0308 R	1 partial	
Medium-sized *Myotis*	0320 R	10.0, 10.3, 10.4, 10.0, 10.3, 10.0, 10.4, 10.4, 10.0, 10.1	10.1, 10.5, 10.4, 10.1, 10.2, 10.1
Myotis sp.	0030 L	1 partial	
Myotis sp.	0038 L	1 partial	
Myotis sp.	0089 R	1 partial	
Myotis sp.	0100 R		1 partial
Myotis sp.	0101 R	2 partials	3 partials
Myotis sp.	0102 R	2 partials	1 partial
Myotis sp.	0128 L	10.0	10.6
Myotis sp., small	0183 R	L & R pair (not measured)	
Myotis sp.	0225 L		1 partial
Myotis sp.	0234 L	1 partial	
Myotis sp.	0256 R	1 partial	1 partial
Myotis sp.	0271 L	4 partials	1 partial
Myotis sp.	0291 R		10.0
Myotis sp.	0293 R	4 partials	2 partials
Myotis sp.	0301 R	14 partials	10 partials
Myotis sp.	0304 R	1 partial	3 partials
Myotis sp.	0305 R		3 partials
Myotis sp.	0307 R	12 partials	16 partials
Myotis sp.	0320 R	9 partials	12 partials
Myotis sp., very small-sized (either *M. leibii* or juveniles)	0320 R	4 partials	5 partials
Myotis sp.	0325 L		1 partial
cf. *Myotis (juvenile)*	0292 R		~8.5
cf. *Myotis*	0301 R	21 partials	34 partials
cf. *Myotis*	0320 R	9 partials	14 partials
Pipistrellus subflavus	0171 R	9.3	
P. subflavus	0269 R	9.1	

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CHAPTER 7
Re-investigation of a bone deposit in Bat Cave

INTRODUCTION

Before Mammoth Cave was officially designated as a national park in 1936, three groups - the Mammoth Cave National Park Association, Kentucky National Park Commission, and the National Park Service - jointly operated the Mammoth Cave property; and, in 1941 the NPS became fully responsible (Goode 1986). At some time in the past, local residents named Bat Cave, which is located in the limestone bluff nearly 90 feet above the Green River, presumably for its large bat population (Figure 7-1). Since at least the 1930s, Bat Cave has drawn official attention; an extensive deposit of bat bones mixed with sediment has been of particular interest. Among the past researchers were Bailey (1933) in the 1920s, Hibbard (1935), Hall in 1959, Jegla (1961), Keefer (1969), B. Trevor-Deutsch (1972), and MacGregor (1991).

FIGURE 7-1. Approach and entrance to Bat Cave.

In the 1930s, Claude Hibbard, then Assistant Naturalist, was very concerned about the management practices that were literally driving bats out of the Park's caves. In July of 1934, Hibbard made a special trip to Bat Cave to assess the bat situation. He noted the absence of bats, save for two pipistrelles, which he thought was due to 1) local residents making fires at the base of formations in order to break off slabs of cave onyx for tourist items, 2) local residents blasting formations with dynamite, again to obtain formation material, and/or 3) the Kentucky Park Commission's blasting shut more than 25 cave entrances, Bat Cave among them (Hibbard 1935a). Curiously, Hibbard did not mention that the absence of a large number of bats might have been due to the timing of his visit in July, a month when most species would be living outside the cave. Hibbard wrote of his July 1934 trip that each of the two passages in Bat Cave "had been blasted shut but later worked out so that one could worm their way over the blasted material just below the ceiling though not enough room to allow a lantern to remain upright" (Hibbard 1935a:2). On 19 June 1935, Hibbard made another special trip to Bat Cave, this time with geologist Dr. E. R. Pohl, about which he wrote the following in his 1935 report:

> ... the left avenue into the main portion of the cave had broken down due to the blast either early this spring or last winter. It is in this avenue that the bats hibernate. The question as to whether the bats were trapped by this breakdown can not [*sic*] be answered until it is removed. The breakdown is small though forming a tight plug since the opening was just large enough to allow a medium sized man to slide through into the avenue. This should be opened by all mean. (Hibbard 1935:2)

In his diary entry for June 19, 1935, Hibbard (1935b) wrote, "Bat Cave was found closed at the main passage (I was through this passage a year ago)." To repeat, Hibbard's primary recommendation was "That all caves now closed due to blasting in the Park Area on our land shall be opened" (Hibbard 1935a:3). A report by Dr. E. R. Pohl (1935) dated July 1935 noted that an emergency request had been made to open Bat Cave, which had been closed "several years ago by the Kentucky National Park Commission."

In 1960, Thomas Jegla became the first researcher to study the bone deposit in Bat Cave. He described the deposit as measuring 34 feet long by 4 feet wide by 2 feet deep with bones concentrated in the upper 3 inches (Jegla 1961a). Jegla collected an 18 cubic inch sample (dimensions unknown) from which he counted humeri and made measurements on 10 bat skulls. Comparing the means of measurements, Jegla's study concluded that the skulls were consistent with those of *Myotis sodalis* and that the deposit was an accumulation of drowned bats. An important aspect of Jegla's work was his determination that the entrance to Bat Cave lies 90 feet above Green River bottom and that the top of the bone bed lies 42 feet above river bottom, with the passage ceiling of the deposit area at 49 feet above (see Figure 7-2, taken from Jegla's 1961 report).

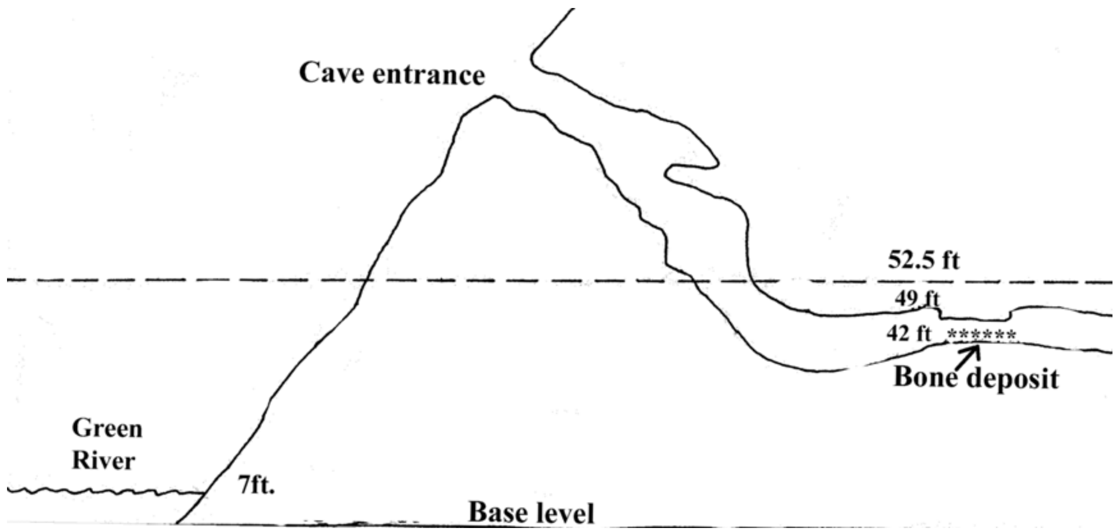

FIGURE 7-2. Position of the bone bed relative to the Green River, the cave entrance, and the height of the 1937 flood (from Figure 2 in Jegla's 1961 report).

In the mid-1990s Mammoth Cave Park Ecologist, Rick Olson and Illinois State Museum researcher Rick Toomey proposed another examination of the bone bed. Finally, on May 20, 1999 Illinois State Museum researchers Toomey and Colburn, accompanied by Olson, visited Bat Cave to excavate a small section of bones from the wall of the crawlway. It is unclear how effectively Hibbard's number one recommendation -- that of opening dynamited caves -- was implemented at Bat Cave. A visit today reveals a 35 foot long crawlway dug through sediments in the passage of the A survey -- it does not seem to be much larger than that described by Hibbard nearly 70 years ago (Figure 7-3).

FIGURE 7-3. Bat Cave, view between survey stations A 8 and A9 in crawlway that cuts through the bone deposit.

The crawlway was dug through sediments containing a large, concentrated accumulation of bat bones; thus, it provides an excellent profile of the bone bed (Figure 7-4).

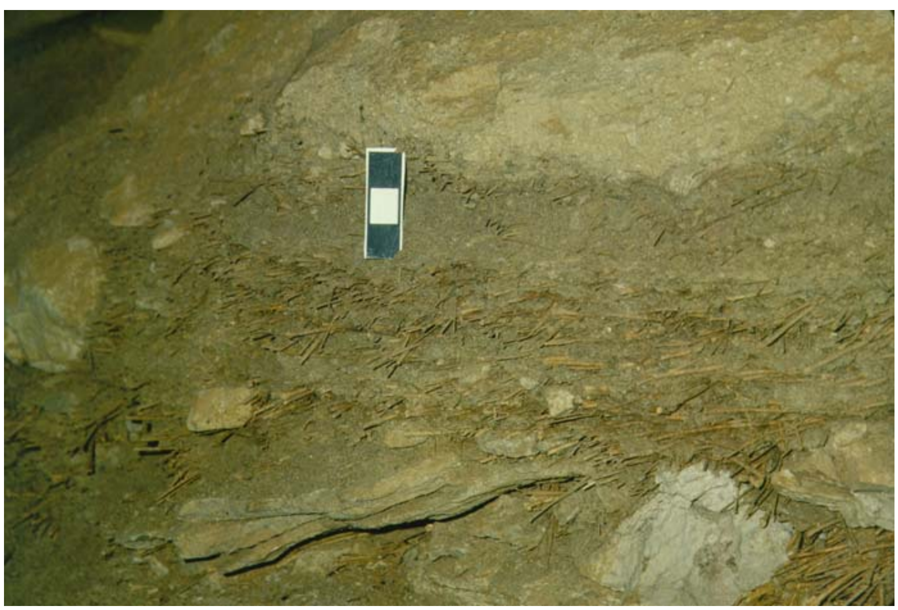

FIGURE 7-4. Bat Cave, view of massive deposit of bat bone exposed in the wall of the crawlway in the vicinity of Survey Station A10.

METHODS

Station A9', which is located on the ceiling, served as datum. The surface of the excavation area was 50 cm below the station, along the left edge of the crawl. A single unit (Unit 1) measuring 15 cm (length along trail) x 10 cm wide x 40 cm high was excavated in 11 levels, which ranged from 2.0 cm to 7.0 cm thick (Table 7-1). The deposit appears to have zones of sediment separating some of the bones; however the levels had to be teased out during excavation because of the intertwined nature of the bone. Thus, the excavated levels are somewhat, but not strictly, reflective of the natural stratigraphy. After excavation, the small pit was lined with plastic and backfilled with rocks and sediment.

TABLE 7-1. Unit 1 excavation levels.

Level	*cm below datum*	*Thickness of level*	*Comment*
L1	50-53	3.0 cm	
L2	53-55.5	2.5 cm	
L3	55.5-58.5	3.0 cm	
L4	58.5-61	2.5 cm	
L5	61-66	5.0 cm	small rock debris, charcoal at base of level 5
L6	66-70	4.0 cm	
L7	70-73	3.0 cm	
L8	73-75	2.0 cm	
L9	75-79	4.0 cm	pale beige color, silty to clayey, tight sediments containing angled limestone chips, some charcoal, little bone
L10	79-86	7.0 cm	color is browner (due to more organics?) & contains more bones than previous level; silty to clayey, tight sediments containing angled limestone chips, some charcoal; 3 pockets of bone at 83 cm below datum.
L11	86-90	4.0 cm	reddish brown with pockets of bone, pebbles, silty-clayey sediment

The collected samples were taken to the Illinois State Museum Research and Collection Center and sifted through geological screens. Figure 7-5 shows an example of bone deposit material from Level 4 that was caught in a 12.5 mm mesh screen (larger sized rocks removed from this screening). As the photgraph shows, the screened material from Level 4 contains a large ratio of bone to rock.

FIGURE 7-5. Material from Level 4 that was caught in 12.5 mm mesh screen, larger sized rocks already removed.

Level 11, the lowest in the sampled unit, yielded only about 30% as much bat bone as Level 4 (Figure 7-6).

FIGURE 7-6. Material from Level 11 that was caught by 12.5 mm mesh screen. Although large sized rocks were removed, the low ratio of bone to rock can be seen.

Bones selected for analysis included postcranial limb elements that were whole and could be measured and skull parts that could provide information for identification. The selected bones were identified and measured by Blaine Schubert and Colburn (Schubert screened and sorted samples, and measured post-cranial elements of bat; and, Colburn measured bat dentaries and skulls and identified non-bat mammals). To be consistent with Jegla's use of bat humeri to obtain an estimated number of individuals, Schubert pulled humeri that possessed their distal ends from the 1999 sample.

RESULTS

A total of 3,064 bat bones were tallied (thousands of fragmented bat bones were not picked out of the excavated matrix) from the 6,000 cubic centimeters (366 cubic inches) of excavated material. Five species of bat, 4, of mammal, and 1 salamander were identified. The bulk of the bone was derived from Levels 2 through 7, that is, between 53 and 73 cm (about 21-29 inches) below the ceiling datum. Adapting Jegla's method, the current study estimated the number of individual bats represented by distal ends of the humerus. Clearly, each distal end was not identified to genus or species. Rather, the size and configuration of most indicate medium-sized myotis; no humerus of a large-sized bat species was found; and the several small humeri could be either pipistrelle or very small myotis, although, no skull or dentary of the former was identified. Thus, based on a tally of distal humeri (mostly *Myotis*), an estimated 1321 individuals are represented in the 6,000 cm^3 (366 in^3) sample (Table 7-2).

TABLE 7-2. NISP (number of identified specimens) and MNI (minimum number of individuals) recovered from each of 11 levels in Bat Cave Unit 1.

Level	*NISP non-bat*	*MNI non-bat*	*NISP bat*	*MNI based on humeri (primarily Myotis spp.)*	*MNI other bat species*
1			59	26	
2			307	106	
3			388	165	
4			419	195	1
5			426	183	1
6	1	1	418	191	
7			316	138	
8			144	67	
9	2	2	181	88	1
10	6	3	281	111	1
11	2	2	125	52	
Totals	11	8	3064	1321	4

Among bat cranial fragments, only those that could be identified to at least the level of genus were tallied (e.g., dentaries, maxilla, rostrum). One hundred forty-one skull fragments were identified to genus or better. As Table 7-3 shows, a majority of the skull parts are lower jaws of *Myotis* spp. most being from individuals in the medium-size range. Six small dentaries were attributed to *M. leibii* based on having a total length measurement of less than 10 mm; however, no cranial fragments of this species were encountered.

TABLE 7-3. Bat skull elements and measurements from Bat Cave Unit 1. Abbreviations: med.=medium-sized, L=left, R=right, crest=sagittal crest. See text for TL, GLS, CBL, I-M3, M3s, IOB, BB, and OD.

Level	Taxon	Skull element	TL	GLS	CBL	I-M3	M3s	IOB	BB	OD	Crest
1	med. *Myotis*	L dentary	10.5								
1	med. *Myotis*	R dentary	10.3								
2	med. *Myotis*	L dentary	10.2								
2	med. *Myotis*	L dentary	10.0								
2	*Myotis leibii*	L dentary	9.8								
2	*Myotis* sp.	L dentary	n/m								
2	*Myotis* sp.	L dentary	n/m								
2	med. *Myotis*	R dentary	10.3								
2	med. *Myotis*	L maxilla				6.7					
2	med. *Myotis*	L maxilla				6.2					
3	med. *Myotis*	L dentary	10.3								
3	med. *Myotis*	L dentary	10.1								
3	med. *Myotis*	L dentary	10.1								
3	med. *Myotis*	R dentary	10.5								
3	med. *Myotis*	R dentary	10.1								
3	med. *Myotis*	R dentary	10.0								
3	med. *Myotis*	rostrum				n/m		4.0			
3	med. *Myotis*	L. maxilla				n/m					
4	*Eptesicus fuscus*	L dentary	n/m								
4	*Myotis* sp.	L dentary	n/m								
4	med. *Myotis*	L dentary	10.4								
4	med. *Myotis*	L dentary	10.4								
4	med. *Myotis*	L dentary	10.5								
4	*Myotis leibii*	R dentary	9.3								
4	med. *Myotis*	rostrum				6.6	6.4				
5	med. *Myotis*	L dentary	10.2								
5	med. *Myotis*	L dentary	10.2								
5	med. *Myotis*	L dentary	10.3								
5	med. *Myotis*	L dentary	10.4								
5	med. *Myotis*	L dentary	10.1								
5	*Myotis* sp.	L dentary	n/m								
5	med. *Myotis*	R dentary	10.4								
5	med. *Myotis*	R dentary	10.4								
5	*Myotis* cf. *lucifugus*	cranium		14.4	14.1	6.6	5.7	n/m	7.1	4.9	no
5	med. *Myotis*	partial rostrum				6.2					
5	med. *Myotis*	L. maxilla				6.7					
5	*Corynorhinus* sp.	cranium		16.1	15.1	6.2	6.2	3.9	9.0	6.2	
6	med. *Myotis*	L. dentary	10.0								
6	med. *Myotis*	L. dentary	10.1								
6	med. *Myotis*	L. dentary	10.1								
6	med. *Myotis*	L. dentary	10.1								
6	med. *Myotis*	L. dentary	10.2								
6	med. *Myotis*	L. dentary	10.3								

Level	Taxon	Skull element	TL	GLS	CBL	I-M3	M3s	IOB	BB	OD	Crest
6	med. *Myotis*	L. dentary	10.4								
6	med. *Myotis*	L. dentary	10.5								
6	med. *Myotis*	L. dentary	10.7								
6	med. *Myotis*	R. dentary	10.1								
6	med. *Myotis*	R. dentary	10.2								
6	med. *Myotis*	R. dentary	10.2								
6	med. *Myotis*	R. dentary	10.2								
6	med. *Myotis*	R. dentary	10.2								
6	med. *Myotis*	R. dentary	10.4								
6	med. *Myotis*	R. dentary	10.7								
6	*Myotis* sp.	maxilla				6.8	5.9	4.1			
6	*Myotis* cf. *sodalis*	cranium				6.7	5.8	4.1			yes
6	*Myotis sodalis*	cranium		14.2		6.4	5.8	3.9			yes
6	*Myotis sodalis*	cranium		14.0		6.2	5.8	3.8	7.0		yes
6	*Myotis lucifugus*	cranium		15.1		6.8	6.0	4.1			no, wide
7	med. *Myotis*	L. dentary	10.1								
7	med. *Myotis*	L. dentary	10.1								
7	med. *Myotis*	L. dentary	10.2								
7	med. *Myotis*	L. dentary	10.3								
7	med. *Myotis*	L. dentary	10.4								
7	*Myotis* sp.	L. dentary	n/m								
7	med. *Myotis*	R. dentary	10.4								
7	med. *Myotis*	R. dentary	10.5								
7	med. *Myotis*	R. dentary	10.7								
7	*Myotis* sp.	R. dentary	n/m								
7	*Myotis* cf. *sodalis*	squashed cranium				n/m	n/m				yes
7	med. *Myotis*	R. maxilla				n/m					
8	med. *Myotis*	L. dentary	10.2								
8	med. *Myotis*	L. dentary	10.2								
8	med. *Myotis*	L. dentary	10.3								
8	med. *Myotis*	L. dentary	10.4								
8	med. *Myotis*	L. dentary	10.0								
8	*Myotis leibii*	R. dentary	9.0								
8	*Myotis leibii*	R. dentary	9.1								
8	*Myotis* sp.	R. dentary	n/m								
9	*Eptesicus fuscus*	L. dentary	n/m								
9	med. *Myotis*	L. dentary	10.2								
9	med. *Myotis*	L. dentary	10.3								
9	med. *Myotis*	L. dentary	10.0								
9	med. *Myotis*	R. dentary	10.1								
9	med. *Myotis*	R. dentary	10.2								
9	med. *Myotis*	R. dentary	10.3								
9	med. *Myotis*	R. dentary	10.0								
10	*Myotis liebii*	L. dentary	9.8								
10	med. *Myotis*	L. dentary	10.1								
10	med. *Myotis*	L. dentary	10.2								
10	med. *Myotis*	L. dentary	10.3								

Level	Taxon	Skull element	TL	GLS	CBL	I-M3	M3s	IOB	BB	OD	Crest
10	med. *Myotis*	L. dentary	10.3								
10	med. *Myotis*	L. dentary	10.4								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis* sp.	L. dentary	n/m								
10	*Myotis leibii*	R. dentary	9.9								
10	med. *Myotis*	R. dentary	10.1								
10	med. *Myotis*	R. dentary	10.1								
10	med. *Myotis*	R. dentary	10.3								
10	med. *Myotis*	R. dentary	10.6								
10	*Myotis* sp.	R. dentary	n/m								
10	*Myotis* sp.	R. dentary	n/m								
10	*Myotis* sp.	R. dentary	n/m								
10	*Myotis* sp.	R. dentary	n/m								
10	*Eptesicus fuscus*	R. up C1									
10	med. *Myotis*	maxilla				6.6					
10	med. *Myotis*	maxilla				6.5	5.5				
10	med. *Myotis*	L. maxilla				6.5					
10	*Myotis* sp.	L. maxilla				n/m					
11	med. *Myotis*	L. dentary	10.2								
11	med. *Myotis*	L. dentary	10.4								
11	med. *Myotis*	L. dentary	10.2								
11	med. *Myotis*	L. dentary	10.3								
11	med. *Myotis*	L. dentary	10.6								
11	med. *Myotis*	L. dentary	10.0								
11	med. *Myotis*	L. dentary	10.0								
11	med. *Myotis*	L. dentary	10.0								
11	*Myotis* sp.	L. dentary	n/m								
11	med. *Myotis*	R. dentary	10.3								
11	med. *Myotis*	R. dentary	10.3								
11	med. *Myotis*	R. dentary	10.0								
11	med. *Myotis*	R. dentary	10.2								
11	med. *Myotis*	R. dentary	10.2								
11	*Myotis* sp.	R. dentary	n/m								
11	*Myotis* sp.	R. dentary	n/m								
11	*Myotis* sp.	R. dentary	n/m								
11	*Myotis* sp.	R. dentary	n/m								
11	med. *Myotis*	rostrum				6.6	5.9				
11	med. *Myotis*	rostrum				6.6	5.8				
11	med. *Myotis*	L. maxilla				n/m					
11	med. *Myotis*	L. maxilla				n/m					
11	med. *Myotis*	L. maxilla				n/m					
11	med. *Myotis*	L. maxilla				n/m					
11	med. *Myotis*	R. maxilla				6.2					
11	med. *Myotis*	R. maxilla				n/m					

Two crania consistent with *M. lucifugus* or *M*. cf. *lucifugus* were identified from Levels 5 and 6; and, four cranial parts consistent with *M. sodalis* or *M.* cf. *sodalis*, from Levels 6. A *Corynorhinus sp*. skull was found level 5. *Eptesicus fuscus* was identified from dentaries in Levels 4 and 9, and a canine in level 10.

