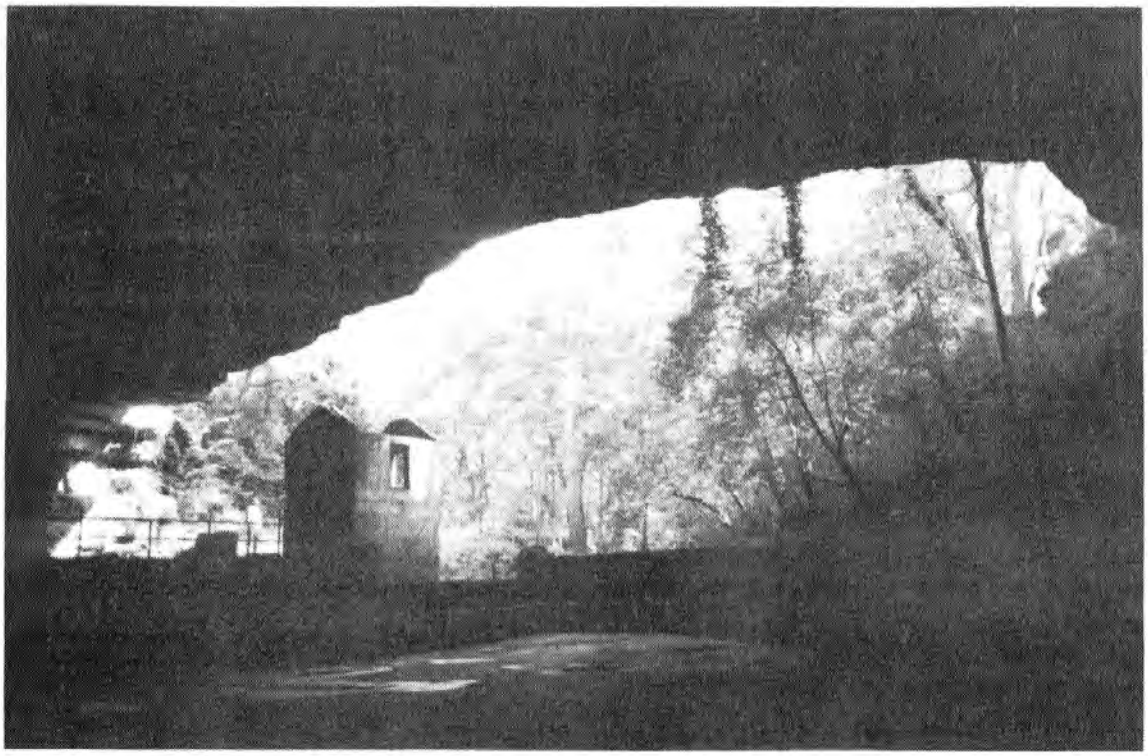

Geomorphology and Environmental Problems of the Central Kentucky Karst

Annual Field Conference of the
Geological Society of Kentucky
October 14-15, 1994

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Field Trip Leaders

Dr. Nicholas C. Crawford is a Professor in the Department of Geography and Geology and Director of the Center for Cave and Karst Studies at Western Kentucky University. He has written more than 140 technical reports and articles primarily dealing with the contamination of groundwater in carbonate aquifers. The recipient of 25 grants for hydrologic research on environmental problems of karst regions, he was awarded Western's highest award for Outstanding Achievement in Research in 1985. As a consultant specializing in carbonate aquifers for the past 16 years, Dr. Crawford has performed over 500 dye traces and has worked on numerous groundwater contamination problems for private firms and for federal, state, and local government agencies. This year he was honored as the recipient of the National Speleological Society's Honorary Membership Award, the society's highest honor.