In addition, the bone bed yielded 11 bones from which non-chiropteran animals that were identifiable: raccoon, deer, mouse-sized rodent, rat-sized rodent, plethodontid salamander, indeterminate fish, and an unknown fragment from a bird or mammal. The most interesting specimens are teeth of juvenile raccoon, a left lower pm4 from level 9 and a right lower deciduous pm3, and the unfused metacarpal diaphysis of a fetal deer.

DISCUSSION

Comparing the means of measurements, Jegla's 1960 study concluded that the skulls were consistent with those of *Myotis sodalis*. MacGregor (1991) identified skulls of *Eptesicus fuscus*, *Pipistrellus subflavus*, and *Myotis* spp. from the deposit. The 1999 Illinois State Museum sample contained not only *M. sodalis* and *Eptesicus fuscus*, but also *M. leibii*, possibly *M. lucifugus*, hundreds of bones of indeterminate medium-sized myotis bats, and *Corynorhinus* sp.

Originally, Jegla concluded that the Bat Cave bone deposit may have resulted from a recent flood event and cited the January 1937 flooding of the Green River, which raised the river level to 52.5 feet as the possible catastrophe. Catastrophic flooding of hibernating bats is not unknown. For example, DeBlase et al. (1965) concluded that floods in the Ohio River valley decimated a population of 6000 hibernating bats (*M. lucifugus, M. sodalis,* and *Pipistrellus subflavus*) on February 7, 1964 in a lower passage of Wind Cave (Breckinridge County, Kentucky) to only 170 by the following month on March 19**.**

Later, though, in a March 1961 letter to Supervisory Park Naturalist Willard Dilley, Jegla (1961b) expressed being baffled by Bat Cave. He was convinced that the bat remains did not result from blasting in the 1930s; however, he was no longer sure that the drowning had been a single recent event:

> I really wonder if we aren't looking far enough into the past, and that the deposit is on the order of centuries of years old instead of decades of years old. There was a good amount of silt covering the bones in the crawlway which suggests to me that several floods have occurred since the bones were deposited. There is little doubt in my mind that the bats died by other means than by drowning.

Today, evidence of dynamiting, such as shrapnel marks on walls near the bone bed, is not apparent; which has led Olson to wonder if and where blasting took place. Jegla's rethinking seems to have been prompted by a letter that Willard Dilley (1960) wrote to John Hall pointing out the information in Hibbard's diary that Bat Cave had been made inaccessible to bats by the time as of his July 1934 trip to the cave when he observed that both passages were blocked. Because two bat bones submitted for radiocarbon dating failed to date, the present project cannot offer an estimated time for the kill event(s).

As Jegla concluded some 40 years ago, the Bat Cave bone deposit indeed appears to have resulted from one or more past flood events that occurred during winter hibernation and not from the blasting shut of the passage entrance. Three pieces of evidence offer seasonality information. First and most obvious is that wintertime flood events -- such as the recorded January 1937 event -- would be the most devastating for a species that hibernates in large, densely packed clusters. A second clue to a wintertime event is provided by the fetal deer metacarpal (Level 9). This seasonality estimate is based on the rut taking place in November-December and parturition in May (Barbour and Davis 1974:287). Outside the cave, bones of a young deer are likely to be consumed by carnivores or rodents. If a woodrat or a carnivore had transported the bone into the cave, it is likely that it would show evidence of gnawing, but it does not. The presence of juvenile raccoon premolars marginally supports late winter to late spring seasonality. Raccoons mate from January to March and births can occur from early March through May (Barbour and Davis 1974:256).

Jegla estimated that the Bat Cave deposit represented some 300,000 individual bats (the current study did not attempt to make an estimate for the entire bone bed). On his January 1960 trip, Jegla saw hibernating *M. sodalis* and recorded a temperature of 4^{o} C in the passage just beyond the bone bed. Researchers before and after Jegla have reported on the various species found in Bat Cave. The United States National Museum has *Pipistrellus subflavus* and *M. lucifugus* specimens collected by Vernon Bailey in 1929 from Bat Cave (Smithsonian Institution 1996), where he wrote that the latter species was found in "small numbers ... in late September" (Bailey 1933:453). In addition, Bailey commented that Bat Cave contains "large numbers" of *M. sodalis* (Bailey 1933:457). In 1959 Hall captured *M. austroriparius* and *M. sodalis* (Smithsonian Institution 1996). In the fall of 1969, Keefer (a zoology student at Southern Illinois University) estimated Bat Cave to house 200-250 *M. sodalis* and 300 *M. lucifugus*; in February of 1971 he estimated counts to be 200-300 and 250-300 for the two species and that *M. lucifugus* had shifted its hibernation location. In November of 1972, B. Trevor-Deutsch (Carleton University, Ottawa, Canada) observed approximately 300 hibernating bats, primarily *Myotis*, in the first 1000 feet of the "large tubular part of this cave" and noted the bone deposit in the crawlway that led to the tubular passage (i.e., the passage currently labeled as the "A-survey"). Officially, endangered bat species in Kentucky are monitored by the Kentucky Department of Fish and Wildlife Resources, the Kentucky State Nature Preserves Commission, the U.S. Forest Service, and the U.S. Fish, and Wildlife Service (Traci Wethington 2004, personal communication). Bat counts are conducted every other winter. From 1985 to 1994, estimates of hibernating *M. lucifugus* have remained consistent, in the range of 223-311; but *M. sodalis* have declined from a high of 212 in 1982 (*M. lucifugus* was not counted that year) to 66 in 1985 and down to between 31 and 39 individuals in the last nine years (MacGregor 1999; Wethington 2004, personal communication). In addition, small numbers of hibernating *P. subflavus*, E. fuscus, Corynorhinus rafinsesquii, M. septentrionalis, and M. grisescens have been observed over the years; and, a bachelor colony of *M. grisescens* is present in summer.

Thus, data appear to indicate that winter use by *M. lucifugus* and/or *M. sodalis* has declined since the time(s) of the bone bed deposition. MacGregor (1991 and 2004 personal communication) judges that Bat Cave does not offer suitable conditions for an *M. sodalis* hibernaculum because most of it is not cold enough and many areas are too humid. He surmised that for Bat Cave to house populations of the large size indicated by the bat bone deposit, then either the upper passage had been configured differently or that one or more additional entrances had existed to make the microclimate suitable. Species composition of the identifiable cranial material found in the present study of the bone bed (though limited in numbers) suggests that the contributing population was a mixture of medium-sized *Myotis* (*M. lucifugus* and *M. sodalis*), *M. leibii*, *E. fuscus*, and *Corynorhinus* sp.

RECOMMENDATIONS

Evidence from past literature (Bailey 1933), the bone deposit, and the cave's appellation indicate that Bat Cave may have been a far more inviting hibernaculum for *M. lucifugus* and *M. sodalis* than current figures indicate. Flood events likely decimated past populations, but it seems unlikely that those past populations were as small as those currently indicated by recent bat counts (i.e., comprised of fewer than five hundred individuals). Another attempt needs to be made to radiocarbon date the bone deposit. Something has restricted cold airflow to the passage beyond the deposit: perhaps flooding plugged small holes and passages, or caused collapses; perhaps, the constriction caused by the accumulation of thousands of dead bats, sediment, and small rockfall (from flooding or rock instability from dynamiting in Bat Cave and/or nearby Ganter Cave) created an effective dam. If the welfare of the endangered *M. sodalis* and *M. grisescens* is the paramount concern, then the gap in the deposit may need to be enlarged to restore former access dimensions or past microclimatic conditions to provide suitable habitat.

Further research is needed to investigate the necessity and viability of such a scenario. The NPS and Bats Conservation International have installed data loggers; it will be important to continue monitoring microclimatic conditions at a variety of locations beyond the constriction and in the large chamber situated proximal to the deposit. Bones removed for any reason should be identified. If removed for creating an enlarged access, multiple samples should be submitted for radiocarbon dating.

Mapping and biological inventory trips and biannual bat counts conducted in the A-survey necessitate crawling through the bone deposit. Access was carved through the deposit many years ago; however all researchers traveling into the passage need to be aware of the deposit and encouraged to pass carefully through the crawlway to minimize the inevitable damage. Perhaps flagging tape could be placed as a reminder.

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CHAPTER 8
Re-investigation of Fossil Avenue in the New Discovery Section

INTRODUCTION

The public has never had the privilege of seeing the delicate wonders that lie beyond the New Discovery Entrance. In the summer of 1939, when Frederick G. Vosburgh (no date, p. 17), of the National Geographic Society, visited the newly discovered section of Mammoth Cave named "New Discovery," he was charmed by the cave's "virgin newness" and considered it a "masterpiece, unspoiled and perfect" that had been "decorated by the hand of Time." Albert Wilkerson, a past Park naturalist, thought that Fossil Avenue looked like a huge pincushion due to the numerous needle-thin and hair-thin (1/16 to 1/32 inch diameter) crystals (sometimes 2 feet long) projecting from the floor for several hundred feet along the passage (quoted in Vosburgh n. d. p. 28). Vosburgh saw raccoon scratches on a wall of Fossil Avenue and noted that C. Gilmore of the Smithsonian Institution had identified nearby bones as raccoon and elsewhere in Fossil Avenue, had identified an ulna of a large bear (Vosburgh n.d., p. 24). In addition, Vosburgh saw "millions of bats' bones" that had been "carried by a stream of water" from a higher level or from the upper end of Fossil Avenue to their current locations. When Leo Hunt, Carl Hanson, and Pete Hanson first discovered these remarkable scenes in October of 1938, they had to be cognizant of the weather. They traveled for 14 hours by boat on Roaring River and crawling and walking through some four thousand feet of passage before reaching the formations of Paradise and Purgatory. Since 1940, though, travel time has been cut to minutes. In that year, the Park Service excavated a 100-foot entrance shaft that intersected Fossil Avenue (Hagan and Sutton 1999). Now, researchers traverse a far less treacherous route to view the same remarkable scenery, walking to Fossil Avenue and points beyond via the man-made entrance.

In 1941 (January 7-11) Kenneth Dearolf (Educational Director, Public Library Museum, in Dayton, Ohio) conducted a biological reconnaissance of the New Discovery Section, meant to be an assessment preliminary to a proposed opening of the section to the public. Primarily, Dearolf reported on his observations and trapping of 12 species of live invertebrates (crickets, beetles, bristletail, isopods, crayfish, etc.) and a few living pipistrelles. Additionally, he reported on finding bones of 5 mammal species: pine marten, woodrat, raccoon (scratches, also), bobcat (all identified by the National Museum), and little brown bat.

In 1960, Thomas Jegla (1961) took measurements from 57 fragile bat skulls found between the walls of various travertine dams in Fossil Avenue. He concluded that the skulls represented little brown bats of recent origin (Jegla 1961, 1963). Jegla did not think that the bats had drowned in a flooding of the Fossil Avenue passage, but rather that the bones derived from bats drowned in a dome-pit in which they had been hanging and then their bodies had been washed into Fossil Avenue where they were trapped by the rimstone dams.

In September 1979, Tom Brucker and Tom Gracinin collected the following from the C survey: *Procyon lotor* (distal right radius, station C 37), a large mammal (a rib, C 33-34), and bird (a partial femur, C 33). All are curated by the Carnegie Museum in Pittsburgh (Wilson 1980).

In 2001 (March 13-15), Illinois State Museum researchers Colburn and Toomey visited Fossil Avenue again to conduct a paleontological inventory of the passage between survey stations F1 and F14. Because the National Park Service never opened the New Discovery section to tourists after constructing the artificial entrance and tunnel, Fossil Avenue has retained its unspoiled character. The entire floor is a series of rimstone dams that are filled to varying degrees with sediment, limestone grains, popcorn, and bones. Limestone grains from the ceiling have filled and obscured the rimstones down the center of the passage (location of the trail). Pieces of rimstone dam (which may have been broken out of the trail area before survey station F5) demarcate the path. Between the trail and the cave wall, overhangs protect the rimstones and the tops of the dams are exposed from a fraction of an inch to two inches above the sediment level. The rimstones on the right side are more filled with sediment/limestone grains; while those on the on the left side are deeper/more exposed and more rugosely sculpted with popcorn. It is in these areas -- to either side of the trail -- that bones are preserved.

METHODS

Due to the delicate and undamaged nature of the passage, our field methodology differed from that practiced in the main Mammoth Cave survey. We crawled down the designated trail and selected only specimens that could be reached from the trail. Element selection was limited to humeri and bones of the skull from bats, and, to any element from a non-bat animal. The humerus was the only postcranial element of bat that was measured; its length, and all measurements, were taken with dial calipers. Bat skulls were examined for sagittal crest condition and the following measurements were taken: greatest length of skull (GLS), condylobasal length (CBL), distance between front of maxilla (excluding incisor) and M3 (I-M3), breadth across the M3s (M3M3), interorbital breadth (IOB), maximum breadth of the braincase (BB), occipital depth (OD).

RESULTS AND DISCUSSION

Alcove-like areas in the undulating walls of the passage (see Figure 8-1) define the boundaries for most of the data point locations. Many of the alcoves included several feet of floor surface and a maze of rimstone dams. On the tops of the limestone pieces lining the path, are scattered limestone particles and a few cricket legs, but no bat bones. Pellets of bat guano are very thinly scattered throughout the passage.

FIGURE 8-1. Characteristic appearance of Fossil Avenue passageway.

No bat staining was observed on ceiling, walls, or overhangs. Live pipistrelles hang scattered throughout. The fossil bones lie amongst the rimstone dams (Figure 8-2).

FIGURE 8-2. Example of extensive rimstone dams on floor of Fossil Avenue (scale is 5 cm).

The bat bones do not appear to be from raccoon scat as most bones are complete or nearly so, and none of the bone displays the crushing typical of scat. My general impression is that rimstones along the right side (as one walks away from the entrance) of the passage yield more bones, contain more skulls, and produce skulls that are more complete than the rimstones on the left. This may be because its less busy surface affords an easier background for one's eye to search; hence, yielding a higher rate of return when visually scanning for fossils. On the left side, bat rostra predominate; however, they were not tallied due to their lack of defining components. Although the delicate skulls often exhibit fractured crania, many are 3/4 present to complete. Most of the observed humeri were complete, while the longer, thinner radii exhibit more breakage. The current study located, measured, and identified vertebrate remains from 25 locations in nearly 900 feet of passage stretching between stations F1 and F16. Five samples of bone were collected from the cave and taken to the Illinois State Museum where Colburn used modern skeletal specimens to identify them.

The 25 datae points yielded remains of nine mammal taxa: *Myotis grisescens, M. lucifugus, M. sodalis, Pipistrellus subflavus, Spilogale putorius, Mustela nivalis, Procyon lotor, Neotoma floridana,* and *Peromyscus* sp. Vosburgh noted that a bear ulna had been found in Fossil Avenue, and Dearolf collected bones of pine marten and bobcat; no sign of these animals was found by the 2001 fieldwork. The remains of animals identified in the current study, but not noted by Vosburgh or Jegla are as follows: deer mouse (*Peromyscus* sp.), indeterminate mouse, least weasel (*Mustela nivalis*), and spotted skunk (*Spilogale putorius*), Indiana bat (*Myotis sodalis*), and gray bat (*M.* cf. *grisescens*). The point distribution of the fauna is presented in Table 8-1.

TABLE 8-1. Ubiquity of fauna in Fossil Avenue. Xs indicate data point locations where a particular taxon was found.

Taxon	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***	***21***	***22***	***23***	***24***	***25***	***Total***
Chiroptera																										
Vespertilionidae																										
Myotis cf. *grisescens*										x																1
Myotis lucifugus	x				x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x		x	x		19
Myotis cf. *lucifugus*										x						x										2
Myotis sodalis					x	x				x					x	x		x								6
Myotis cf. *sodalis*										x								x								2
M. lucifugus or *sodalis*								x																		1
medium-sized *Myotis*						x	x			x								x								4
Myotis sp.																			x	x				x		3
Pipistrellus subflavus			x			x										x	x									4
Unidentified vespertilionid																						x				1
Carnivora																										
Mustelidae																										
Spilogale putorius									x																	1
Mustela nivalis																x										1
Procyonidae																										
Procyon lotor		x		x	x																					3
medium-sized mammal					x																					1
Rodentia																										
Muridae																										
Neotoma floridana					x	x										x									x	4
Peromyscus sp.						x										x										2
Indeterminate mouse					x																					1

Peromyscus sp. (deer or whitefooted mouse) was identified from point 6 (right dentary with all teeth: TL=14.2, length excluding incisor=12.7 mm) and point 16 (upper incisor; maxilla). Elements of indeterminate type of mouse were identified at point 5 [(right ulna; right dentary that is 16.1 mm long including the incisor and 14.3 mm long, excluding incisor; a left lower incisor; scapula; innominate fragment; left premaxilla with incisor (not located with the other mouse bones)].

Woodrat (*Neotoma floridana*) signs consist of occasional fecal pellets and nutshells, a very extensive larder/nest across the passage from survey station F2, and a few bones. Bones were found at points 5, 6, 16, and 25. At location 5, woodrat bones were spread out over a 2x3 foot area on floor of alcove (probably dispersed by water). The other points yielded an atlas fragment (point 6), frontals (point 16), and various non-measurable, broken, gray encrusted elements, including the tibia and loose epiphysis, humerus, and splintered fragments (point 25).

Raccoon was identified at data locations 2, 4, and 5. Point 2 is the location of raccoon scratches noted by previous researchers. An examination of the scratch marks on the left wall just beyond the survey station concurs with the conclusions of Vosburgh and Jegla that they were probably made by raccoon. They consist of two sets of scratches on the edge of a ledge about seven feet above the trail Figure 8-3. One set consists of three lines and the other of four lines; the scratches measure approximately 3.5 cm wide and 15 cm long, and 21 cm apart.

FIGURE 8-3. Two sets of raccoon scratches (above) and closeup of the right hand set.