Dr. Christopher G. Groves is an Assistant Professor in the Department of Geography and Geology at Western Kentucky University. He received his Ph.D. in Environmental Science from the University of Virginia where he developed computer simulation models leading to a better understanding of the earliest stages of karst development. Other current research interests include application of theoretical and empirical dissolution kinetics models to problems of landscape evolution, as well as the field testing of these models. Dr. Groves has been actively involved in karst research for the past twelve years. He has been exploring and surveying caves for the past twenty years, especially the large cave systems of the Mammoth Cave Plateau.

Dr. Kenneth W. Kuehn is a Professor of Geology at Western Kentucky University where he has been employed since 1984. He earned his Ph.D. from Penn State University in 1981 specializing in regional stratigraphy, fossil fuels, and geostatistics. Over the past 13 years, he has consulted widely for the fossil fuels industries. His present research interests include exploration and development of petroleum in carbonate reservoirs, and the more efficient utilization of Kentucky's coal resources. Active in research and publication, Dr. Kuehn endeavors to integrate classroom, laboratory and field experiences. In 1990, he was honored as the outstanding teacher in Western's Ogden College of Science, Technology, and Health.

Mr. Joe Meiman is the Hydrologist at Mammoth Cave National Park. He earned his B.S.(1985) and his M.S.(1989) degrees in geology from Eastern Kentucky University. He is an adjunct faculty member in the Department of Geography and Geology at Western Kentucky University. Joe is kept busy by directing hydrologic research at the Park which includes: water quality monitoring, dye-tracing, three-dimensional schematic karst aquifer modeling, and development of new techniques and equipment for water monitoring.

Acknowledgements

The authors wish to express their heartfelt thanks to all those who contributed their efforts, either directly or indirectly, to the 1994 Annual Field Conference of the Geological Society of Kentucky. We are especially grateful to Art Palmer and Will White who granted us permission to use some of their original materials in this guidebook and we appreciate the assistance from Keith Barnhill, Mary Snow, and Richard Snow who worked on the logistics of the field trip. We also appreciate very much the support of the National Park Service in providing special assistance and access to the resources of Mammoth Cave National Park.

Introduction to the Central Kentucky Karst

Chris Groves

The Central Kentucky Karst is loosely defined by geomorphologists as the area of south-central Kentucky that lies between the Green and Barren Rivers, and it is clearly one of the most well developed karst landscapes on the planet. Besides Mammoth Cave, which at a current surveyed length of 348 miles is the world's longest known cave, several other great cave systems are located here: Fisher Ridge Cave (74+ miles), Hicks Cave (20+ miles), Whigpistle Cave (19+ miles), and James Cave (13+ miles), as well as thousands of shorter ones. On the surface many classic landforms are developed as well, such as sinkhole plains and deep karst valleys.

The Central Kentucky Karst has been subdivided into several different physiographic regions (Figures 1 and 2), including the Pennyroyal Plateau (largely sinkhole plains) and the Mammoth Cave Plateau (sometimes called the Chester Upland), a gently dipping cuesta which rises 150-200 feet above the Pennyroyal surface. The Mammoth Cave Plateau is capped by a series of mixed carbonate and clastic units which protect the underlying limestones from erosion. These two roughly horizontal plateau surfaces are separated by the Dripping Springs (Chester) Escarpment, which defines the northwest boundary of the Pennyroyal in the area we will visit. The non-karstic Glasgow Uplands, where rocks of the lower St. Louis Limestone are exposed at the surface, delimits the southeastern boundary of the Pennyroyal. A fourth unit which controls much of the subsurface landscape development in the region is the 300-foot gorge that the Green River has cut into the Mammoth Cave Plateau, providing the local baselevel. The goal of our field excursion is to explore these areas, in order to understand how these features and their relative positions have combined to form an unparalleled, classic karst landscape, both on the surface and below it.