A chalky, broken caudal vertebra (the end including bony protuberances measures 7.5 mm wide and 5.5 mm in height and the length of the fragment is 13.1 mm long) lies on the surface at point 4. Point 5 yielded several raccoon elements: small fragment of the middle portion of a left dentary (basically alveoli for m2 & m3); an entire right carpal; and the proximal half of a right calcaneum. A shaft fragment (possibly metapodial or ulna) of an indeterminate mammal was also present. No intact or deteriorated raccoon scat was observed.

Mustelid bones were collected from two data points in order to make comparisons with known specimens at the Illinois State Museum laboratories. Several chalky pieces of bone were scattered over a 1x1 foot area at point 9. At the laboratories, Colburn identified the elements (scapula; middle portion of a right dentary with fragmented m1, alveoli for m2 and p4; partial atlas; and nearly whole sacral vertebra) to *Spilogale putorius* (Figure 8-4).

***FIGURE 8-4. Spotted skunk,* Spilogale putorius,**
right dentary, atlas fragment, and sacral vertebra (scale is 1 cm).

While the striped skunk is a common animal that lives throughout most of the United States, the spotted skunk is not. The Kentucky State Nature Preserves Commission (2000) classifies and monitors it as a species of "Special Concern." In 1974, Barbour and Davis (1974:266) reported that the spotted skunk had been found only in three counties of eastern Kentucky and likely lived throughout the Cumberland Plateau; and, by 1992, spotted skunk had been reported from 13 eastern counties (Meade 1992:130-131). For the most part, spotted skunk is not present in the midwestern region that includes Wisconsin, Michigan, Ohio, Indiana, Illinois, and most of western Kentucky. However, in 1974, a single spotted skunk was reported from western Kentucky along the Ohio River based on a sighting in car headlights in Henderson County (Richins and Panke 1976). In addition, its remains have been reported from Native American sites in southern Indiana and Illinois. The species avoids wetlands preferring to inhabit brushy, wooded terrain of rocks and cliffs where it dens in basal cliff crevices or boulders and feeds on insects (primarily), small mammals, birds, carrion, and plant matter (Barbour and Davis 1974: 266, Kinlaw 1995:4).

A right dentary (middle fragment, >1/2 present) from point 16 was identified by Colburn as *Mustela nivalis*, least weasel (Figure 8-5). *Mustela nivalis*, a northern species, is absent from the southern United States. Pleistocene-aged remains were found

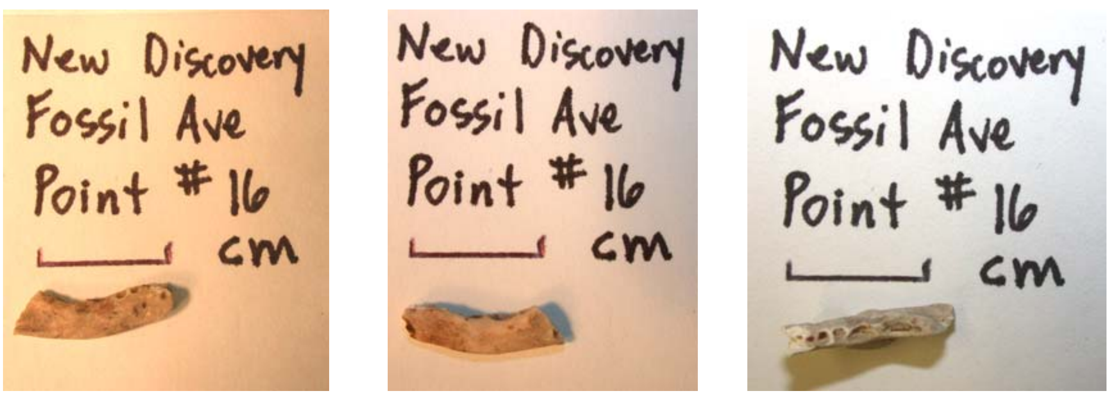

FIGURE 8-5. Three views of right dentary of least weasel,* Mustela nivalis *(scale is 1 cm).

in Welsh Cave in Woodford County (Guilday et al. 1971). Barbour and Davis (1974) reported that the least weasel did not occur in Kentucky in the 1900s. However, by 1992, it was known from several eastern Kentucky counties (Meade 1992). The species now has the status of "Special Concern" (Kentucky State Nature Preserves Commission (2000). The least weasel specializes in hunting small rodents, but also eats bird eggs, young birds and rabbits, moles, shrews, squirrels and chipmunks, small herptiles, and insects (Sheffield and King 1994).

Bat guano is sparsely scattered throughout the study area. However, as previous visitors have noted, the floor of Fossil Avenue is littered with countless bat bones; those belonging to genus *Myotis* are ubiquitous. The only humeri located and measured were identified as *Myotis*. A single left humerus (total length of 24.4 mm) was tentatively attributed to gray bat (*Myotis* cf. *grisescens*) due to its robust nature. The other 32 humeri (15 lefts and 17 rights) are from medium-sized *Myoti*s spp., the measurements are as follows:

- left humeri measurements: 22.3, 23.0, 22.3, 23.1, 21.8, 23.6, 23.4, 22.6, 21.5, 22.2, 23.2, 21.8, 23.5, 22.6, 22.4 mm
- right humeri measurements: 23.2, 21.2, 22.7, 22.7, 23.0, 21.7, 22.7, 23.0, 22.7, 22.5, 22.5, 21.7, 21.5, 22.5, 23.1, 23.4, 23.6 mm

Little brown bat was the most commonly identified species (see Table 8-1). Skulls of 117 *Myotis lucifugus* were found at 19 of the 25 data locations, 9 *M. sodalis* at 3 locations, and 5 *Pipistrellus subflavus* at 4 locations. No skull attributable to *M. grisescens* was found. Numerous *Myotis* skulls for which the species identification could not be confidently assigned were noted at 10 of the 25 locations (3 *M*. cf. *lucifugus*, 1 *M*. cf. *sodalis*, 1 *M*. *lucifugus* or *sodalis*, 2 medium-sized *Myotis*, and 3 *Myotis* sp.). In addition, point 10 yielded a partial maxilla of a medium-sized *Myotis*, and point 22 had three very encrusted bat skulls, which were not measured. Eleven skulls were collected from Paleo Data Point 18, located along the right side between survey stations F10 and F13 (Figure 8-6).

FIGURE 8-6. Bat skulls from Paleo Point 18.

One of the skulls was identified as *M. lucifugus* (based on skull characteristics) with anomalous dentition (present are the p^4 and an enlarged alveolus for only one small premolar) (Figure 8-7, skull on left). Another *M*. *lucifugus* skull had both small premolars, but they were crowded as evidenced by the p^3 alveolus being positioned medially and next to the anterior-most root of the p^4 (Figure 8-7, skull on right).

FIGURE 8-7. Skulls from Paleo Point 18 that were identified to* Myotis lucifugus *with anomalous dentitions.

Several researchers have reported the lack of development of a small upper premolar in *Myotis*. Barbour and Davis (1969) noted the loss of the upper premolars in California specimens; Findley and Jones (1967) noted missing premolars in Colorado specimens and in *M. occultus*, which they considered conspecific wit*h M. lucifugus*; Frum (1946) studied West Virginia specimens of *M. lucifugus* exhibiting either absence or size reduction of the second small premolar (i.e., pm^3).

CONCLUSIONS AND RECOMMENDATIONS

In 2001, the Illinois State Museum's inventory of paleontological resources in Fossil Avenue recorded data for 25 Paleo Data Points and collected samples from 5 of the Data Points. Nine mammalian taxa were identified from faunal remains in Fossil Avenue: *Myotis grisescens, M. lucifugus, M. sodalis, Pipistrellus subflavus, Spilogale* *putorius*, *Mustela nivalis*, *Procyon lotor*, *Neotoma floridana*, and *Peromyscus* sp. The remains of animals identified in the current study, but not noted in earlier reports by Vosburgh, Dearolf, or Jegla are as follows: deer mouse (*Peromyscus* sp.), indeterminate mouse, least weasel (*Mustela nivalis*), and spotted skunk (*Spilogale putorius*), Indiana bat (*Myotis sodal*is), and gray bat (M. grisescens). One hundred forty-one whole or fragmented bat crania were identified and measured. Skulls of *M. lucifugus* (and *M.* cf. *lucifugus*) predominate, accounting for 85% of the skulls. Only 7% are *M. sodalis* or (*M.* cf. *sodalis*), 4% are indeterminate *Myotis*, and 4 % are *Pipistrellus subflavus*. This concurs with Jegla's 1960 study in which he measured 57 skulls and found that the majority represented *M. lucifugus*. Future investigations further into the passage will likely yield new finds.

Fossil Avenue presents several management concerns. The cave biota and the cave formations are particularly untouched in the New Discovery area. Obviously, the decision to limit access to this sensitive area of the Mammoth Cave system is necessary and is lauded. I am also quite concerned about the impact of the creosote treated stairs on the cave biota. Brooks (2000:1) states that creosote is "complex mixture of at least 160 detectable hydrocarbon compounds, all 18 major components are cyclic and aromatic." Hence, creosote has the acronym PAH for polycyclic aromatic hydrocarbon. While the chemicals used to treat the wood may be classified as pesticides, the treated wood itself is not because lethal dosage is not high enough. Federal regulations do not classify creosote treated lumber as a hazardous waste; in fact, creosoted lumber is officially deemed a non-hazardous solid waste and therefore, it can be reused or even disposed of in landfills (U.S. Environmental Protection Agency 1984). Ironically, an industry Consumer Information Sheet for creosote lists precautions for handling and distinguishes appropriate from inappropriate use (American Wood-Preservers' Association). Brooks' study of the effect of railroad ties on wetlands inhabited by the Federally endangered Hine's emerald dragonfly (*Somatochlora hineana*) reaches the conclusion that "newly treated railway ties pose minimal environmental risk -- even in sensitive wetland environments" (Brooks 2000:82) and confirmed other studies that have shown that most creosote migration takes place in the first couple of years and that PAH does not biomagnify up the food chain. However, recent studies and anecdotal information attest that creosote leachate can be quite detrimental to plants and invertebrates (personal communication, E. D. Cashatt, Entomology Section, Illinois State Museum, 2004). However, there can be no doubt that migration rates and resident time in the sediment in the cold environment of a cave differ from those in the hot sunny environment of the common railroad track, where the main factors degrading PAH would be sunlight and chemical weathering. Further, Brooks (2000:77) states "Regardless of the source of PAH [polycyclic aromatic hydrocarbons, creosote is a mixture of 160], it is the cumulative effect of all observed PAH that contribute to potential stress and at low concentrations to chronic toxicity." In sum, for the well-being of the sensitive cave biota, I recommend that the Park err on the side of caution and remove the creosote-treated lumber used to construct the stairway.

In addition, there is much wood and metal debris in Fossil Avenue, leftover from late 1930s-early1940s mining efforts to connect the north end of the passage with Solitary Cave. The Park maintains a policy of leaving old man-made debris and trash in the cave once such detritus becomes "historically" old at 50 years. However, for the preservation of this sensitive region, it seems that the Fossil Avenue mining debris should be investigated and removed if found to be detrimental in any way to the cave life. The debris could be used, along with photographs and interpretation, in the Visitor Center to educate the public. Possible educational foci are listed below:

- The Park could virtually "show" an off-limits area of the cave.
- The debris is an important part of the social history of Mammoth Cave National Park. It could be used in an exhibit to show the Herculean efforts by cave managers in the past to open new passages and to connect with known passages.
- A contrast between pristine passage and damaged tour trail could be used to help the public understand what and why the Park must protect some resources.

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CHAPTER 9
Re-investigation of Fox Avenue
(near Kentucky Avenue in Mammoth Cave)

INTRODUCTION

One goal of the Paleontological Project was to revisit Mammoth Cave localities that were known to have fossil remains of animals other than bat. Separate chapters in this volume provide the results of the reinvestigation of known fossil-yielding areas in Sophy's Avenue and Proctor Cave. This chapter presents the findings from a revisit to Fox Avenue, which lies in the Kentucky Avenue area. In addition, a comment is made on Sandy Avenue, which lies along Kentucky Avenue.

RESULTS AND DISCUSSION

Fox Avenue -- Hagan and Sutton's (1999) Gazetteer of Mammoth Cave catalogues multiple passages that are, or have been, called "Fox." The Paleo Project reinvestigated the Fox Avenue that lies in the vicinity of Kentucky Ave. The naming of this particular Fox Avenue has become part of Mammoth Cave lore. In 1929 or so, George Morrison reported that Fox Avenue was "so named due to the finding of the remains of three foxes at the extreme end of the terminal of this avenue" (Morrison circa 1929:47). Interestingly, Morrison also wrote that the three were "found in close proximity" and he asked if the scent lasted for "ages." I presume that he was wondering if they had followed each other's scent into the dead end passage, thus, dying in close proximity. It is interesting to note that Hibbard's diary (19 December 1934) mentions that tracks and the soft bones of a raccoon were located beyond the New Entrance "far back in the cave." It is not known if he was referring to a Fox Avenue specimen.

Forty-six years after Morrison, Diana Daunt (CRF researcher and Mammoth Cave guide) added to the lore. She reported that there existed only one skeleton in Fox Avenue; that the skeleton was raccoon, not fox; and that it was not near the terminus of the passage (Daunt 1975). In 2000, Cave guide Chuck DeCroix led the Paleo Project to Fox Avenue in order to examine the raccoon skeleton and passage (Figure 9-1). The bones were partially buried in flood sediments and many were in poor condition because they had been stepped on previously (Figure 9-2).

FIGURE 9-1. Context of the known raccoon skeleton in Fox Avenue.

FIGURE 9-2. Closer view of previously known raccoon skeleton in Fox Avenue.

Now, the Paleontological Inventory Project can add more information to the continuing legend of George Morrison's Fox Avenue. An astragalus was collected for radiocarbon dating; the result shows that it was modern. The skull and a tibia (Figure 9-3) that had escaped trampling, were measured (Table 9-1).

FIGURE 9-3. Close-up of raccoon skull.

TABLE 9-1. Measurements of raccoon bones in Fox Avenue.

Feature measured	***Measurement***
Tibia	112.0 mm
Greatest length of skull	107.5 mm
Condylobasal length	104.0 mm
C-M^3	39.9 mm
Canine alveolus (anterior-posterior)	5.8 mm
I-M^3	49.4 mm
Breadth across M^3s	35.3 mm
Interorbital breadth	24.2 mm
Braincase breadth	46.5 mm
Occipital depth	26.7 mm

Approximately 10 feet further along Fox Avenue, along the left wall is an area of undisturbed sediment that has a small surface scatter of bat bones and skeletal parts from at least three different individual frogs. And yet a little further, in the now dry water channel that runs along the right wall Colburn found another raccoon skull (Figure 9-4).

FIGURE 9-4. Context of second raccoon skull in Fox Avenue.

Could this be the second of the Morrison's three so-called foxes? A search of the surrounding area yielded no additional bones. As can be seen in Figure 9-5, spotting the skull was a fortuitous find, and it is not surprising that it was overlooked by earlier trips. It is the larger of the two objects immediately to the right of the centimeter scale.

FIGURE 9-5. The well camouflaged second raccoon skull found in Fox Avenue.

It is doubtful that this is one of the individuals mentioned by Morrison -- at least not in its present location and/or condition. As the next photograph shows (Figure 9-6), the in situ skull looks like a rock at first glance. It is more than half buried in the small-grained sediment of the dry streambed and its exposed surface (the basal portion of the skull) is slightly encrusted with gray calcite. The rostrum is missing so no measurements were taken (Figures 9-6, 9-7, and 9-8). Because its weight indicated that some mineralization is occurring due to deposition in the intermittently moist sediment, it was not sampled for dating.

FIGURE 9-6. Closeup of second raccoon skull in situ.

FIGURE 9-7. Second skull after removal from sediment.

FIGURE 9-8. Colburn, DeCroix, and the second raccoon skull.

We found no additional bones between survey station C23 and the shafts located at the terminus of Fox Avenue. Relative to the size of the passage, one could say that the two raccoon skulls were in "close proximity" as Morrison described. However, no one, today, would judge the two sets of remains to be close to the "extreme end" of Fox Avenue. *If* these two skulls represent Morrison's original specimens, then, clearly they have been redeposited. Perhaps the bones were transported by water because it is evident that Fox Avenue has had flowing water since the deposition of the bones. Thus, there still exists a slight chance that the third of Morrison's "fox" skeletons and additional skeletal elements are yet to be discovered.

After searching Fox Avenue, the Paleo Project explored a portion of the D-survey, a passage that branches to the north around station D8. A few scattered bat wing bones were spotted. And a *Myotis* skull was found on the sandy floor near the left wall approximately 30 feet into the passage. The skull possessed a slight sagittal crest and the following measurements (in mm): greatest length of skull 15.1, condylobasal length, 14.7; I-M^3, 7.1; breadth at M^3s, 5.8; interorbital breadth, 3.6; braincase breadth, 7.1; occipital depth, 4.6. The ceiling changes above had been stained by roosting bats.

Sandy Avenue -- Between Grand Central Station and Lover's Leap, on the south wall of Sandy Avenue (left side as leaving the Frozen Niagara formation) is a large bank of in situ sediment that has been mined for trail construction. The dark red sediment is an old flood deposit. Mining activity has exposed 2 fragments of very white colored bone, from very small-sized animal(s). The sediment bank is about 3 feet high and the bones are within 1-inch of the top-most surface. No further work was done and the fragments were left in place.

RECOMMENDATIONS

The raccoon material and bat bones in Fox Avenue are safe from further human impact. Few people enter the passage and the raccoon skeleton is marked with flagging tape. The bones in Sandy Avenue are interesting because they are occur within *in situ* fill sediment. At this point in time, they are of little significance. Investigations to determine when the sediments were deposited or to locate identifiable faunal materials may make this site significant in the future. In addition, though close to the tourist trail, they are unlikely to be found.

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CHAPTER 10
Re-investigation of Sophy's Avenue

Sophy's Avenue is a 1,000-foot long passage that terminates at its north end in Kennedy Domes, and its south end originally fed into Marion Avenue (Hagan and Sutton 1999). Ron Wilson and others collected several animal bones in Sophy's Avenue in December 1978 (Wilson and M. Mezmar) and on a return trip February 1979 (Wilson and K. Carlton). At the north end of Sophy's, in the bottom of Kennedy Domes, the crews recovered parts of small-sized mammals, *Peromyscus* sp., *Neotoma floridana*, *Sciurus* sp., and medium-sized *Myotis* sp. Most interesting, though, was the recovery in 1978 of a black bear (*Ursus americanus*) tibia from Sophy's Avenue in the vicinity of Z20. All of the remains collected by Wilson are curated at the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania.

In March 2001, Rick Olson led Colburn and Toomey to Sophy's Avenue looking for additional bones. Intensive search in the Z passage produced no bear fossils. However, about 20 feet into a southwest-northeast trending crawlway in the left wall of Sophy's, known as the N survey, Olson spotted a bone along the right wall of the crawl. As Figures 10-1 through 10-4 show, the bone was well camouflaged being partially coated with flowstone and lying on the floor amongst limestone rubble. Three quarters of the bone was above the surface of the moist sediment with the disto-lateral end touching the right wall of the small crawl. It was the left tibia of a bear and is the only paleontological fossil that we found. Because Sophy's Avenue is an infrequently traveled passage, paleontological remains that we may have missed are safe from harm.

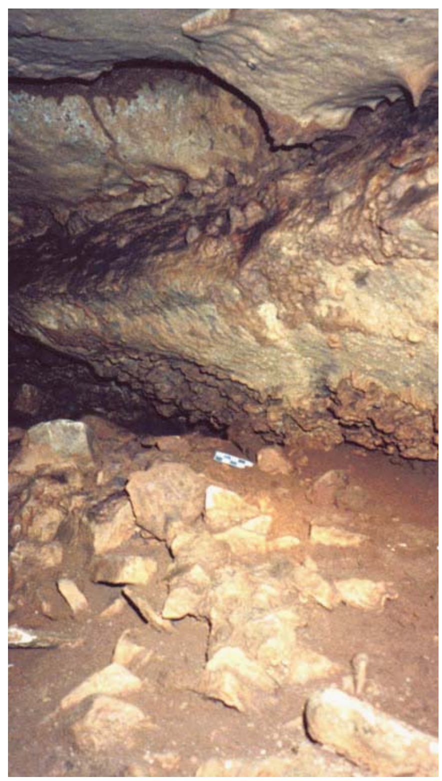

FIGURE 10-1. Context of the bear tibia as found (lying to right of scale).