The landscape owes it's nature, in large part, to the sequence of nearly horizontal, very pure limestones of Mississippian age (Figure 3), which have been divided (in ascending order) into the St. Louis, Ste. Genevieve, and Girkin Formations. Above the Girkin is the Big Clifty Sandstone, also of Mississippian age, which acts as a protective "caprock" for the Mammoth Cave Plateau. On some areas of the plateau Pennsylvanian clastics also occur, along with minor carbonate units. The upper boundary for major karst development, therefore, is the contact between the Girkin Limestone and the Big Clifty Sandstone, and the current lower limit is set by the Green River which, in Mammoth Cave National Park, pools at the middle of the St. Louis Limestone. Some minor cave development also occurs in the Haney Limestone, a 40-foot thick unit above the Big Clifty. Although structure is very gentle in the area, we will see that it has had a significant influence on landscape development. The area lies on the flank between the Cincinnati Arch to the east and the Illinois Basin to the northwest; regional dips are generally a few degrees or less to the northwest. Local flexures also occur, and have been shown (Palmer and Palmer, 1993) to influence the detailed development of groundwater flow in some areas of Mammoth Cave. The cuesta form of the Mammoth Cave Plateau results from the steep southeast-facing

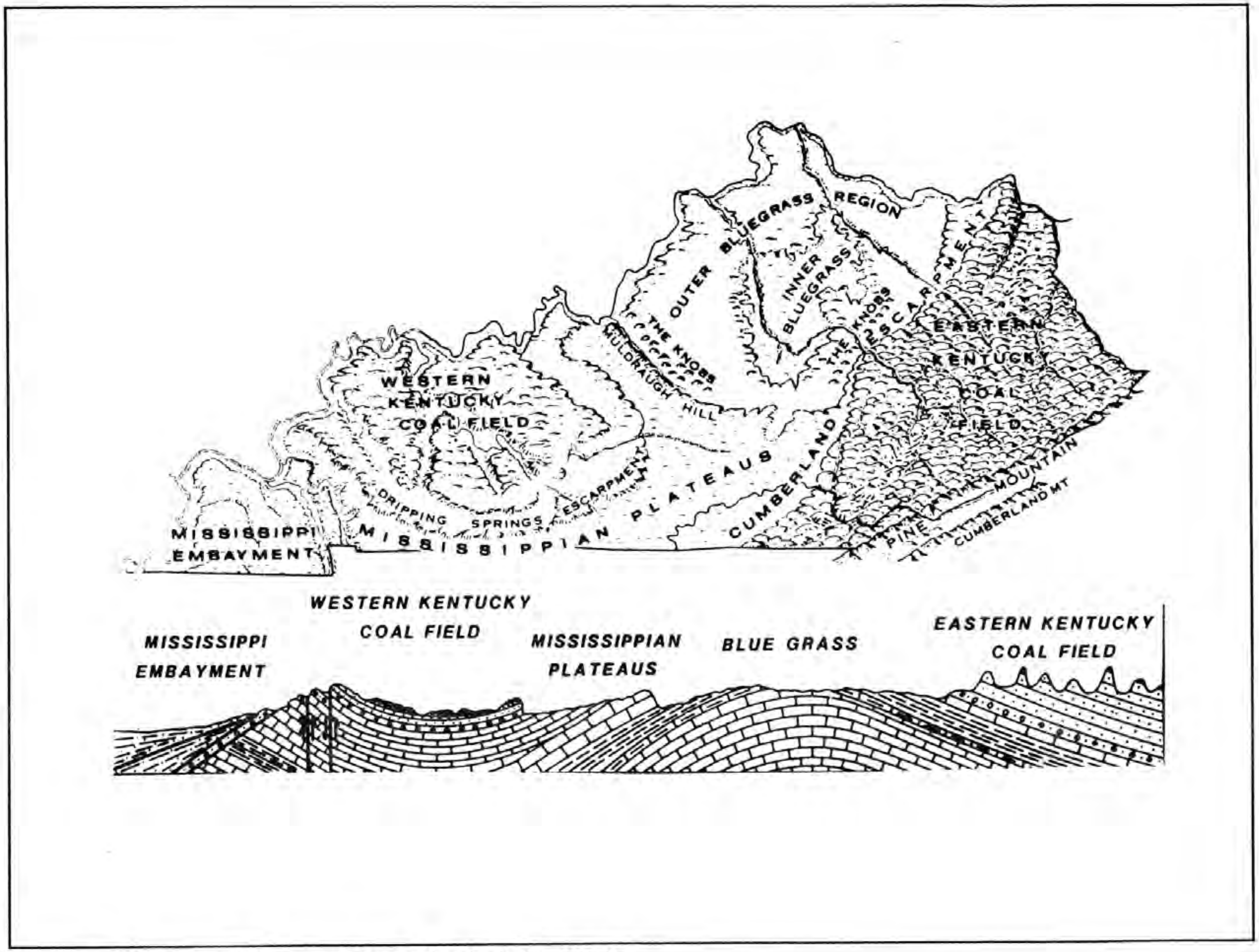


Figure 1. Physiographic map of Kentucky (Lobeck, 1932).