FIGURE 10-2. Photograph showing the cramped location of the bear tibia. Note hand and helmet light at left edge of photo.

FIGURE 10-3. Another view of bear tibia in side passage off Sophy's Avenue.

During excavation, we found that calcium carbonate had cemented the tibia to two small pieces of limestone that were below the surface of the sediment (Figure 10-4).

FIGURE 10-4. Bear tibia exposed after excavating surrounding dirt and rock. Left, view of posterior aspect; right, proximal end.

The bone was collected for closer examination at the lab (Figures 10-5 and 10-6).

FIGURE 10-5. Left bear tibia recovered from Sophy's Avenue with attached rocks.

FIGURE 10-6. Close-ups showing heavy coating of calcium carbonate at proximal end.

The rock attached to the medio-proximal portion of the shaft popped off, removing a bit of cortical bone (Figure 10-7). At the point of attachment, the bone is slightly mineralized. No attempt was been made to remove the rock that is cemented to the front of the shaft or to remove the coating of calcium carbonate.

FIGURE 10-7. Close-up of tibia shaft showing area where rock had been attached.

Where exposed, the bone is white and chalky (Figure 10-8). It is likely that the bone is not datable.

FIGURE 10-8. Close-up of tibia shaft showing mineral deposits and leached bone.

The tibia has been attributed to black bear (*Ursus americanus*) based on comparison with modern specimens (Figure 10-9).

FIGURE 10-9. Lateral aspects of modern black bear tibia and Sophy's Avenue fossil, both are lefts.

Measurements taken with the calcium coating in place are given in Table 10-1.

TABLE 10-1. Measurements on black bear (Ursus americanus) tibia collected in 2001 from Sophy's Avenue.

Reference points for measurement	***Measurement***
Maximum width at proximal end	73.4 mm
Medial length of tibia (tip of distal epiphysis to the medial condyle)	265.0 mm
Maximum length of shaft at center	266.0 mm
Width of distal end	56.0 mm
Depth of distal end	30.5 mm
Circumference at midshaft	98.0 mm

In a 1980 letter to John Guilday, Wilson included a list cataloguing the bones that had been collected from Mammoth Cave. Because Wilson listed a right tibia from Sophy's Avenue, it was assumed that the 2001 tibia would be the mate to the earlier find. However, when I looked at an old photograph of the 1978 find, it did not look like the right side. To resolve the matter, I visited the Carnegie Museum to reexamine the bear tibia and other bones collected by Ron Wilson and CRF researchers. The following photograph (Figure 10-10) shows the anterior aspects of three tibiae oriented in the same direction. Comparison of the 1978 tibia, a modern specimen, and the 2001 reveals a surprise. The Sophy’s Avenue specimens are from the left side; thus, the two fossil tibiae represent two different individuals!

FIGURE 10-10. Anterior aspect of 3 left tibiae of black bear; from top to bottom, the 1978 tibia, a modern black bear, and the 2001 fossil.

The 1978 bear tibia does not have the build up of calcium carbonate seen on the 2001 specimen. This may be due to its different location or the Carnegie specimen may have been cleaned. The elements collected by Wilson and others from Sophy's Avenue and from Kennedy Domes (at end of Sophy's Avenue) are curated at the Carnegie Museum; they are shown in Table 10-2 and Figures 10-10 and 10-11.

Table 10-2. Bones collected in 1978-1979 from Sophy's Avenue. * indicates reassessment.

Taxon	**Element identifications by Wilson (1980)**	**Figure #**
Ursus americanus	right tibia * (Colburn reassessed as left side in 2003)	Figure 10-10
Bat * (re-identified as medium-sized *Myotis* sp.)	right mandible	Figure 10-11a
Sciurus sp.	parietals & lower incisor	Figure 10-11b
Neotoma sp.	partial left mandible, no teeth	Figure 10-11c
Peromyscus sp.	2 partial skulls, 4 left mandibles, 1 right mandible, 3 tibiae, 1 femur, 5 humeri, 1 radius, 1 ulna	Figure 10-11d

a ***b*** ***c*** ***d***

FIGURE 10-11. Bones recovered in 1970s from Kennedy Domes at end of Sophy's Avenue and referred to in Table 10-2.

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CHAPTER 11
An ancient entrance to Frozen Niagara, a preliminary report

INTRODUCTION

The following is a report on the work conducted by the Paleontological Inventory Project in the Frozen Niagara section, where bones were discovered within sediments overlain by a blanket of flowstone. For a number of reasons, as the following progression of events will help to explain, the results are preliminary at this point in time. The Paleo Project had not planned to work in this section of the cave; however, after Toomey fortuitously noticed bones in the vicinity of the Frozen Niagara tourist trail while he was on a CRF field trip, an investigation was warranted. Upon closer investigation, Colburn and Toomey found additional pockets of bone in sediments below the flowstone. Ten sediment samples from *in situ* deposits were washed and sorted; the faunal remains proved to be extensive and diverse.

The great formation known as "Frozen Niagara" was discovered in 1923, during the days of the Cave Wars. To facilitate visitation, George Morrison had an artificial entrance – the "Frozen Niagara Entrance" – carved through flowstone and sediments in 1924 (Hagan and Sutton 1999). In the 1930s, the Civilian Conservation Corps further remodeled and disturbed the entrance area (Figure 11-1). Multiple episodes of trail

FIGURE 11-1. Above, Civilian Conservation Corps workers excavating prior to landscaping at the Frozen Niagara Entrance in January of 1938; right, landscaping on March 18, 1938 (NPS images downloaded from the Western Kentucky University website, URL:http://www.wku.edu/Library/nps/ccc/).

construction inside the cave has exposed a deposit of mixed sediments and travertine on both sides of the tourist path. The 1.5-meter thick exposure lies beneath a flowstone cap; and is visible for some 35 meters into the cave. The exposed portion may be only the top of a much thicker travertine and sediment deposit. Overall, travertine dominates the section, and the sediments occur as pockets in the travertine mass (Figure 11-2).

FIGURE 11-2. Frozen Niagara area, bank of sediment from which Data Points 1388, 1389, 1397, and 1398 were sampled.

The travertine is comprised of masses of cave popcorn and carbonate crusts that range from thin to thick. The sediments are a red-colored matrix consisting of clay and small pieces of limestone, chert, and small bones. Some of the sampled pockets of clay-rich sediment had abundant bone, while others had little to no bone (Figure 11-3). The mass of travertine, sediments, and bones suggests that an ancient natural entrance to the cave system was nearby – perhaps a small fissure that opened to the surface.

FIGURE 11-3. Frozen Niagara area: left, Data Point 1386, close-up **Geomys** ***sp. incisor in sediment; right, bat dentary at Data Point 1387.***

RESULTS AND DISCUSSION

Because the tourist trail was scheduled for further improvements, the Illinois State Museum collected bags of sediment from ten data points and six travertine samples for uranium-series dating in January of 2000. At the Museum's Research and Collections Center, Colburn washed and screened the bags of sediment in water, subjected the screened material to a mild acid bath, and after being dried, brushed through the matrix and extracted all of the potentially identifiable bone. Hundreds of skeletal elements and bone fragments were picked from the samples. This has made it apparent that a complete analysis of the faunal remains would require investigations that were well beyond the original scope of work, and that additional funding would be required to analyze the assemblage thoroughly. Figure 11-4 shows an example of the small bone fragments sorted from the Data Point 1386 sample.

FIGURE 11-4. Frozen Niagara area, bone picked from Data Point 1386 sample (photograph by Gary Andrashko, Illinois State Museum).

Jeff Dorale (then at the University of Minnesota, Department of Geology and Geophysics) conducted the uranium-series dating. Dorales' uranium-series analysis of the carbonate from a level that coincides with the capping layer of flowstone provided an age of 125,000-126,000 years before present. The discovery of the Frozen Niagara Entrance area bones was originally reported at the Mammoth Cave 8th Science Conference (Colburn et al. 2000); at that time it was thought that *if* the deposition of the bones coincided with the formation of the dated carbonate layer, then the bones, also, might date to the last interglacial (the Sangamon Episode). However, different possibilities must be considered. If the dated carbonate is from a capping layer, then the assemblage could predate the Sangamon Interglacial.

Preliminary analysis of the bones indicates that a wide taxonomic range of vertebrates inhabited the area. In fact, the Frozen Niagara assemblage is the most diverse of all the areas investigated by the Paleontological Inventory Project. The faunal remains include the following: amphibians (frog and salamander), reptiles (turtle, snake, and lizard), birds, and a variety of mammals. Most of the animals represented are small, with bats and rodents dominating the assemblage. A close perusal of the bat bones yielded no remains readily identifiable to free-tailed bat (*Tadarida*), a taxon found to be widespread in Pleistocene deposits in the historic section of Mammoth Cave; nor to vampire bat (*Desmodus*), also found in the Historic Section. Deer (*Odocoileus virginianus*) and raccoon (*Procyon lotor*), which still inhabit the Mammoth Cave region, are represented in the assemblage.

Teeth and other elements of pocket gopher are plentiful. Identification of *Geomys* sp. is based on bisulcate upper incisors. It is likely that some of the other unidentified rodent elements will prove to be from this taxon, as well. The Frozen Niagara specimens are probably *G. bursarius* (plains pocket gopher) or *G. pinetis* (southeastern pocket gopher). *Geomys* is an extralimital taxon; although it does not occur in Kentucky today, it did in the past. *G. bursarius*, is considered to be a western species; it currently inhabits western and Midwestern states, but the fossil record shows that in the past, it ranged farther east (Figure 11-5). [Note: all map images used in this chapter were produced by the FAUNMAP Working Group (1994, 1996) and were downloaded from www.museum.state.il.us/research/faunmap. Because the FAUNMAP project collected faunal data for late Quaternary sites (circa 110,000 years to present, i.e., 1994), the maps do not reflect geologically older locations from which a taxon might be known. They are used in this report for the purpose of illustrating the general distribution of fossil records and the present-day ranges, for applicable taxa. I did modify some maps to reflect older localities for select taxa.] Guilday et al. (1971) found *G. bursarius* in circa 13,000-year-old faunal remains from Welsh Cave (Woodford County, Kentucky), and thought that the species had a range distribution during the Pleistocene that was continuous from the Midwest to Florida. Since Guilday's study in Kentucky, *G. bursarius* has been identified from as far east in the U. S. as New Trout Cave, West Virginia, in an assemblage that is 17,000-29,000 years old (FAUNMAP Working Group 1994). Plains pocket gophers live in open habitats (grasslands and open woods) and prefer well-drained, loose, sandy soil in which to dig its burrows (Nowak 1991:621).

Another species of pocket gopher, the southeastern pocket gopher, *G. pinetis*, is a species currently found only in the northern half of Florida, and southern portions of Alabama and Georgia, where it inhabits dry sandy (and sometimes gravelly) soils in long leaf pine forests (Pembleton and Williams 1978) (see Figure 11-5). Pleistocene specimens of the southeastern pocket gopher have been recorded in Florida, and it was recovered from a Native American mound site in northern Georgia.

Pocket gophers are fossorial and herbivorous obtaining grasses and forbs above ground and, roots and tubers while underground. Thus, the Frozen Niagara *Geomys* inhabited a dry, open habitat such as grasslands or prairies (in the case of *G. bursarius*) or, open pine forests (in the case of *G. pinetis*). Further analysis is needed to determine the species of the Frozen Niagara specimens.

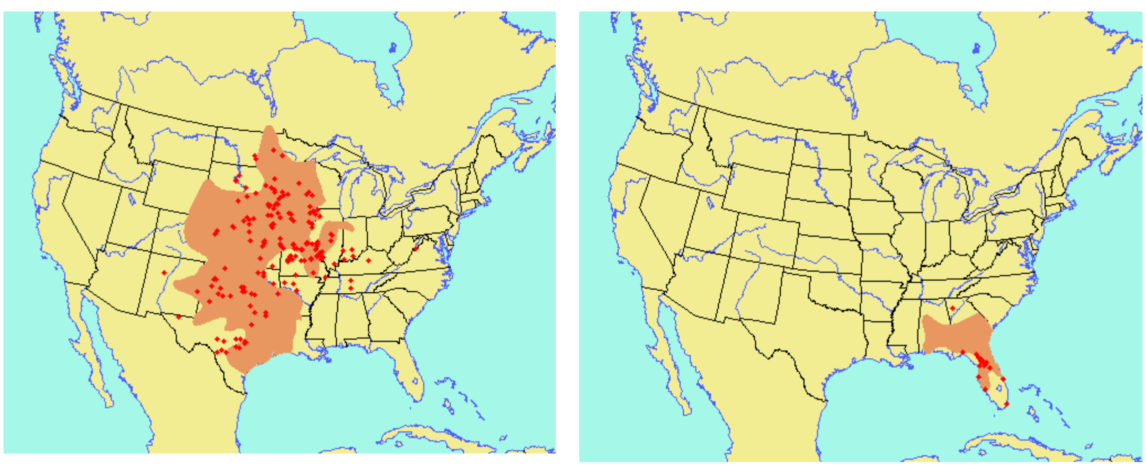

FIGURE 11-5. Current ranges and Late Quaternary records for plains pocket gopher (**Geomys bursarius*****), left, and southeastern pocket gopher* **(Geomys pinetis)***, right (maps from FAUNMAP database).***

Extinct mammals identified in this preliminary examination of the Frozen Niagara faunal assemblage include the following: *Equus* sp. (horse), *Dasypus bellus* (beautiful armadillo), *Platygonus* sp. (peccary), and *Neofiber leonardi* (water rat). A fragmentary tooth with poor preservation is attributed to horse, *Equus* sp. (Figure 11-6). Many species of horse were present in North America during the Pleistocene, but it is difficult to distinguish *Equus* to species, and no determination was made on the fragmentary specimen from Frozen Niagara. North America's native horses were extinct by the end of the Pleistocene, 10-12,000 years ago. Guilday et al. (1971) identified *Equus* sp. at Welsh Cave (Woodford County, Kentucky). Other Kentucky sites producing horse fossils are a fissure at Mundy's Landing (Mercer County) where *Equus complicatus* (complex-toothed horse) was recovered, and Glass Cave (Franklin County) with *Equus* sp (Wilson 1985).

FIGURE 11-6.* Equus *sp. tooth fragment from Frozen Niagara area (photograph by Gary Andrashko, Illinois State Museum).

Several dermal scutes (Figure 11-7) are identified to the extinct species, *Dasypus bellus* (the beautiful armadillo) on the basis size. Osteologically, *D. bellus* is identical to *Dasypus novemcinctus* (modern nine-banded armadillo), except that its bones are larger. *D. novemcinctus* shows up in the fossil record after *D. bellus* and occupies the ecological niche vacated by the latter (Klippel and Parmalee 1984). Klippel and Parmalee (1984) found that scutes from small-sized *D. bellus* are almost as small as large individuals of the modern species. In addition, as more fossils come to light, *D. bellus* appears to have occupied a geographic range similar to that of the living armadillo (Graham 1993).

Schubert and Graham (2000) consider the possibility that the two species may be clinal or temporal variants of the same taxon.

FIGURE 11-7. Dermal ossicles of* Dasypus bellus *from Frozen Niagara section of Mammoth Cave; left, exterior surfaces, and right, the underside of the scutes (photographs by Gary Andrashko, Illinois State Museum).

By the end of the Pleistocene, *D. bellus* had attained a size at least twice that of the modern armadillo (Kurten and Anderson 1980:131). The nine-banded armadillo is the size of a domestic house cat, and the beautiful armadillo was a "large hog-sized carbon copy" (Guilday and McCrady 1965). Schubert (2003) obtained a terminal date of 11,000 ± 60 years BP for *D. bellus* in Missouri (Little Beaver Cave). The majority of *D. bellus* finds are found in late Pleistocene sites (Klippel and Parmalee 1984, Voorhies 1987). *D. novemcinctus* became a noticeable part of the fossil record only **after** the end of the Pleistocene; all fossil records of this species shown in Figure 11-8 derive from archaeological contexts (FAUNMAP Working Group 1994).

Kurten and Anderson (1980:130) note that Florida was the stronghold of *D. bellus*. The fossil record shows that *D. bellus* ranged primarily over the southern portion of the Midwestern and eastern U.S. (Figure 11-8). Its northernmost occurrence is in Nebraska at a 2.5 million year old locality (Voorhies 1987). In Kentucky, beautiful armadillo was identified from A-maze-in Cave, Bullitt County (Wilson 1985). Other Pleistocene localities in the eastern U.S. that have produced remains of beautiful armadillo are Illinois (personal knowledge), Indiana, Missouri, Tennessee, and West Virginia (FAUNMAP Working Group 1994).

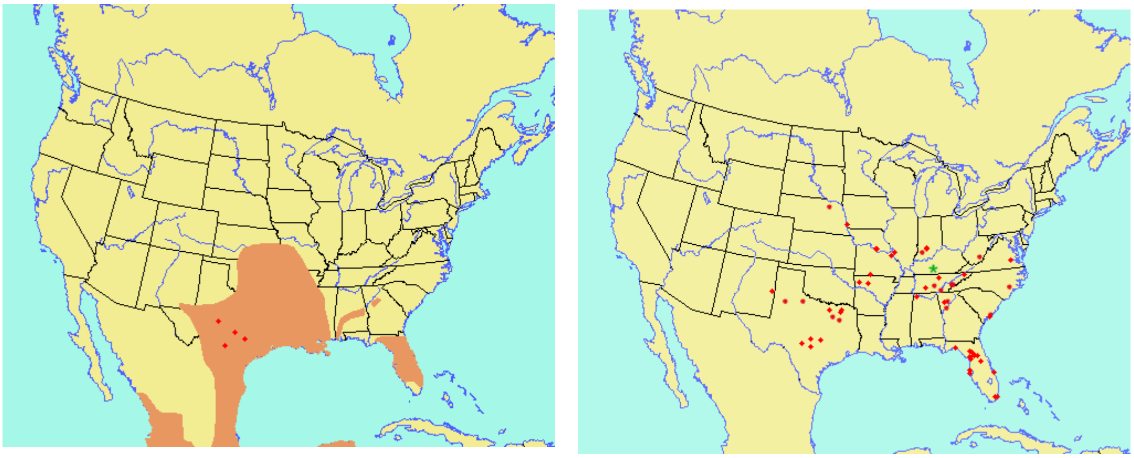

FIGURE 11-8. Left, current range and fossil records (all archaeological contexts) for the living nine-banded armadillo (Dasypus novemcinctus) (FAUNMAP image). Right, Pleistocene localities with remains of the extinct beautiful armadillo (Dasypus bellus, green star is Mammoth Cave) (modified FAUNMAP image).

Based on analogy with the modern nine-banded armadillo, Slaughter (1961) surmised that the extinct form was likely to have preferred environments with mild winters that were no colder than those found in modern-day northern-central Texas, and with annual rainfall of more than 20 inches. However, the range of *D. novemcinctus* has expanded northward greatly since Slaughter conducted his study, more than 40 years ago. In addition, the discovery of *D. bellus* at the Craigmile site in Iowa associated with boreal taxa suggests that it may have been more cold tolerant than has been suspected (Rhodes 1984).

A tooth fragment of peccary appears to be an unerupted enamel cap of a cheek tooth (Figure 11-9). It is identified as *Platygonus* sp. based on the absence of low, rounded cusps characteristic of *Mylohyus nasutus* (long-nosed peccary).

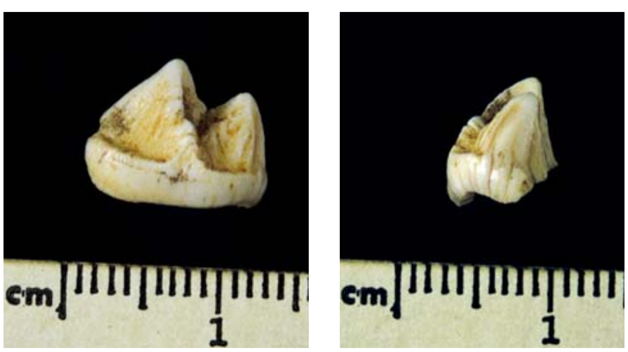

FIGURE 11-9. Two views of a tooth fragment identified as* Platygonus *sp. (photographs by Gary Andrashko, Illinois State Museum).

Peccaries of the genus *Platygonus* were herd animals whose remains are quite common and widespread in the North American fossil record. Kurten and Anderson (1980:295) write that the flat-head peccary was "probably the most numerous medium-sized mammal during the late Pleistocene" (Figure 11-10). Evidence shows that *Platygonus compressus* utilized caves; fossil cave localities often contain multiple individuals, likely due to its gregarious nature. For example, in Kentucky, 31 individuals are represented at Welsh Cave (Woodford County) (Guilday et al. 1971) and approximately 24, at Toolshed Cave (Bullitt County) (Wilson 1985). Remains of 98 individuals occur in a single passage at Bat Cave (Pulaski County, Missouri) (Hawksley et al. 1973). Other Kentucky localities with remains of flat-head peccary are Proctor Cave (Mammoth Cave National Park), Wells Cave (Boyle County), Chickasaw Bluffs and Hickman (Fulton County), Lone Star Peccary Cave and Granny Puckett Cave (Hart County), Savage Cave (Logan County), Great Saltpeter Cave (Rockcastle County), and a cave in Wayne County (FAUNMAP Working Group 1994, Wilson 1985). Leidy's peccary (*P. vetus*), which was found in Lisanby Cave, Caldwell County, Kentucky (Wilson 1985), was larger than *P. compressus*, is less common in the fossil record, and occurs earlier in the record in the early to middle Pleistocene (perhaps greater than 400,000 years before present) (Kurten and Anderson 1980).

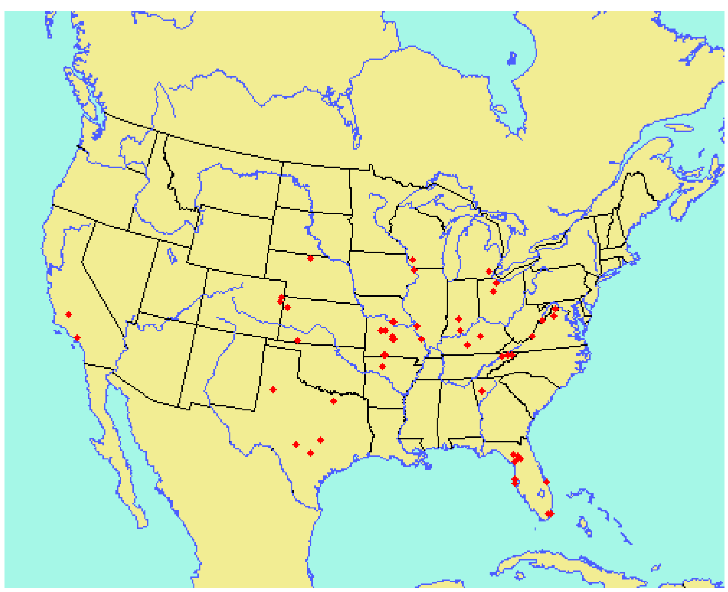

FIGURE 11-10. Late Quaternary localities with remains of flat-headed peccary (**Platygonus compressus*****) (FAUNMAP image).***

The single most interesting fossil in the Frozen Niagara assemblage is the dentary of a large microtine rodent, identified as the extinct water rat, *Neofiber leonardi*. The specimen is a partial left dentary with i-m_2 of an adult. The incisor and first molar are in place in the dentary, and the exposed enamel on the occlusal surface of the m_1 is stained black. The second molar is not fully surrounded by bone; however, it is cemented to the bone by calcium carbonate (Figure 11-11). No attempt was made to completely remove the calcium carbonate.

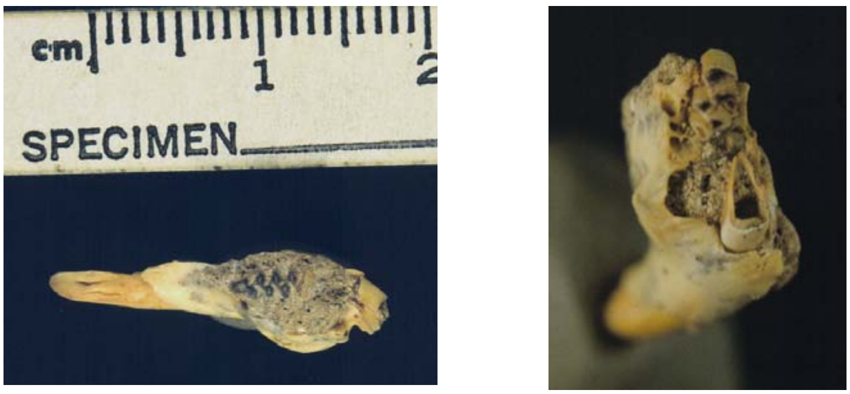

FIGURE 11-11. Fossil* Neofiber leonardi *from Mammoth Cave: left, occlusal view; right, closeup of posterior aspect showing that the m_2 is slightly dislodged from the horizontal ramus (photographs by Gary Andrashko, Illinois State Museum).

This specimen is identified to the genus *Neofiber* on the basis of size and tooth morphology. Both molars have the triangles characteristic of microtine rodents. The dentary and teeth are larger than those of *Microtus* or *Pitymys*. The molars are rootless, thus separating it from *Ondatra* and from *Proneofiber* (Hibbard and Dalquest 1973), both of which have rooted teeth.

Species determination to *Neofiber leonardi* is based on the first lower molar. It possesses no dentine tracts on the triangle apices of the molars, as was described by Hibbard (1955) for *N. diluvianus* at Port Kennedy Cave in Pennsylvania (*Microtus diluvianus* in Cope 1896 and *Schistodelta sulcatus* in Cope 1899). Hibbard and Dalquest (1973) also found interrupted enamel on the molars of *Proneofiber guildayi*. Frazier (1977) reports dentine tracts on McLeod Quarry specimens. The m_1 of the Frozen Niagara specimen possesses 5 completely closed triangles between the anterior loop and the closed posterior loop; and the enamel is thick. The anteroposterior measurement is

5.0 mm. Measurements by Dalquest (1967) on twelve isolated lower first molars range from 5.65 to 6.5 mm. The third buccal reentrant angle on the Frozen Niagara m_1 is oriented anterior-posteriorly. Frazer (1977) found this characteristic to be present in all lower first molars of *N. leonardi* and in half of the fossil *N. alleni* specimens that he examined, but rare in modern *N. alleni (n* = 200).

Hibbard (1943) first described *Neofiber leonardi* from the Rezabek fauna in Kansas; later, Hibbard and Dalquest (1973) identified it in the local Kanopolis fauna, Kansas. It has also been recorded for Pleistocene localities in Texas (at Slaton Quarry by Meade 1952 and Dalquest 1967; at Carrol Creek by Kasper 1992), Florida (McLeod Limestone Quarry by Frazier 1977), and in West Virginia (Trout Cave by Frazier 1977) (see Figure 11-14). These sites are early to middle Pleistocene in age. Frazier (1977) judged that *N. leonardi* remains derive from Yarmouthian interglacial deposits or early Illinoian deposits.

Hibbard reported the Rezabek *N. leonardi* as being larger than modern *N. alleni*, and Meade reported Slaton Quarry *N. leonardi* as about the same size. The Frozen Niagara specimen is smaller as shown in Figure 11-12. Frazier (1977) considered *N. leonardi* to be ancestral to *N. alleni*.

FIGURE 11-12. Top, modern* Neofiber alleni*; bottom, fossil* Neofiber leonardi *(photograph by Gary Andrashko, Illinois State Museum).

The living water rat is *Neofiber alleni*, commonly called the Florida water rat or the round-tailed muskrat. It is a nocturnal sub-tropical rodent that is herbivorous and lives in shallow, grassy marshes (Birkenholz 1972). Its present day range is restricted to Florida and extreme southeastern Georgia; most fossil *N. alleni* have been found in Florida (FAUNMAP 1994, Figure 11-13).

FIGURE 11-13. Current range and fossil records for* Neofiber alleni *(modified FAUNMAP image).

FIGURE 11-14. Pleistocene locations with remains of extinct* Neofiber: N. leonardi *(circles; green star indicates Mammoth Cave) and* N. diluvianus *(red cross in Pennsylvania) (Modified FAUNMAP image).

Birkenholz (1963) studied modern *N. alleni* for 3.5 years in the 13,000-acre Paynes Prairie in north-central Florida. He reports that the water rat's ability to burrow in terrestrial habitats would not allow a population to survive dry conditions on a long-term basis. Furthermore, he found that a 2-month long drought affecting his study area reduced several thousand individuals to only a few individuals (Birkenholz 1963:275). If *N. leonardi* had similar habits, the presence of a viable population would have required a shallow, fairly permanent body of water (not necessarily in the immediate vicinity because the individual could have been deposited by an owl or a carnivore) and that the region had a warmer climatic regime.

In August 2003, Colburn took the *Neofiber* fossil to the Smithsonian Institution National Museum of Natural History for verification. Frederick Grady (Smithsonian Institution, Department of Paleobiology, Washington, D.C.) confirmed the identification. He also agreed that the deposit has a good possibility of being older than Sangamon age, as possibly indicated by a date of 125,000-126,000 for the overlying flowstone. The Sangamon interglacial, which occurred between 130,000-75,000 years before present (YBP) (Marine Isotope Stage 5, substages a-e), would have been the most recent climatic warming (aside from our current interglacial), with the warmest segment coinciding with Substage 5e (130,000-115,000 YBP) (Kukla et al. 2002, Shackleton et al. 2002). In addition, Grady suggested that the Frozen Niagara faunal assemblage might derive from an Irvingtonian fauna (early to middle Pleistocene). As was discussed for the possible age of the *Tadarida* remains found in the Historic Section of Main Mammoth, warm periods prior to the Sangamon interglacial occurred at 300,000-350,000 YBP (Marine Isotope Stage 9); 362,000-423,000 YBP (Marine Isotope Stage 11); 472,000-502,000 YBP (Marine Isotope Stage 13); 540,000-590,000 YBP (Marine Isotope Stage 15); 625,000-645,000 YBP (Marine Isotope Stage 17); and 820,00-900,000 YBP (Marine Isotope Stage 23) (Burckle 1993, Lowe and Walker 1984).

CONCLUSIONS AND RECOMMENDATIONS

As can clearly be seen, a thorough examination of the faunal remains collected from the ancient Frozen Niagara entrance would have required a substantial detour from the target areas outlined in the original scope of work. However, this initial study was done to demonstrate the uniqueness and value of the Frozen Niagara assemblage and the need to acquire future funding to conduct a complete analysis of the deposit and the faunal remains.

The faunal assemblage supports a hypothesis that the ancient Frozen Niagara material represents a period (or periods) of time when the central United States had a warmer climate, and when the Mammoth Cave area had a patchy environment with habitats and animals that were different than those we see in the area today. *Geomys*, a western species, and *Platygonus* indicate the presence of open habitat; *Dasypus bellus* may reflect warm winters and non-arid conditions; and *Neofiber leonardi* needed a fairly permanent marshy area. Perhaps the region was a savanna or a steppe environment. The generally fine-grained sediments, and the small size of the bones and bone fragments suggest that the much of the assemblage may have resulted from owls roosting above a small fissure or sink, or, it could have accumulated from feeding activity by small to medium-sized carnivores.

The taxonomic diversity of the vertebrate remains in combination with the potential to date the deposit makes the Frozen Niagara faunal assemblage paleontologically significant. The preliminary results highlight questions that only future research can help to answer:

- Are there additional extinct taxa?
- Are there additional extralimital species?
- Can the *Geomys* material be distinguished to species?
- Are there any signature species for the middle Irvingtonian present in the samples?
- Can we get a date from lower in the sequence of travertine?
- What will more speleothem dates tell us?
- Can we obtain isotopic information from the horse tooth?

Whether future analyses show that the assemblage represents the Sangamon interglacial episode or an earlier time period, the Frozen Niagara assemblage will provide insights into a portion of the United States for which we have little information.

The significant paleontological resources in the Frozen Niagara Entrance area are located in an *extremely* vulnerable location and could be easily damaged or destroyed. The data points are highly visible and within easy reach of the trail (in fact some visitors currently brush against them). In addition, the *in situ* deposits are not abundant and visitors picking at them would destroy the irreplaceable remnants. Thus, it is imperative that the bone locations not be pointed out to visitors. However, a viable alternative would be to protect the embankment with a wall of Plexiglas and then use the locality as a point of interpretation. Any pockets of sediment that would be impacted by such a structure should be examined by a paleontologist before work commences, and the excavated sediments should be collected for processing and sorting of paleobiological remains.

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Chapter 12
Vertebrate Fossils found in Proctor Cave

INTRODUCTION

According to historical lore, an ex-slave named Jonathan Doyle found the opening to Proctor Cave in 1863, and in the late 1800s Larkin Procter, a former manager of Mammoth Cave, opened his own commercial cave – “Procter’s Cave” (since his time, the spelling “Proctor” has become common usage) – to tourists (Hagan and Sutton 1999) (Figure 12-1). At that time a visitor could ride the Mammoth Cave Railroad from Glasgow Junction (now Park City) -- a station on the Louisville and Nashville Railroad line -- and stop at the Proctor Hotel, which was located uphill from the cave entrance. Old signatures in the so-called "historic section" attest that visitation was confined to the upper level passages. Long after the demolition of the Proctor Hotel and the railroad tracks and long after Proctor Cave was closed to tourists, adventurous explorers have continued to probe the cave well beyond the historic upper level passages.

Figure 12-1. Old gate at entrance to Proctor Cave; 1935 construction by Civilian Conservation Corps (NPS image downloaded from Western Kentucky University, URL:http://www.wku.edu/Library/nps/ccc/).

The passages beyond were unlike any seen by the early tourists. By 1979 the Cave Research Foundation (CRF) had explored and mapped 7 miles of Proctor Cave, including a 1-2 foot high, quarter mile long crawlway, fondly known as the “Proctor

Crawl" (Hagan and Sutton 1999). After CRF members discovered a connection to Mammoth Cave in mid-1979, this paltry mileage would be added to the rest of the mileage known for the Flint-Mammoth Cave System. In 1978, Ron Wilson (1980) and a CRF crew found a premolar of an extinct species of tapir (*Tapirus* cf. *veroensis*) in the Proctor Crawl (Wilson 1980). In 1979 and 1980, Wilson and others made 24-hour trips that took them far beyond the long, low sandy crawl. Besides mileage, they collected other fossils that included additional extinct species. A jaw of giant short-faced bear (*Arctodus simus*) (Figure 12-2) was collected from a stream channel, and very fragmentary proboscidean remains from the terminal breakdown at the end of Frost Avenue. All fossils collected by the Wilson crews are curated at the Carnegie Museum of Natural History in Pittsburgh; they are discussed at the end of this chapter.

FIGURE 12-2. Photograph of a cast made from the* Arctodus simus *right dentary collected by Wilson and crew in 1979. The Carnegie Museum curates the original fossil and made the cast.

Thus, the Proctor Section became one of the known fossil-yielding localities designated for reexamination by the Paleontological Inventory Project. Rickard Toomey looked for fossils during CRF mapping trips (two were made before the Paleontological Inventory Project started, and two were made after: 25 May 1996 (Toomey, Olson, and Womack), 3 July 1996 (Toomey, Olson, and Wagner), 13 February 1999 (Toomey, Schubert, Sikora, and Hoke), and 17 February 2001 (Winkler, Sikora, Mezydlo, Toomey, and Olson). Colburn synthesized information found in Toomey's notes and in CRF trip reports, which are on file with the Cave Research Foundation; the pertinent information is presented in the results section. In July 2001, with the express goal of collecting bones, Colburn, Toomey, and Olson traveled into Proctor Cave with a CRF crew that was resurveying the Y-survey (Winkler, Willmes, and Martz). To facilitate transportation of collected specimens through the various crawls and tight canyons, Colburn constructed three 24" long capped tubes made of 4" PVC pipe. Each tube could be tied to a person's ankle in order to pull it through the various crawlways and tight places. Our destination was lower level stream passages from which Wilson's crew had recovered fossils in the 1970s, and where Toomey and Olson had spotted additional bones. The Paleontology Project crew was not going to search the terminal breakdown where Wilson had also found fossils because Toomey thought that it would be unproductive based on his previous examination.

RESULTS AND DISCUSSION OF PALEONTOLOGICAL RESOURCES IN PROCTOR CAVE

Early CRF trips made by Toomey and others

On some of the early CRF trips, preliminary observations were noted; on other trips, specimens were re-recorded and measured, and two specimens were collected. Table 12-1 summarizes the paleobiological information compiled from the CRF trip reports.

Table 12-1. Summary of remains found during CRF trips in May 1996, July 1996, February 1999, and February 2001. The first 3 columns reflect information extracted from various trip records. Comments are by Colburn.

Location (trip notes)	***Taxon (trip notes)***	***Skeletal elements, measurements in millimeters (from trip notes)***	***Comment***
X-36	*Pipistrellus subflavus*	Partial skeleton (skull, dentary & other postcranial bones, L humerus=19.8 mm)	
X 56- X 57	Bat	Bat bones abundant	
X 57-X 58	*Myotis*	7 L dentaries 10 R dentaries	Discussed below
	Myotis	Rostrum	Discussed below
	Myotis sp.	1 R humerus=23.5, 1 radius=40.9	
	Myotis	L dentary	

Location (trip notes)	***Taxon (trip notes)***	***Skeletal elements, measurements in millimeters (from trip notes)***	***Comment***
	Eptesicus	L dentary	
	Mouse-sized rodent	2 upper incisors	
	bat	Possible, faded stain on ceiling and walls; Possible bat guano in sediment	
X 58-X 59	bat	Possible bat guano in sediment; bones associated on surface of sediment & exposed in drip holes (latter are reddish-brown color). Radius=39.1, L humerus=19.7	
	Myotis	L dentary, R dentary	
	Mouse-sized rodent	Incisor	
	Shrew	Skull with articulated dentaries in drip hole (white bone color differs from bat bones)	Collected February 1999; later identified as S*orex fumeus;* Discussed below
X 59- X 60	Bat	Abundant bone on surface; possible faded staining on ceiling; possible bat guano layer ca. 5mm; & darker color exposed in drip holes and in trail sediment	Discussed below
	Bat	Radius=39.7	
	Myotis	L dentary	Discussed below
X 60- X 61	Bat	Small mass of bat bones including many wing bones	
	Myotis	5 L dentaries	Discussed below
	Myotis	4 R dentaries	Discussed below
	Myotis	L dentary	
	Myotis	Rostrum	Discussed below
X 62	*Peromyscus*	Partial skeleton (R mandible, some postcranial)	
	Noted in field notes variously as the following: large mustelid, fisher, martin, mink, *Martes*	Skull, several vertebrae, dentary fragment, atlas fragment, distal humerus, foot	May 1996: rostrum & atlas found; Feb 1999: additional bones found & skull measured; See discussion below
X 65	Bat	Bat bones abundant	
	Pipistrellus subflavus	Skull	
	Neotoma	Partial skeleton scattered (R jaw, L & R femur, rib, tibia)	
X 66	Bat	Bat bones abundant	
X 113	Bat, possibly *Eptesicus*	Ulna shaft fragment	
X 114	Bat	Humerus fragment	
X 116	Bat	Bones	

Location (trip notes)	***Taxon (trip notes)***	***Skeletal elements, measurements in millimeters (from trip notes)***	***Comment***
	Mouse-noted as probably *Peromyscus*	Femur	Mouse-sized rodent
	Mouse (*Peromyscus* or *Microtus*)	Upper incisor	Mouse-sized rodent
X 118	Unidentifiable large mammal	Bone fragments	Noted in February 2001, collected in July 2001
	Bat (?pipistrelle)	Bones	
Y 73- Y74	Large mammal	Femur shaft in stream	Noted in February 2001, collected in July 2001
Y 74	Large mammal	Rib fragment in stream	Noted in February 2001, collected in July 2001
Y 78	*Neotoma*	Pelvis in sediment	Noted in February 2001, collected in July 2001
Beyond Y 84	Deer or peccary sized mammal	2 long bones on ledge cemented to limestone and sediment	Noted in February 2001, collected in July 2001
	Rabbit or skunk sized mammal	Tibia, distal end cemented in sediment & broken proximal end sticking out of sand	Noted in February 2001, collected in July 2001

July 2001 CRF-Paleontological Inventory Project collecting trip

The July 2001 crew traveled to survey station X 118, which marks the terminal breakdown pile at the end of Frost Avenue. We were not scheduled to search it because the lower level stream channel was our primary goal; but Toomey wanted Colburn to see the breakdown. In short order a small piece of bone from a large animal was spotted. Consequently, the crew spent 30 minutes searching a small section at the base of the talus pile. As was the case for previous finds from this drippy location, the bones were wet, mushy, leached of organics, stained black, and coated with mud. Flecks of charcoal could be seen in the mixture of dirt, sandstone, and limestone rubble. After 30 minutes, we all descended to the lower level Y-survey where three party members continued with surveying and mapping the passage. Colburn, Toomey, and Olson spent 2 hours examining the area between survey stations Y 65 and Y 84. Olson donned his wetsuit for the purpose of checking the end of the passage. However, the passage reduces to only 5-inches of air space over watery mud. We collected 13 bones from the gravel floor of the stream. Because all were loose, re-deposited finds, we did not record their individual locations. We also collected the smaller of two bones that were cemented to the passage just beyond Y 84. A skull cemented to the floor, under a ledge at circa Y 74 was identified as raccoon; it was not collected.