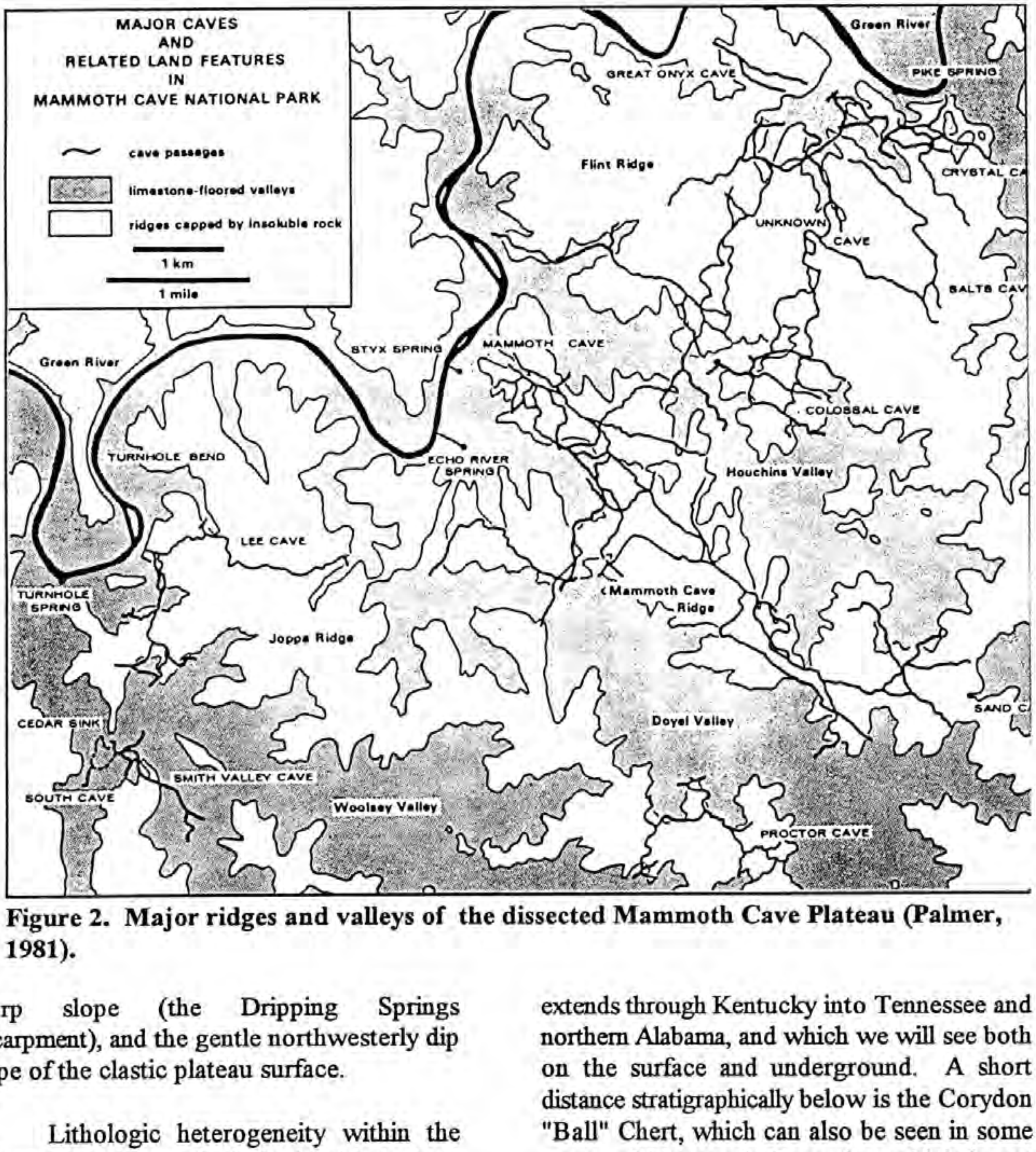


Figure 2. Major ridges and valleys of the dissected Mammoth Cave Plateau (Palmer, 1981).

scarp slope (the Dripping Springs Escarpment), and the gentle northwesterly dip slope of the clastic plateau surface.

Lithologic heterogeneity within the carbonate rocks, particularly the thin bedded cherts which occur near the contact between the Ste. Genevieve and St. Louis Limestones (Howard, 1968; Woodson, 1981), have some influence on cave and landscape development. The most prominent of these is the Lost River Chert, a discontinuously bedded chert that extends through Kentucky into Tennessee and northern Alabama, and which we will see both on the surface and underground. A short distance stratigraphically below is the Corydon "Ball" Chert, which can also be seen in some areas of Mammoth Cave, but which is not exposed at the surface in the area that we will be visiting. The location of the contact between the Ste. Genevieve and St. Louis Limestones has been identified by some workers based on the position of the Lost River Chert, but this is depending on whose