The fossils were packed in the PVC tubes with bubble wrap and all extra clothing; all of the bones emerged undamaged 22 hours after the crew had entered Proctor Cave. Colburn took the collected bones to the Illinois State Museum's Research and Collections Center for cleaning and identification. Specimens from the talus were soft and crumbled with handling; and, bones from the stream channel were saturated but in excellent condition. The bones were allowed to dry slowly. After drying, tap water was used to remove the dirt.

I. Paleontological Resources in Proctor Trunk.

***Myotis grisescens* –** In the Proctor Trunk between survey stations X 56 and X 61 is an area that is identified as a former bat roost. There is an abundance of bat bones on the surface and mixed in the sediment. Faded staining on the ceiling (Figure 12-3) is interpreted as bat roosting stain, and a dark band in the sediment is thought to be a layer of degraded guano. Numerous drip holes provide views below the surface, allowing us to see that bat bones are quite abundant in the sediment (Figure 12-4).

FIGURE 12-3. Ceiling stain located within area of old gray bat roost in Proctor Cave.

FIGURE 12-4. One of many drip holes containing bat bones; located within area of old gray bat roost in Proctor Cave.

Several cranial elements (dentaries and rostra) from surface contexts were measured in the field. Based on size, most of the myotis have been assigned to *Myotis grisescens* (Table 12-2).

TABLE 12-2. Measurements taken in the field on bat skull parts found in Proctor Trunk.

Provenience	***Skull part and measurement in mm***	***Taxon***
X 57-X 58	7 L dentaries (11.5, 11.5, 11.5, 11.5, 11.6, 11.4, 11.4) 10 R dentaries (11.2, 11.4, 11.6, 11.5, 11.4, 11.2, 11.6, 11.5, 11.7, 11.7)	*M. grisescens*
	Rostrum (I-M^3 7.3, breadth across M^3-M^3 6.7)	*M. grisescens*
	L dentary 10.7	medium-sized *Myotis*
	L dentary 15.7	*Eptesicus fuscus*
X 58-X 59	L dentary 11.6, R dentary 11.4	*M. grisescens*
X 59- X 60	L dentary 11.1	*M. grisescens*
X 60- X 61	5 L dentaries (11.2, 11.5, 11.5, 11.6, 11.6)	*M. grisescens*
	4 R dentaries (11.1.11.3, 11.5, 11.5)	*M. grisescens*
	L dentary 10.5	medium-sized *Myotis*
	Rostrum (I-M^3 7.3, breadth across M^3-M^3 6.2)	*M. grisescens*

The added evidence that many of the bones are identified to *M. grisescens* supports the idea that the ceiling stain is roosting stain, and that the dark band is old guano. Thus, it is concluded that the area was once a large *M. grisescens* roost. In addition, the former roost is far from a currently open entrance, and it seems likely that the gray bats gained access through a former entrance. A likely candidate is the collapsed sink at the end of Frost Avenue at station X 118.

***Sorex fumeus* –** A shrew cranium with articulated dentaries was found adhering to the side of a drip hole located within the bat roost area, between stations X58 and X59. (Figure 12-5). Figure 12-6 shows the cleaned specimen.

FIGURE 12-5. Shrew skull in Proctor Cave drip hole. February 1999, Schubert collected the skull and surrounding sediment. At the ISM-RCC labs, the skull was submerged in water effectively separating the sediment.

FIGURE 12-6. Dorsal and ventral views of a smoky shrew (*Sorex fumeus**) skull found in Proctor Cave between X58 and X59.

The size and general morphology of various shrew skulls and dentaries are similar. Schubert identified the Proctor Cave specimen as *Sorex fumeus* using the Museum's comparative collection, the key developed by Junge and Hoffmann (1981), and criteria noted by Semken (1984). He used the following characters to make the identification:

- Absence of postmandibular foramen distinguishes it from *S. arcticus* (character is strong in *S. arcticus*, but usually absent in *S. palustris* and weak to absent in *S. fumeus*).

- When viewed from buccal side, the valley between the protoconid and hypoconid of m1 is weak (in *S. arcticus* and *S. palustris* the valley is deep).

- Third upper unicuspid in the fossil is larger than the 4th (they are of similar size in *S. palustris* and *S. dispar*).

The following characters were measured on the fossil specimen:

- Condyle width = 2.1 mm
- Length of unicuspid tooth row = 2.5 mm (after Junge and Hoffman, 1981)
- Length of maxillary tooth row = 6.9 mm (after Junge and Hoffman, 1981)
- Greatest width across M2-M2 = 4.8 mm (after Junge and Hoffman, 1981)
- Mandibular body depth = 1.3 mm (after Semken, 1984)
- Length of m1-m3 = 3.8 mm (after Semken, 1984)

In the 1930s, Bailey and Giovannoli reported smoky shrews as being common at Mammoth Cave's old historic entrance and captured several specimens in the vestibule (Bailey 1933:440). Hibbard (1935) trapped a smoky shrew at River Styx. Due to its moisture requirements, Barbour and Davis (1974:35) considered the species “scarce and irregular” in Kentucky. Owen (1984) reports that the species is expanding westward from the center of its distribution in the Appalachian Mountains. The fallen trees, rocks, brush, swampy grassland, and protected streams within the boundaries of Mammoth Cave National Park provide numerous areas of suitable habitat with adequate moisture and cover for *S. fumeus*. A broken skull was also found in a pit in Wandering Woods (see chapter on Miscellaneous Pits, this report).

***Martes americana* --** On the May 1996 trip, Olson spotted the rostrum and half of an atlas of a large mustelid in the Proctor Trunk (near station X-62); it was variously thought to be fisher, marten, or mink. Later, several vertebrae, a dentary fragment, a distal humerus, and foot bones were found. Fragments of humerus, dentary, and vertebra were collected for radiocarbon dating, but were never submitted. I re-examined the collected fragments of bones; they are very white with light beige exteriors, brittle and flake easily when handled and likely to be leached of datable organic materials. Through direct comparison with specimens in the Illinois State Museum's osteological collection, I identified the specimens as *Martes americana*, marten (also called American marten, pine marten, or American sable). My assessment was based on the posterior portion of the left dentary and on the distal right humerus, which are shown in Figure 12-7 along with the caudal vertebra. The following cranial measurements were taken in the field: P^4 P^4 = 25.7 mm; I-M^1= 36.2 mm; width of M^1= 8.2 mm, length of M^1 = 4.4 mm, anterior width of P^4 = 5.5 mm, length of P^4 = 8.2 mm).

FIGURE 12-7. Three bones of* Martes americana *from Proctor Cave X-62. Photographs left to right: left dentary (lateral and medial views), right humerus, and caudal vertebra.

The marten is a boreomontane species whose present-day habitat is found primarily in Canada; in the United States it occurs in Alaska and some areas of the northern tier of States (Maine, New York, Minnesota, upper Michigan) and at high elevations (Rocky Mountains and Cascades). The marten was extirpated from areas south of the Great Lakes by the mid to late 1800s (Strickland et al. 1982). However, during the Pleistocene, when glaciers were extensive and conditions were cool and moist, marten ranged south into the boreal forest that existed in the continental U.S. Graham and Graham (1994) synthesized the prehistoric distribution of *Martes* in North America.

Late Pleistocene (10,000-20,000 years ago) records of *Martes americana* show that it lived as far south as northern Alabama and Tennessee, but early Holocene (8,000-10,0000 years ago) records are restricted to eastern Tennessee and northern Illinois where their typical spruce and pine habitat gave way to deciduous forests. By historic times (1600) their distribution was well north of the Mammoth Cave area (northern Illinois and Indiana, and southern Ohio). Most archaeological sites with marten remains are outside their historic range, although a few sites may reflect localized populations living in pockets of suitable habitat. *M. americana* is not unknown from Mammoth Cave. Dearolf (1941) collected pine marten bones (identified by the National Museum) from Fossil Avenue in the New Discovery Section. Based on the aforementioned analyses, the Proctor Cave and Fossil Avenue specimens are Pleistocene in age.

II. Paleontological Resources from the terminal breakdown, X 118

Proboscidea – In 1979 and 1980, Wilson (1980, 1985) and others collected a few pieces of bone and one of tusk of Proboscidea from the breakdown pile at the end of Frost Avenue (these bones are discussed further at the end of this report). In February 2001, Toomey and Olson noted a couple more bone fragments of large mammal. The July 2001 trip collected over a dozen bone fragments. At the Illinois State Museum laboratories, I washed off the dirt and exposed 10 good-sized bone fragments, 5 small scraps of bone, and 1 piece of proboscidean tusk. The large fragments appear to from ribs and limb bones. All bone fragments were from a very large mammal, presumed to be proboscidean, as well.

In order to determine what kind of proboscidean lay among the talus, I took the tusk fragment to Dr. Dan Fisher at the University of Michigan. Fisher's research has discovered that mammoth and mastodon tusks can be separated by characteristics in their ivory growth patterns. Schreger lines are formed by the dentin tubules that spiral through the ivory. The spiraling tubules of dentin grow in concentric layers throughout the year creating the well-known layers in elephant ivory. A cross section view of a tusk can show the intersection of the lines, which create a pattern of multiple angles that resembles the herringbone pattern familiar in cloth. Fisher's studies have determined that Schreger angles of mastodons average about 125^{o} and those of mammoths, about 87^{o}. Thus, by measuring the angles formed by oppositely directed Schreger lines in a cross-section of tusk, Fisher can determine whether an unknown specimen belonged to a mastodon or a mammoth. Fisher thin sectioned the fragment of tusk dentin from Proctor Cave that measured about 7 cm long and 3-4 cm radially and transversely. After polishing the surface, he was able to measure the angles formed by the Schreger lines. It had an angle of 120^{o}, from which Fisher determined the Proctor Cave tusk fragment to be from mastodon, *Mammut americanum*. It is quite likely that all of the large mammal bone fragments retrieved thus far are mastodon. Although the Proctor Cave mastodon is the first record of the species for Mammoth Cave National Park, its presence is not unexpected. The FAUNMAP (1994) distribution of late Pleistocene-aged sites yielding mastodon fossils illustrates that it was a wide-ranging species with its remains having been found throughout the United States (Figure 12-8). Elsewhere in Kentucky, mastodon has been identified from Barren County (Turner Cave), Bullitt County (Hall's Cave and Toolshed Cave), and Fayette County (Walnut Hill Farm Cave) (Wilson 1985).

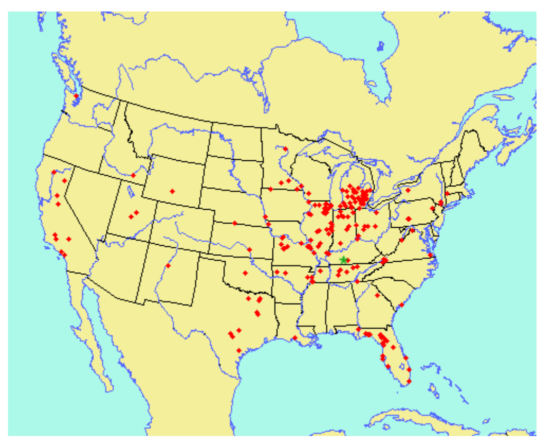

FIGURE 12-8. U.S. Distribution of sites with remains of* Mammut americanum; green star is Mammoth Cave. B*ase map at FAUNMAP URL: http://www.museum.state.il.us/research/faunmap.

III. Fossils recovered from the stream channel.

Because Wilson and his crew collected *Arctodus simus* (giant short-faced bear) and *Bos taurus* (cow) in the 1970s, it was known that the stream had yielded a mix of Pleistocene and modern materials. The 14 bones were pulled from the stream passage on the July 2001 trip also reflect a mixture of extinct Pleistocene species and modern living animals. The bones were saturated, but in excellent condition; they underwent slow drying at the Illinois State Museum labs where they were identified. Because many extant species also lived during the Pleistocene in North America (e.g. opossum, rabbit), it is impossible to determine the age of each bone without submitting each for radiocarbon dating.

Didelphis virginiana **–** A single, entire cervical vertebra represents opossum (Figure 12-9). It is stained black and a light crust of calcite is present in a few spots. The vertebral foramen (a.k.a. neural canal) is occluded with a deposit of cemented sand and calcium carbonate.

FIGURE 12-9. **Didelphis virginiana *cervical vertebra.***

Sylvilagus **cf. *floridanus*** **–** A right innominate was identified to rabbit, in the size range of eastern cottontail (Figure 12-10). The bone fragment is comprised of the acetabulum, ¾ of the ischium, and a small portion of the pubis. The individual was subadult based on a barely visible line of fusion. The bone is stained black and has gnaw marks from a mouse-sized rodent.

FIGURE 12-10. **Sylvilagus *cf.* floridanus *right innominate.***

Equus **sp. –** Horse is represented by an upper left second premolar (Figure 12-11) and a skull fragment. Because it is difficult to distinguish modern horse from Pleistocene forms, the Proctor Cave specimens have been identified as *Equus* sp. The P^2 is extremely worn and stained black.

FIGURE 12-11. Equus sp. left P^2.

The horse skull fragment (Figure 12-12) is an occipital with attached left occipital condyle and jugular process. Rodent gnaw marks are present on the left squamous of the occipital, and deep scratches are visible on the right squamosal. The bone is a medium brown color. The skull fragment, however, shows no mineralization and I would judge it to be Holocene material.

FIGURE 12-12.* Equus *sp. skull fragment, posterior and dorsal views.

cf. *Platygonus* – Two shaft fragments from an unknown mammal(s) in the medium to large size range were discovered along the right wall, above the water in the stream passage near station Y 84 (Figure 12-13). The bones were cemented to a ledge; only one was retrievable (it broke at the midpoint during recovery).

FIGURE 12-13. Unknown bone (below pencil) found on ledge in stream passage of Proctor Cave near Y84. Unidentified long bone (above pencil), cemented to ledge was not retrieved.

The bone is well on its way to becoming mineralized after being under water periodically; it was cemented to chunks of limestone, largely covered with a 2 mm thick layer of flowstone, and the inside of the shaft was completely filled with a cement-like mixture of sediment and calcium carbonate (Figure 12-14).

FIGURE 12-14. Two views of a bone after removal from Proctor Cave stream passage near Y84.

After most of the calcium carbonate coating was removed (Figure 12-15), I tentatively identified the fossil as the shaft of a right femur of a juvenile peccary (cf. Platygonus). The bone is 9.9 cm long, and its midshaft diameter measures 20.1 mm anterio-posteriorly and approximately 17.1 mm medio-laterally.

FIGURE 12-15. After cleaning, the unknown fossil was identified as cf.* Platygonus *sp. Left, anterior aspect, and right, posterior view.

Bos taurus – Six elements of cow were recovered from the stream (Figures 12-16 through 12-21). A lower incisor is very worn and stained black.

FIGURE 12-16.* Bos Taurus, *two views of a lower incisor found in stream channel.

A fragment of cow rib is 5.5 cm long and stained a grayish brown color.

FIGURE 12-17. **Bos taurus** ***rib fragment from stream channel.***

The sixth cervical vertebra from a juvenile cow is missing only its two unfused epiphyses and the distal edge of the dorsal spine; it has been stained a rich brown color (Figure 12-18). A spinous process of a thoracic vertebra from a juvenile individual is also medium brown in color with only a little bit of black staining (Figure 12-19).

FIGURE 12-18. Left, **Bos taurus** ***6th cervical vertebra from stream channel.***

FIGURE 12-19. Right, **Bos Taurus** ***dorsal spine of thoracic vertebra from the stream channel.***

The left and right femora (found between Y 73 and Y 74) appear to be a matched pair of diaphyses (both ends are unfused) from a calf (Figure 12-20). The left femur is a grayish brown mottled with black stain and has small rodent gnaw marks across the *linea aspera* and on the anterior surface of the shaft. The right is more uniformly medium brown in color and also has rodent gnawing across its *linea aspera*.

FIGURE 12-20. **Bos taurus** ***left femur (bottom specimen) and right femur (top) from stream channel.***

In the 1970s, the Wilson party collected a right humerus of *Bos taurus* from a small pit in the stream channel near station Z 11. It is shown in an image taken at the Carnegie Museum in 2003 (Figure 12-21). As the photograph shows, the humerus is also from a juvenile and its state of preservation is similar to the femur recovered by the Illinois State Museum, that is, stained medium to dark brown and with the cortical bone exfoliating.

FIGURE 12-21.* Bos taurus *right humerus found in Proctor Cave stream channel near Z-11; collected by Wilson in 1979 and curated at the Carnegie Museum.

Procyon lotor – is represented by a skull cemented to the floor of the stream channel near Y-74 and a fragment of left tibia (Figure 12-22). The skull was not removed from the cave. The tibia is the about the distal ¾. A deposit of calcium carbonate obscures the distal end. The proximal portion of the shaft is broken across the shaft and stained black (the rest of the shaft is not stained). Based on size and bone texture, the raccoon tibia was from a subadult. The bone was recovered at the farthest end of the stream passage, past station Y 84. Wilson's 1979 crew recovered raccoon bones from this passage at Y 78 and Y 73-74, respectively, a femur and fibula.

FIGURE 12-22. Two views of a left tibia from a juvenile* Procyon lotor *found in Proctor Cave stream passage. Proximal portion is to the left; left is anterior aspect, and right is medial.

***Lynx* cf. *rufus* --** An intriguing fossil retrieved from the bottom of the flowing stream channel was almost completely coated with a thick layer of popcorn. Because the partially visible articular surface (see middle photograph of Figure 12-23) and the exposed shape of the shaft reminded me of a fibula, I worked to remove the calcium carbonate in hopes of being able to obtain a taxonomic identification.

FIGURE 12-23. Proximal end of fibula before removal of popcorn, Left photograph shows the medial aspect.

After cleaning (Figure 12-24) and direct comparison with modern specimens, I identified the bone as the right fibula of *Lynx* cf. *rufus*. Less than a quarter of the element is present. While small, the fibula is from a mature individual; in size it compares favorably with a female. Wilson (1980) catalogued a right tibia of *L*. cf. *rufus* from the stream at Y 81 (and both sides of a mandible of *L. rufus* at K 118 from an upper level of Proctor Cave.

FIGURE 12-24. **Lynx *cf.* rufus:** ***proximal end of right fibula after removal of popcorn. Medial surface shown at left and lateroposterior surface, at right.***

***Smilodon* sp. –** The identification of the most interesting bone was not suspected at the time of discovery. At the ISM labs, I identified the fossil as the proximal quarter of a left fibula from a very large member of the cat family and assigned it to *Smilodon* sp., a saber-toothed cat. *Smilodon* is an extinct member of the Felidae, the family that includes a number of large-sized cats that lived in America during the Pleistocene. Though shorter in stature and lacking a long tail, the *Smilodon* was much more massive than today's African lion. *Smilodon fatalis* stood about 3 feet tall at the shoulders, and had a head-body length of 6.5 feet, and weighed about 765-974 pounds (weights converted from Graham et al. 1996). For comparison, the modern male African lion (*Panthera leo*) averages 4 feet tall at the shoulders, 5.6-8.2 feet long excluding the tail, and 330-551 pounds; figures for females are 3.5 feet tall, 4.6-5.7 feet long, and 180-264- pounds (figures converted from Nowak 1997, online source). The extinct American lion is purported to have been about 25% larger than the African relative, with males weighing an estimated 517 pounds and females, 385 pounds (Stock and Harris 1992:36). Pleistocene remains of *Smilodon*, *Homotherium serum* (scimitar cat, estimated to weigh 322-509 pounds, weight estimate converted from Graham et al. 1996), and *Panthera onca* (large Pleistocene jaguar [some researchers call the large jaguar *P. augusta*], estimated to weigh 192 pounds vs. the 117 pounds of the modern form, weight estimate converted from Van Valkenburgh and Hertel 1998) have been found in Tennessee (Corgan and Breitburg 1996, FAUNMAP Working Group 1994). Remains of a single individual *Panthera onca* were found in Kentucky at A-maze-in Cave, Bullitt County, but the skull, dentaries, and major limb bones have been lost (Wilson 1985). The Proctor Cave specimen is the first *Smilodon* reported from a Kentucky locality (Figure 12-25).