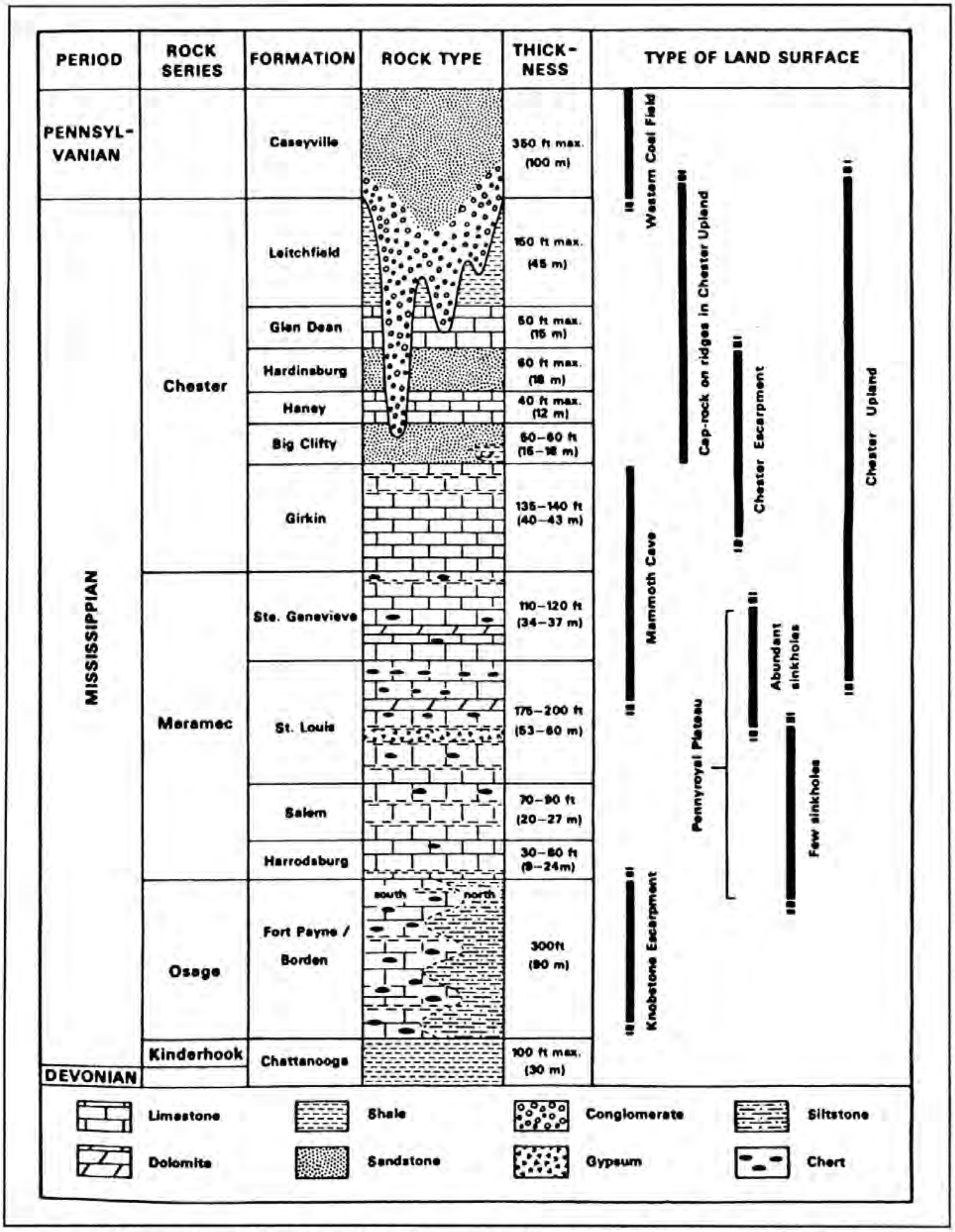


Figure 3. Generalized stratigraphic column for the rocks of the Central Kentucky Karst (Palmer, 1981).

stratigraphic section is consulted. On this field trip we will use the section of Palmer (1981) (Figure 3), which places the chert within the Horse Cave Member of the St. Louis Limestone.

Why is the World's Longest Known Cave Here?

The development of karst landscapes can be said to depend on the existence of four basic elements, and the nature of a particular one can be understood by analysis of the existence of, and interplay between, these elements. What are they and how are they expressed in the Central Kentucky Karst?

1. *Existence of a suitable body of rock.* Although minor karst features can develop in a variety of rock types, including evaporite minerals, quartzite, and granite, clearly carbonate rocks are the primary ones on which these features develop. Due to both its relatively high solubility in carbonic acid, as well as its kinetic behavior, pure limestone is an excellent material for this purpose. Here in the Central Kentucky Karst the St. Louis, Ste. Genevieve, and Girkin Limestones provide an ideal framework for karst development. Although there is some heterogeneity, with minor amounts of dolomite, clay, and other clastic impurities, these units are relatively pure. From about the middle of the St. Louis downwards (generally below baselevel here) the rocks contain more clastic impurities which inhibit dissolution and therefore karst development. The geometry of the rocks also is important: because of the very gentle dips these limestones are exposed over a vast area at the surface, supporting hundreds of miles of cave development within a thickness of only about 300 feet.

2. *Existence of a suitable solvent for dissolution.* Limestones are only slightly soluble in pure water. In solutions of carbonic acid, however, the solubility increases dramatically. The carbon dioxide comes in small part from the atmosphere where CO_2 concentrations are very low, but primarily derives from contact with soil gas where microbial degradation of organic material can drive carbon dioxide pressures to over 100 times atmospheric levels (White, 1988; Atkinson, 1977). Karst development is thus favored in areas of: a) abundant rainfall b) thick soils, and c) relatively warm temperatures supporting both vegetation and microbial communities to enhance soil CO_2. Note that although limestone solubility increases with decreasing temperatures, this is a relatively minor factor and is probably overshadowed by abundant microbial CO_2 production in warmer climates.

South-central Kentucky receives an average of about 50 inches of rain per year, and has an average temperature of 57°F. Within the relatively thick soils of the region measured CO_2 pressures reach 0.1 atmosphere (White, 1988), providing an abundant supply of carbonic acid for limestone dissolution.

3. *Hydrogeologic relations resulting in a sufficient hydraulic gradient.* The nature of the carbonic acid/limestone interaction is such that the time scales over which the solvent typically becomes saturated are on the order of a few days (Rauch and White, 1977; Hess and White, 1988). For this reason if groundwaters cannot move into, through, and out of an incipient carbonate aquifer at a sufficient rate, the waters will so closely reach saturation while still within the rock that karst development will not occur (Groves and

Howard, 1994). In order to provide the energy to move the solvents through the rock sufficiently rapidly, a hydraulic gradient must be available. Many of the world's great karst landscapes form on escarpments or above river valleys where there is an elevation difference that will provide a steep hydraulic gradient.

At Mammoth Cave, the Green River has cut downward into the Mammoth Cave Plateau, carving through the Big Clifty Sandstone caprock, the Girkin and Ste. Genevieve, and the upper St. Louis limestones (Figure 4). A gradient thus exists from the sinkhole plains of the Pennyroyal, through the limestones beneath the plateau surface, and down to the Green River. This has resulted in the establishment of very large subsurface drainage basins which collect water over hundreds of square miles of sinkhole plain and drain to a series of large springs along the Green River (Figure 5). These waters have not only carved the world's longest known cave system, but have also removed many cubic miles of rock from the area that is now the sinkhole plain.

4. *Time*. Although modern geomorphologists tend to shy away from the Davisian concept of clearly defined stages of landscape development, there is without doubt an evolutionary sequence of events here in the Central Kentucky Karst. There was an exact moment some millions of years ago that rainwaters first touched the Girkin Limestone, and there will occur a time in the future when the last cubic foot of that formation will be removed from the region by dissolution. The karst landscape forming process is, as White (1988) puts it, one of decay.

Several lines of evidence independently suggest that the Central Kentucky Karst and Mammoth Cave have been under development for less than ten million years, and that much of the work has taken place in the last few million (Palmer, 1981; White and White, 1989). These include paleomagnetic dating of cave sediments (Schmidt, 1982), radioactive dating of speleothems (Harmon *et al.*, 1978), and consideration of the time scales associated with limestone dissolution kinetics in carbonic acid (Dreybrodt, 1990; Palmer, 1991). We are lucky to be here (if you consider having the world's longest cave in your back yard lucky) at a time when the caprock has been sufficiently dissected to allow water to enter and dissolve the rock at a large number of locations, but when there is still enough caprock to protect large sections of cave-rich limestone.

Hundreds of Miles of Cave Passages

During the millions of years that Mammoth Cave has been forming, the Green River has been downcutting its valley deeper and deeper into the Mammoth Cave Plateau. The rates of this downcutting have been highly variable with relatively stable periods interspersed with rapid downcutting events. Periods of valley infilling have occurred as well. Much of the detail of this history has been worked out by Palmer (1981, 1984) from observations of passage geometry combined with careful stratigraphic leveling surveys through miles of Mammoth Cave.