FIGURE 12-25. Distribution of late Pleistocene sites in the U.S. with remains of* Smilodon *sp.; green star is Mammoth Cave. Base map from Illinois State Museum online FAUNMAP (URL:http://www.museum.state.il.us/research/faunmap).

To make the determination, I compared the Proctor Cave fibula with actual specimens in the Illinois State Museum collections of *Smilodon fatalis,* modern *Felis concolor* (mountain lion), modern *Panthera onca* (jaguar), and modern *Panthera leo* (African lion), with illustrations of *Smilodon* and *P. atrox* (American lion) in Merriam and Stock (1939), and with illustrations and descriptions of *Homotherium serum* (simitar cat) in Rawn-Schatzinger (1992). I identified the Proctor Cave fibula as *Smilodon* sp. based on the following features (Figures 12-26 and 12-27):

- ♦ Size is larger than *Felis concolor* (mountain lion), shaft is nearly round, and edge of the proximal end is curved and slightly pointed versus the anterio-dorsally flattened shaft and straight edge in *F. concolor.*
- ♦ Size is considerably larger than modern *Panthera onca* (jaguar) [although the extinct form *P. onca augusta* was larger than the living form] and edge of proximal end is curved and slightly pointed versus the straight edge in *P. onca*
- ♦ Size is larger than *Panthera leo* (African lion, which is morphologically similar but smaller than the extinct American lion, *Panthera atrox*), which considered alone could put it in the size range of American lion; however, shaft is rounder and proximal edge is more curved and pointed.

♦Shape of shaft cross section is relatively round per Rawn-Schatzinger's (1992:45) description of *Smilodon populator*, a character she uses to distinguish *Homotherium serum*, which has a more triangular midshaft cross section (Figure 12-26).

FIGURE 12-26. Left proximal fibula of* Smilodon *found in Proctor Cave, photograph shows that the cross section of shaft is nearly round.

FIGURE 12-27. Left proximal fibula of* Smilodon *sp. from Proctor Cave. Note that specimen is water worn. Characters noted in the discussion are 1) curved and somewhat pointed margin of proximal end and 2) rounded shaft.

Comparison with a *Smilodon fatalis* fibula from Missouri (curated at the Illinois State Museum) shows that the Proctor Cave specimen is from a small, gracile individual. Muscle attachments that are typically prominent on members of *Smilodon* are eroded on the Proctor Cave fossil, and the articular surfaces are worn smooth. The agent of wear was probably the stream. In an effort to find a better match, the Proctor Cave fibula became well traveled. I compared it with several fibulae of *Smilodon fatalis* curated at the Field Museum (Chicago, Illinois, contact Collection Manager Bill Simpson) and with one, at the Smithsonian's National Museum of Natural History (Washington, D.C., contact Frederick Grady, Department of Paleobiology); these comparisons confirmed the Proctor Cave specimen's small size and heavy wear. Dr. Jessica Theodor (Geology Curator, Illinois State Museum) took the fibula to California where she was attending a meeting. Dr. Blair Van Valkenburgh (University of California at Los Angeles) and Shelley Cox, (collections manager at the Los Angeles County Museum, the repository of Rancho La Brea tar pits fossils, which is the source of the world's largest collection of *Smilodon* remains) looked at the fibula. At first glance they were skeptical about my identification because of the specimen's small size and lack of rugosity; however, they ultimately confirmed the *Smilodon* identification. Figure 12-28 shows the Proctor Cave specimen compared to the most similar example that I found in the collection of the Field Museum; it is specimen number FMNH P17451 from the La Brea Tar Pits.

FIGURE 12-28. Comparison of proximal left fibulae of* Smilodon *sp. from Proctor Cave (the lighter colored bone) and with* Smilodon fatalis *from Rancho La Brea (the larger, darkly stained bone, FMNHP17451). From left to right the views are, lateral, posterior, and medial.

IV. Re-evaluation of Proctor Cave fossils curated at the Carnegie Museum.

In 2003, I examined all Proctor Cave fossils collected in 1978-1980 and curated at the Carnegie Museum of Natural History (CMNH). I corrected or refined information on several specimens. Based on information in the Carnegie Museum's catalogue of Vertebrate Paleontology Collections (contact Amy Henrici in the department of Vertebrate Paleontology) and in Wilson (1980 and 1985), I compiled Table 12-3. The table lists the original taxonomic identification, CMNH catalogue number, skeletal identification, and collection data and my reassessment. A discussion of the significant re-evaluations follows the table.

TABLE 12-3. Animal remains collected from Proctor Cave, Mammoth Cave National Park, KY and curated at the Carnegie Museum. Table compiled from information in Wilson (1980, 1985) and from the Carnegie Museum catalogue as of 2003. Reassessments by Colburn.

Original taxon ID & CM Catalogue #	***Specimen collected/ Trip Date[1] /Location***	***Reassessment***
Bufo sp. CM 72675	ilia, femora, tibio-fibulae, urostyle, 5 vertebrae, humerus, scapula Collected Sept 1979 R 2	
Serpentes CM 38367	5 vertebrae collected, rest of skeleton left in cave Collected June 1979 X 61 in pool	
Caudata CM 38366	2 vertebrae Collected Sept 1979 terminal breakdown end of X survey (Frost Ave)	
Blarina sp. CM 38365	R femur Collected June 1979 terminal breakdown end of X survey (Frost Ave)	
Peromyscus sp. CM 38371	partial L dentary with m_1, and isolated m_2 Collected June 1979 X 61 in pool	
Peromyscus sp. CM 38372	R dentary with m_2 Collected June 1979 M 26 in Proctor Crawl	
Peromyscus sp. CM 38373	partial skull, L & R dentaries Collected June 1979 X 61 at base of large flowstone mound	
Neotoma floridana CM 72674	partial skull Collected Sept 1979 Y 28-29 off X 109, in cave popcorn	

Original taxon ID & CM Catalogue #	***Specimen collected/ Trip Date[1] /Location***	***Reassessment***
Neotoma floridana CM72677	R tibia Collected Oct 1979 Y 21 off X 109, mud ledge 3 ft above floor	
Neotoma sp. CM 38370	2 fragments of tibia Collected Sept 1979 Y 28-29 off X 109	*Neotoma floridana*
Sciurus carolinensis CM72678	partial skull Collected Oct 1979 R 15	
Procyon lotor CM 47897	radii, ulnae, tibiae, fibulae, L scapula, R humerus, femur, L & R dentaries, skull fragments, vertebrae, foot bones, ribs Collected Feb 1979 K 118 upper levels	
Procyon lotor CM 38361	R femur Collected Oct 1979 Y 78 off X 109, floor of stream channel	
Procyon lotor CM72676	fibula Collected Oct 1979 Y 73-74 off X 109, in gravel, stream passage	Left side
Lynx rufus CM 47898	partial L & R dentaries, R upper C, P3, P4, M1 Collected June 1979 Y 9 off X109	
Lynx cf. *rufus* CM 38360	R tibia Collected Oct 1979 Y 81 off X 109, in stream, half buried in mud & flowstone	
Arctodus simus CM 38359	R dentary (partial) with c, m_1, m_2 Collected Sept 1979 Y 77-78 off X 109	
Odocoileus virginianus CM47899	R humerus less proximal epiphysis Collected Sept 1979 R 13, floor of stream passage	Natural color, not darkly stained
Tapirus veroensis CM 38557	lower p_4 Collected Nov 1978 N 17, Proctor Crawl	
Tapirus cf. *veroensis* CM 47896	specimen label states P/4	Possible cataloguing error
Platygonus compressus CM 38362	L humerus Collected Sept 1979 Y 76 Off X 109, in water	*Sus scrofa*
Platygonus compressus CM 38363	R humerus distal half Collected Oct 1979 Z 22 off X 109, in dry passage with rat nest	cf. *Platygonus* sp. this is a different individual than CM 38362

Original taxon ID & CM Catalogue #	***Specimen collected/ Trip Date[1] /Location***	***Reassessment***
Bos taurus CM 38364	R humerus less proximal epiphysis Collected Oct 1979 Z 11 off X 109; Small pit in stream passage	surface spalling; erroneously entered in CM database as *Platygonus*, may have been confused with Specimen CM38363, which was mis-entered in database
Leporidae CM 38369	tibia less distal end Collected Sept 1979 Y 76 off X 109, on wall 4.5 ft above floor of stream passage	right side cf. *Sylvilagus floridanus*
Proboscidea CM 38558	tusk fragment Collected Aug 1980 terminal breakdown end of X survey	*Mammut americanum*
Proboscidea CM 38558	postcranial bone fragments Collected Aug 1980 terminal breakdown end of X survey	cf. *M. americanum*
Proboscidea CM 38368	metapodial? fragment Collected Sept 1979 terminal breakdown end of X survey	cf. *M. americanum* transverse fragment of a vertebra

1 CRF party for each collection date: November 25, 1978 = Wilson and party; February 10, 1979 = Zopf, Brucker, & Weller; June 30, 1979 = Wilson, Mezmar, & Hand; September 8, 1979 = Wilson, Dickerson, Gerace, & Oberlies; October 6, 1979 party = Mezmar, Lisowski, & Oberlies; August 2, 1980 = Hand, Woolesy, & Farris.

***Tapirus veroensis* CM 38557/CM 47898 --** On 25 November 1978, a CRF crew found a tapir tooth near N17 in the Proctor Crawl. Wilson (1980, 1981) identified it as a *Tapirus* cf. *veroensis* p_4 with Accession #30991. In Wilson 1985, *Tapirus veroensis* is positively identified (skeletal part not mentioned) as having been found in Proctor Cave. In the Carnegie Museum collection, a tag with Catalogue number CM 38557 accompanies a right lower 4th premolar of *Tapirus veroensis* (Figure 12-29). A label for CM 47898 describing a lower p4 of *Tapirus* cf. *veroensis* from the same locality is in the drawer; however, no additional tooth is present. Wilson's writings mention no finding of a second tapir tooth. It is likely that only one lower p4 was found at station N-17 in Proctor Cave and an error was made in cataloguing.

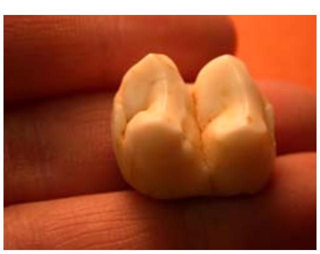

FIGURE 12-29. Two images of CM 38557, a right p4 of* Tapirus veroensis *recovered in 1978 by Wilson et al. in Proctor Cave.

Item CM 38362 -- CM38362 is a nearly complete left humerus (a fragment of the greater tubercle is missing) collected in September 1979 from the stream water near station Y-76 by Wilson and party. Wilson identified it as *Platygonus compressus*, flat-headed peccary. Because I thought that the bone (see Figure 12-28) might be pig, I did the following:

1) I compared the Proctor Cave humerus with the Carnegie Museum's collection of 50 *P. compressus* humeri from Welsh Cave (Late Pleistocene, Woodford County, Kentucky, reported by Guilday et al. 1971).
2) I took several photographs of the Proctor Cave specimen, which I compared with pig humeri at the Illinois State Museum.

***FIGURE 12-30. Left humerus (anterior view) of Proctor Cave specimen CM3862. Originally identified as* Platygonus compressus*, and re-assessed as* Sus scrofa.**

Through these efforts, I have re-assigned CM3862 to *Sus scrofa*, pig (subsequently, the Carnegie Museum corrected their database). I can only speculate about the reasons behind the mis-identification. Two obvious possibilities come to mind. The first, is the brown patina, a coloration that is sometimes mistaken for a sign of antiquity when it has to do with stain caused by minerals in the depositional environment. However, bones can be stained within a matter of years when lying in water. The second reason may lie in the small, gracile character of the specimen. Feral hogs have been present in the United States for 500 years, imported with the Spanish Conquistadors for food. In a study of modern populations of wild boar, feral hogs, hybrids, and domestic swine, Mayer and Brisbin (1991:127) note that domestic pigs have the largest overall body measurements (except snout length is shortest) and are the heaviest. In earliest Colonial times pigs were left to run and forage in the wild. Many faunal analysts are aware that pig bones found in food residues of historic sites are less robust than the bones of modern domestic pigs, the latter of which reflect the large bone structure that has resulted from breeding for increasingly meatier livestock.

The Proctor Cave specimen differed from *P. compressus* in the following ways:

- Viewing the bone either medially (Figure 12-31) or laterally, one can see that the caudate curvature of the proximal end and the cranial curvature of the distal end are more marked than in *Platygonus*.

***FIGURE 12-31. Left, Proctor Cave specimen; middle and right, Welsh Cave* Platygonus.**

- The nutrient foramen is located almost on the epicondyloid crest, distal to the midpoint of the shaft length as in *Sus*, rather than being located on the middle of the shaft typical in the Welsh Cave *Platygonus* (Figure 12-32).

***FIGURE 12-32. Left, Proctor Cave specimen; middle and right, Welsh Cave* Platygonus.**

- As shown in Figure 12-33, head morphology is quite different, the proximal area surrounded by the greater tubercle is more open in *Sus*, but is constricted in the Welsh Cave *Platygonus*.

***FIGURE 12-33. Left is Proctor Cave* Sus *specimen; middle and right are Welsh Cave* Platygonus.**

- When viewed lateroposteriorly and posteriorly (Figure 12-34), the lateral tuberosity is larger in *Sus* than in *Platygonus*, but the cranial portion of the greater tubercle is less bulbous than in *Platygonus*; this difference in the greater tubercle can also be seen in the previous Figure 12-33 (it is apparent even though the Proctor Cave specimen is broken).

FIGURE 12-34. In both photographs, Proctor Cave specimen on left and Welsh Cave **Platygonus on** ***right.***

- The deltoid tuberosity is small, as in *Sus*, and not flared as in *Platygonus;* in some immature *Platygonus* this feature is less pronounced, but still present; this feature is visible on the *Platygonus* specimen in Figures 12-34 and 12-35.

FIGURE 12-35. Proctor Cave specimen, left; Welsh Cave **Platygonus,** ***right.***

Item CM 38363 -- is the distal half of a right humerus partially coated with flowstone, which Wilson and party collected in October 1979 from a dry passage at Z 22. It is from a different individual than CM 38362, as it is a bit larger (Wilson originally identified both specimens CM 38362, discussed above, and CM38363 as *Platygonus compressus*). Also, CM38363 was erroneously miscataloged as *Bos taurus* in the Carnegie database (it may have been confused with specimen CM38364, a *Bos Taurus* humerus that was mis-catalogued in their database as *Platygonus*). However, I would reassign the distal humerus, CM38363, to cf. *Platygonus* sp. My tentative identification is based on the specimen's lack of definitive osteological characteristics (the calcium carbonate is obscuring), and on its similarity to humeri of both *Platygonus* and *Sus scrofa*, (see Figure 12-36).

FIGURE 12-36. Above, from left to right are CM 38363 from Proctor Cave and two* Platygonus compressus *from Welsh Cave. Photograph to right shows two Proctor Cave humeri, CM 38362 (*Sus scrofa*) on left and CM 38363 on right. CM 38363 has been reassigned to cf.* Platygonus *sp.

CM 38369 – is catalogued as a tibia of Leporidae, collected September 1979 from the wall about 4.5 ft above the stream passage in the vicinity of Y 76. I have refined this identification in noting that it is a right tibia of cf. *Sylvilagus floridanus*

CM 38558 – During previous trips, CRF parties found large mammal fossils in the breakdown pile at the end of Frost Avenue. A large fragment of bone collected in 1979 was labeled as a proboscidean "metapodial?" (CM 38368) shown in Figure 12-37. The "metapodial?" fragment is actually a piece of transverse process from a proboscidean vertebra.

FIGURE 12-37. Carnegie Museum specimen CM 38368 originally identified as "metapodial ?"

The next year, 1980, fragments of large mammal postcranial material and a piece of proboscidean tusk (all catalogued as CM 38558) were recovered (Figure 12-38).

FIGURE 12-38. Collection of fossils from Frost Avenue terminal breakdown, all are catalogued as CM 38558.

Among the group of fossils with catalogue number CM 38558, is a sizable piece of proboscidean tusk (Figure 12-39). Because a tusk fragment collected in 2001 from the same provenience has been positively identified as *Mammut americanum* (as discussed earlier in this report), it is likely that the 1980 tusk fragment is also mastodon. In addition, I would identify the vertebral fragment and the rest of the postcranial elements originally identified as proboscidean to mastodon (cf. *M. americanum*).

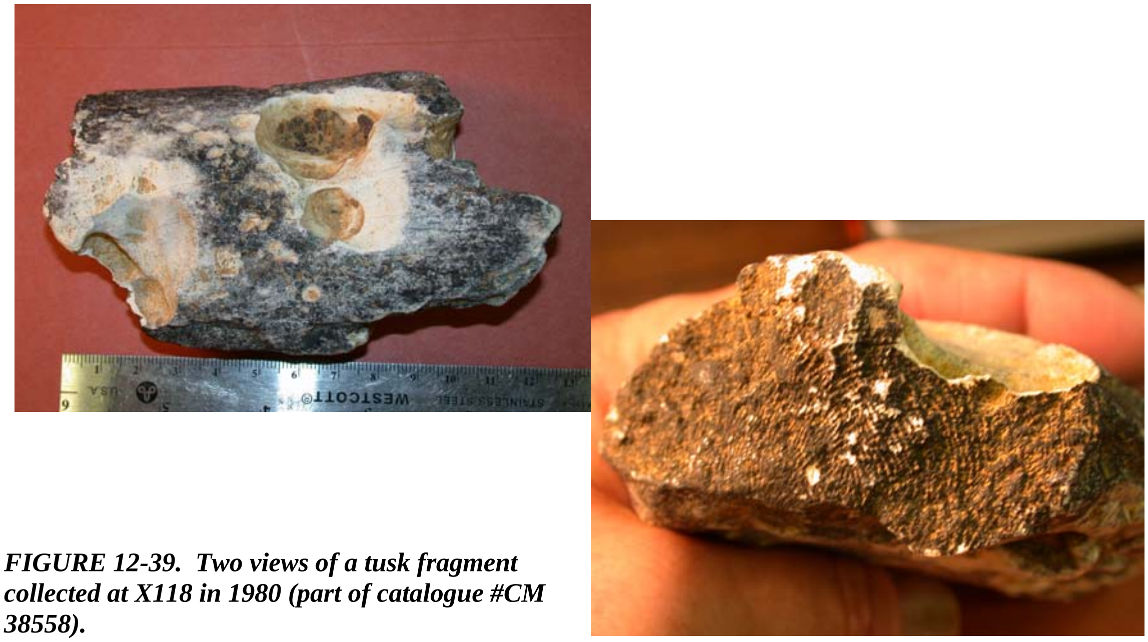

FIGURE 12-39. Two views of a tusk fragment collected at X118 in 1980 (part of catalogue #CM 38558).

CONCLUSIONS AND RECOMMENDATIONS

In 2001 the Paleontological Inventory Project revisited the fossil-producing areas of Proctor Cave first discovered by Ron Wilson and various CRF crewmembers in the late 1970s. It was found that the terminal breakdown and the lower stream channel continue to yield significant Pleistocene materials. Wilson collected bones of proboscidean from the breakdown. The Paleo Project also collected remains of proboscidean from this locality. However, the more important outcome is that the Illinois State Museum submitted tusk fragments to Dan Fisher who determined that they represent the American mastodon, *Mammut americanum*.

From the lower stream channel, Wilson also collected bones of the Pleistocene mammals *Arctodus simus* and *Platygonus compressus.* The Paleo Project revisit found no more bone from giant short-faced bear, but it did recover additional bones of Pleistocene fauna. The most significant discovery was that of a non-glamorous skeletal element – the fibula – that has been identified as having belonged to one of the most exciting of Pleistocene animals – the saber-toothed cat, *Smilodon*. The species is as yet undetermined; but, because the specimen is small, there is a possibility that is *S. gracilis*. A femur shaft was tentatively assigned to cf. *Platygonus*. Bones of *Lynx rufus* and *Procyon lotor* may prove to be Pleistocene in age.

Pleistocene faunal remains make Proctor Cave one of the most significant paleontological sections of the Mammoth Cave system. Because visitation to the fossil producing areas is limited, they are safe from human disturbance. This report demonstrates that the discovery of additional fossils and new taxa with each new visit makes Proctor Cave one of the most promising candidates for additional work. An intensive look at the terminal breakdown will probably produce more proboscidean bone; and it may produce additional taxa. Future work should include selecting and radiocarbon dating of bones identified by this project. In addition, Dr. Dan Fisher and I have been discussing performing isotopic analysis on the dentin of the Mastodon tusk. If a date can be obtained from the Proctor Cave *Smilodon* fossil, it will be interesting to see how the age compares to the 9,500 years BP date obtained by Guilday (1977) from the specimen found at the First American Bank Site in Tennessee.

In addition, the Paleo Project has determined that the area of Frost Avenue between survey stations X 56 to X 61 was a gray bat roost. Bones of *Martes americana*; perhaps dating to the Pleistocene, were also found in the roost area. The area of the roost was utilized at an unknown time in the past, and access was likely gained through a now defunct entrance. Radiocarbon dates need to be obtained from this area.

Also of interest is determining the location of 1) the sink that coincides with the Frost Avenue terminal breakdown, and 2) the surface areas that may be contributing fossils found in the Y-survey streambed. The expressions of these cave features above ground should be investigated.

The story of Proctor Cave vividly demonstrates that the paleontological history of the Mammoth Cave system is a mystery for which clues unfold with each successive investigation. It highlights the fact that there are fossils to be found, even in places previously inspected, and it shows that a concerted effort by trained eyes will be the most likely way to locate additional paleontological resources.

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CHAPTER 13
Paleontological investigations of several pits and small caves in Mammoth Cave National Park

INTRODUCTION

Another goal of the Paleontological Inventory Project was to investigate small caves in Mammoth Cave National Park that were thought to have high potential for housing old bat roosts or fossils of non-bat taxa. Except for caves undergoing surveying and mapping, the so-called "lesser caves" (i.e., anything smaller than Mammoth Cave, itself) are explored infrequently. In the past, explorers in the lesser caves usually did not note old bat roosts – an exception was Claude Hibbard, who, in the 1930s, made observations regarding live bats inhabiting various caves of the Park. In an effort to learn if, and to what extent, bats utilized certain smaller caves, the Paleontological Inventory Project conducted small-scale inventories in 12 pits and small caves: Box Turtle, Dossey Domes, Florentine, Fort's Funnel and a nearby sink, Haunted, Furlong #1, Little Jordan, Owl, Sturgeon, a pit in Wondering Woods, Palmer Cave (a.k.a. White Cave Trail Cave), and White Cave.

Box Turtle Cave

Colburn, Toomey, and Olson investigated Box Turtle Cave in May 2000. The cave, located in a hillside, is aptly named because the carapaces and or limb bones of three or four different individuals were encountered. Three were within the first 20 feet of the entrance and another was in the low crawlway beyond. All were from *Terrapene carolina*, the eastern box turtle. Also found were raccoon (*Procyon lotor*) limb elements and a dentary near the entrance, and two mouse carcasses in the crawl. Most likely the remains are recent as two of the turtle carapaces had dermal scutes, and the mice still had tissue. The entire cave seems to consist of low clearance tube.

Dossey Domes

Dossey Domes is located across the Green River from Mammoth Cave. In the 19th century, Dossey used to be a tourist cave, which was reached by taking a ferry ride across the river. The Paleontological Inventory Project had a more difficult trip, because visiting Dossey Domes required an hour-long trek across a thicket-covered hillside in tick season. Dossey Domes was examined on a CRF trip. Collapsed remnants of the old tourist boardwalk are visible in the wet pit/dome just inside the lower entrance where no vertebrate remains were found. However, passages accessible via the upper pit entrance were not visited.

Florentine Cave

Florentine Cave was investigated in February 1997 on a CRF trip that included Toomey, Colburn, and Scott House. It is another of the caves located on the north side of the Green River. Its entrance is in the bank of Ugly Creek (Figure 13-1). Florentine turned out to be a short, muddy, and wet passage. The investigator who drew the figurative short straw, Toomey, emerged a muddy mess. No bones were found.

FIGURE 13-1. Toomey outside Florentine Cave.

Fort's Funnel Cave

Olson, Toomey, and Colburn inspected Fort's Funnel in May 2000. The entrance to Fort's Funnel is a large, muddy, leaf and stick covered talus cone (Figure 13-2). Within the cave there is an upper level room and a lower level stream passage. We located several recent bones on the talus slope: an *Acris* sp. skeleton, a *Terrapene* carapace, a mole sternum and tibia, and assorted wing bones of bat.

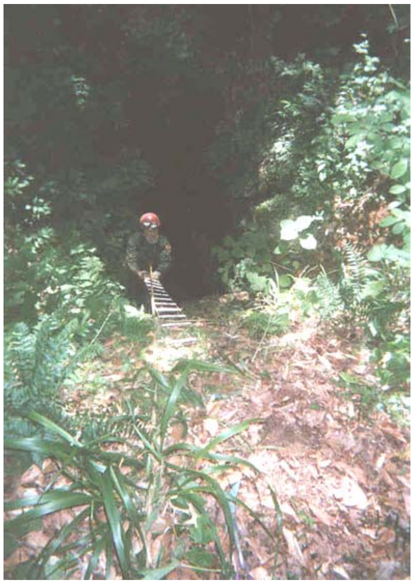


FIGURE 13-2. Olson descending entrance slope into Fort's Funnel.

Assorted large-sized moth wings were present in several places in the upper level room. Bats have roosted in the upper level for some time, although none was present at the time of our visit. On the ceiling is a 2.5 by 1 foot area of bat staining; and, below is a pile of bat guano measuring about 3 feet in diameter with a maximum accumulation of 5 inches (Figures 13-3 and 13-4). No active invertebrate life was visible on the pile. In fact, it appeared that the area had been flooded since the bats last usage because deteriorated leaves were lying on top of the guano. No identifiable bones were found inside the cave.

Extensive mud banks bordered the lower level stream (Figure 13-5). An intensive search produced no fossils. Bat staining is evident on several ceiling areas in the lower level. One of the areas was occupied by about 15 alert, pink-nosed individuals that we identified as *Myotis sodalis*.

FIGURE 13-3. Bat staining on ceiling in Fort's Funnel.

FIGURE 13-4. Pile of guano below the ceiling stain.

FIGURE 13-5. Olson examining the stream located in the lower level of Fort's Funnel.

Small Cave near Fort's Funnel

An examination of a cave situated only a few hundred feet from Fort's Funnel revealed a large sink with a small cave created by undercutting of the limestone bluff. No remains were found.

FIGURE 13-6. Olson and Colburn outside entrance of cave near Fort's Funnel.

Haunted Cave

Like nearby Bat Cave, Haunted Cave is situated in the limestone bluff about 90 feet above the Green River. It is a migrating shaft with an entrance that presents as a narrow vertical fissure in the limestone (Figure 13-7). Inside, the floor slopes upward toward the terminus (Figure 13-8). In 1997, a CRF crew that included Toomey examined a cave that contained human bones and gave it the tentative name, "Vultures Delight;" two days later it was re-examined by a crew comprised of Toomey and NPS personnel Bob Ward, the Cultural Resource Specialist, and Ken Kern, Park Ranger (Toomey 1997). As it turned out, the discovery of human bones was not a new find and the cave was better known by its previous name, "Haunted Cave," likely given for the human bones long known to be in it.

FIGURE 13-7. Entrance to Haunted Cave.

In 1935, Hibbard wrote that it was apparent that Native Americans either had resided in the cave or had used it as a burial place (hence, the human bone in the cave). In the 1990s, Valerie Haskins, then an archaeologist at Western Kentucky University, examined the bones and concluded that they were prehistoric Native American. Haunted appears on a 1940 list of caves whose entrances were blasted (Anonymous 1940). In February 1998, the Paleo Project again visited Haunted with Traci Whethington, who conducted a winter bat count. The cave did not appear to have been blasted shut.

FIGURE 13-8. Whethington standing inside Haunted Cave.

Haunted is well-known for housing a small colony of *Corynorhinus rafinesquii*, Rafinesque's big-eared bat (Figure 13-9), also known by the common names of "rabbit-eared" or " mule-eared" bats. However, in 1935, Hibbard commented, "Haunted Cave is too small and not suitable for bats" (diary entry for 19 June). Earlier, though, circa 1929 (or before), a local resident told Leonard Giovannoli about "*mule-eared bats* found living in a cave farther down river" (Bailey 1933:446).

FIGURE 13-9. Small colony of big-eared bats and inset showing one individual.

Bailey thought that he was referring to Bat Cave. Because Bailey knew of only one colony of big-eared bats near Mammoth Cave, it was more likely that the mule-eared bats were a colony in Haunted, located just down river from Bat Cave. In February of 1971 Keefer (1971) observed only six hibernating Rafinesque's big-eared bats, but surmised that the summer maternity colony was large based on the accumulated guano. In 1998, the Paleo Project saw about 20 individuals.

The surface and upper sediments on the sloping floor of the cave contain bones from *Bufo* sp., a colubrid snake, a small bird, *Didelphis virginiana*, *Neotoma floridana*, *Microtus* sp. (possibly meadow vole), and *Odocoileus virginianus*. At the back of the cave is a large woodrat nest (Figure 13-10). Interestingly, in 1935, Hibbard noticed the same types of bones (bird, mammal, frog, reptile, deer, human) and the presence of woodrat nests (with 2 live, but sleeping inhabitants) in the back of the cave. He decided that the rats had transported many of the small-sized bones. Also, he surmised, "Probably bones of new extinct forms in the park may be found in this cave" (19 June 1935). His prediction has yet to come true for Haunted Cave.

FIGURE 13-10. Woodrat nest at back end of Haunted Cave.

<u>Furlong #1</u>

Furlong # 1 (Figure 13-11), located south of Jim Lee Ridge was another of the pit caves investigated by Olson, Toomey, and Colburn in May 2000. It yielded no bones.

FIGURE 13-11. Furlong #1, a pit south of Jim Lee Ridge.

Little Jordan (Cave #316)

A CRF crew of Toomey, Gary Resch, and Colburn went to Little Jordan Cave in July 2000 (Figure 13-12). Little Jordan presents as a small fissure in the ground that bells open below. Unfortunately, the opening was too tight a fit for two party members (one had to be pulled out). A further attempt to descend was not made due to lack of gear and personnel to help in case of trouble. Little Jordan still needs to be examined for faunal remains.

FIGURE 13-12. Small hole that is the entrance to Little Jordan.

Sturgeon Cave (Cave #81) and Owl Cave

Colburn and Toomey examined Sturgeon Cave on two different CRF trips, in February 1997 (with Mike Yocum and Scott House) and in July 2000 (with Sue Hagan and Gary Resch). Sturgeon (Figure 13-13) and nearby Owl are located in a hillside on the north side of the Green River. Owl Cave yielded no faunal remains. Beyond Sturgeon's gated entrance is a short, man-made stoop-walking passage that ends at an artificial hole in the ceiling (Figure 13-14 inset). Popping up through the hole brings one into a highly decorated, travertine-floored cross passage.

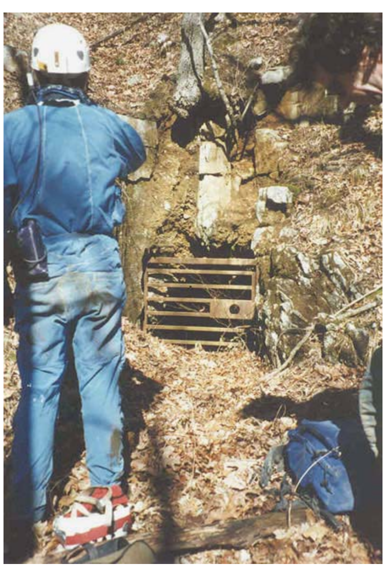
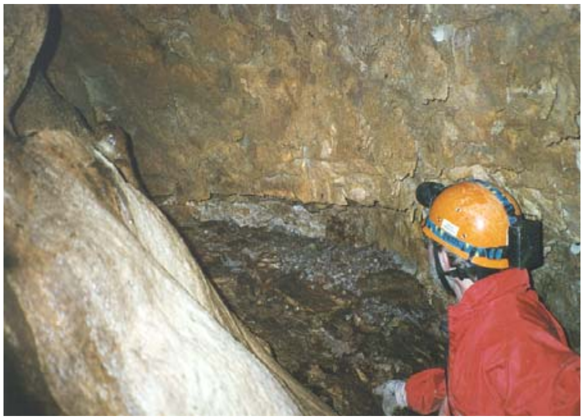


FIGURE 13-13. Mike Yocum at entrance to Sturgeon Cave. Inset shows man-made hole in ceiling that leads to a travertine-coated cross passage.



A large active woodrat nest with moldy rat feces, leaf litter, nutshells, and other plant debris was at the western terminus of the left hand branch (Figure 13-14). No fossils were located in the nest.

FIGURE 13-14. Scott House and the woodrat nest located at western end of Sturgeon Cave.

Sample 1, a skeleton an adult *Corynorhinus* cf. *rafinesquii* with a bit of tissue still adhering was found on the floor of the left branch. Selected elements (major limb bones, several finger bones, scapulae, ribs, pelvis) were collected and measured at the Illinois State Museum Research and Collections Center (Figure 13-15). Postcranial measurements are as follows: left radius=41.8 mm, right radius=41.8 mm, left humerus=24.6 mm, right humerus=24.6 mm, both femora =16.9 mm and 16.7 mm, and tibia=20.9 mm. The right dentary=10.2 mm and the skull has a pronounced sagittal crest, GLS=16.1 mm, CBL=14.9 mm, IM3=5.3 mm, M3s=5.5 mm, IOB=3.7 mm, BB=na, OD=6.7 mm.

***FIGURE 13-15. Sample 1, bones of* Corynorhinus *cf.* rafinesquii.**

In the branch to the right of the man-made hole, we encountered about 30 roosting and flying *C.* cf. *rafinesquii* and much guano on the floor. Bones of another individual (sample 2) were collected from the right hand branch (Figure 13-16). Sample #2 is the skeleton of a full-sized subadult big-eared bat.

FIGURE 13-16. Sample 2, bones of another* Corynorhinus *cf.* rafinesquii*.

The humeri are fully fused. However, distal epiphyses of the tibiae and some metacarpals are unfused and missing; and, those of the radii, a femur, and a metacarpal are attached but still unfused. Figure 13-17 shows the unfused metacarpals.

FIGURE 13-17. Unfused ends of wing elements from Sample #2.

The left and right radii measure 41.3 mm, the femur, 17.0 mm, left humerus, 24.5 mm, and the right humerus, 24.6 mm. The shaft of a tibia *without* its unfused epiphysis is 19.1 mm long. The skull of sample #2 possesses a slight sagittal crest and the teeth are sharp with very pointy tips. Other skull measurements GLS = 16.5 mm, CBL = na, IM3 = 6.0 mm, M3s = 6.3 mm, IOB = 3.6 mm, BB = na, OD = 6.3 mm.

At the northern end of the right hand branch of Sturgeon is a 40-foot pit (Figure 13-18). The pit is about 15 feet wide and 35 feet long. Bones of frogs, bats, woodrat, and deer mouse (*Peromyscus* sp.), and a tooth of eastern cottontail rabbit (*Sylvilagus floridanus*) were found on the floor of the pit. They are probably recent in age.

FIGURE 13-18. Pit at north end of Sturgeon Cave.

Pit in Wondering Woods

Toomey and Colburn rappelled into a pit in Wondering Woods with Tres Seymour and Rick Olson (Figure 13-19) to look for bones. A variety of animal remains were found. In the limestone rubble at the bottom of the entrance shaft are remains of *Bufo* sp., other toads or frogs, the whole skeleton of a gray squirrel (*Sciurus carolinensis*), P*eromyscus* sp., and parts of at least two horses (Figure 13-20).

FIGURE 13-19. Olson at entrance to Pit in Wondering Woods.

FIGURE 13-20. Horse bones at the bottom of the entrance pit.

In a passage off the bottom of the shaft, we found bones of frog/toad, passerine (scapula), pipistrelle (mandible), unidentifiable bat (finger bones), *Odocoileus virginianus* (thoracic vertebra), horse (tooth), *Sylvilagus floridanus* (part of a skull and foot bone), *Peromyscus* sp. (dentaries), *Reithrodontomys* sp. (dentary). In a passage about 10 feet up from the shaft bottom, are bones of *Acris* sp., ground squirrel, *Peromyscus* sp., and a woodrat accumulation.

The partial skull of a shrew was collected and later identified at the Illinois State Museum by Colburn. The skull consisted of the rostrum and cranial vault. The braincase is broken and brittle, molars are present, unicuspids are missing, and calcite encrustations are present on the palate next to teeth (Figure 13-21). It has been identified as *Sorex fumeus* (smoky shrew) based on direct comparison with modern specimens. The condylobasal length is approximately 17 mm. A skull with mandible of *S. fumeus* were also collected from Proctor Cave (see this report).

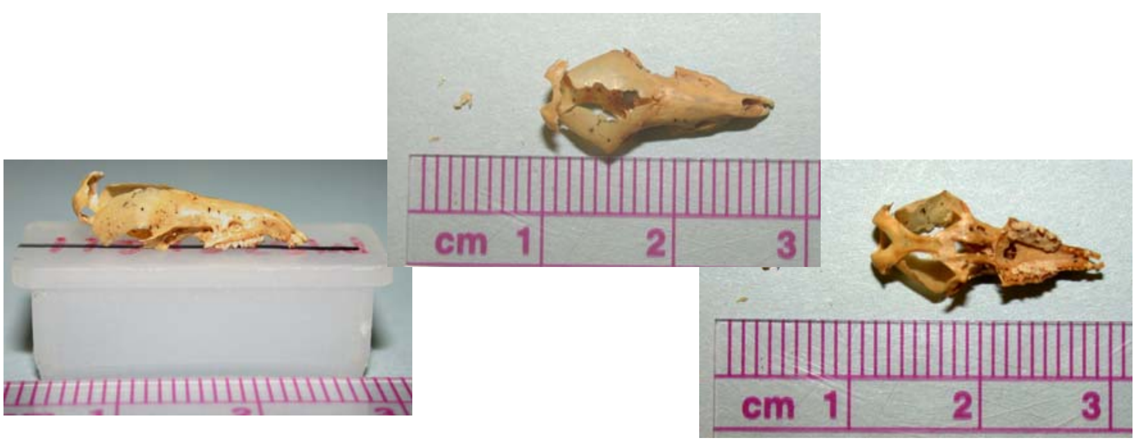


FIGURE 13-21. Three views of the Sorex fumeus skull found in a pit in Wondering Woods.

In 1974, Barbour and Davis (1974:35) considered *S. fumeus* “scarce and irregular” in Kentucky due to its moisture requirements. A decade later, Owen (1984) reported that the species was expanding westward from the center of its distribution in the Appalachian Mountains. Mammoth Cave National Park has many areas of suitable habitat with adequate moisture and cover (fallen trees, rocks, brush, swampy grassland, protected stream). In the 1930s, Bailey and Giovannoli reported smoky shrews as being common at Mammoth Cave's old historic entrance, and captured several specimens in the vestibule (Bailey 1933:440). Hibbard (1935) trapped a smoky shrew outside the cave at River Styx.

Palmer Cave (a.k.a. White Cave Trail Cave)

A quick examination of this large entranced cave produced no remains.

White Cave

Hovey (1912) reported that bones of a giant ground sloth were collected from White Cave (Figure 13-22). According to Ron Wilson, Hovey’s statement was erroneous; the sloth bones were actually recovered (perhaps in the 1830s) from Big Bone Cave in Tennessee. Toomey and Olson saw human bones in White Cave and halted their examination.

FIGURE 13-22. Entrance to White Cave.

CONCLUSIONS

Several pits and miscellaneous small caves were visited during the course of the Paleontological Inventory Project. They were examined for evidence of old bat roosts and carnivore den activity. No old roosts were noted. Fort’s Funnel, Haunted, and Sturgeon had current summer bat usage; winter use in these is unknown. Pits were investigated because they are often natural traps for passing animals. The pit in Wondering Woods had bones of two horses from historic times. No faunal remains attributable to Pleistocene times were found; it is possible that the sinks were not open at that time.

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