During the stable periods baselevel remained steady, with the result that a large amount of dissolution occurred at the associated water table elevations. Thus, distinct, well-developed cave levels are present today. We will visit the major levels of the cave during our trip, the lowest being the level

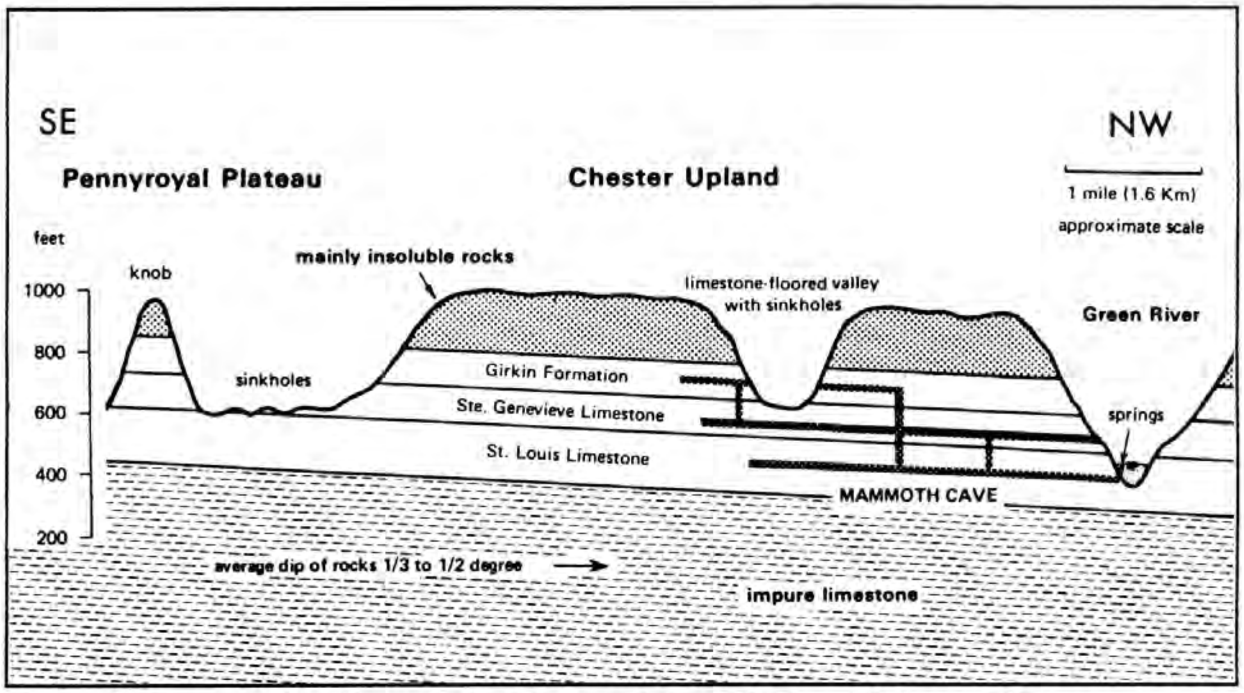


Figure 4. Cross section through the Mammoth Cave Plateau (Palmer, 1981).

of active drainage, where the cave is still enlarging. The various levels are each very extensive, and are well interconnected with vertical shafts as well as a variety of other passages including deep canyons and shaft drains. This vast three-dimensional network extends out over many miles (and, in fact, far beyond the boundaries of the National Park). We will try to get a sense of this arrangement during our trip into the cave.

Much More Information is Available

The purpose of this excursion is to gain an appreciation of the special nature of this world-renowned landscape, as well as a basic understanding of the elements that have fortuitously combined to form it. The area is one of the best studied of the world's karst landscapes, and for those interested in looking more deeply into this topic, several sources are recommended. Art and Peg Palmer have studied the cave system for many years now, and the first reference to consult is Art's excellent book *A Geological Guide to Mammoth Cave National Park* (1981), as well as *Karst Hydrology: Concepts from the Mammoth Cave Region* (1989), edited by Will and Bette White. Fine general books on karst are White's *Geomorphology and Hydrology of Karst Terrains* (1988) and *Karst Geomorphology and Hydrology* (1989) by Derek Ford and Paul Williams. At the end of the guidebook is a general bibliography of sources on karst hydrology and geomorphology, compiled by Will White, that may be of interest.

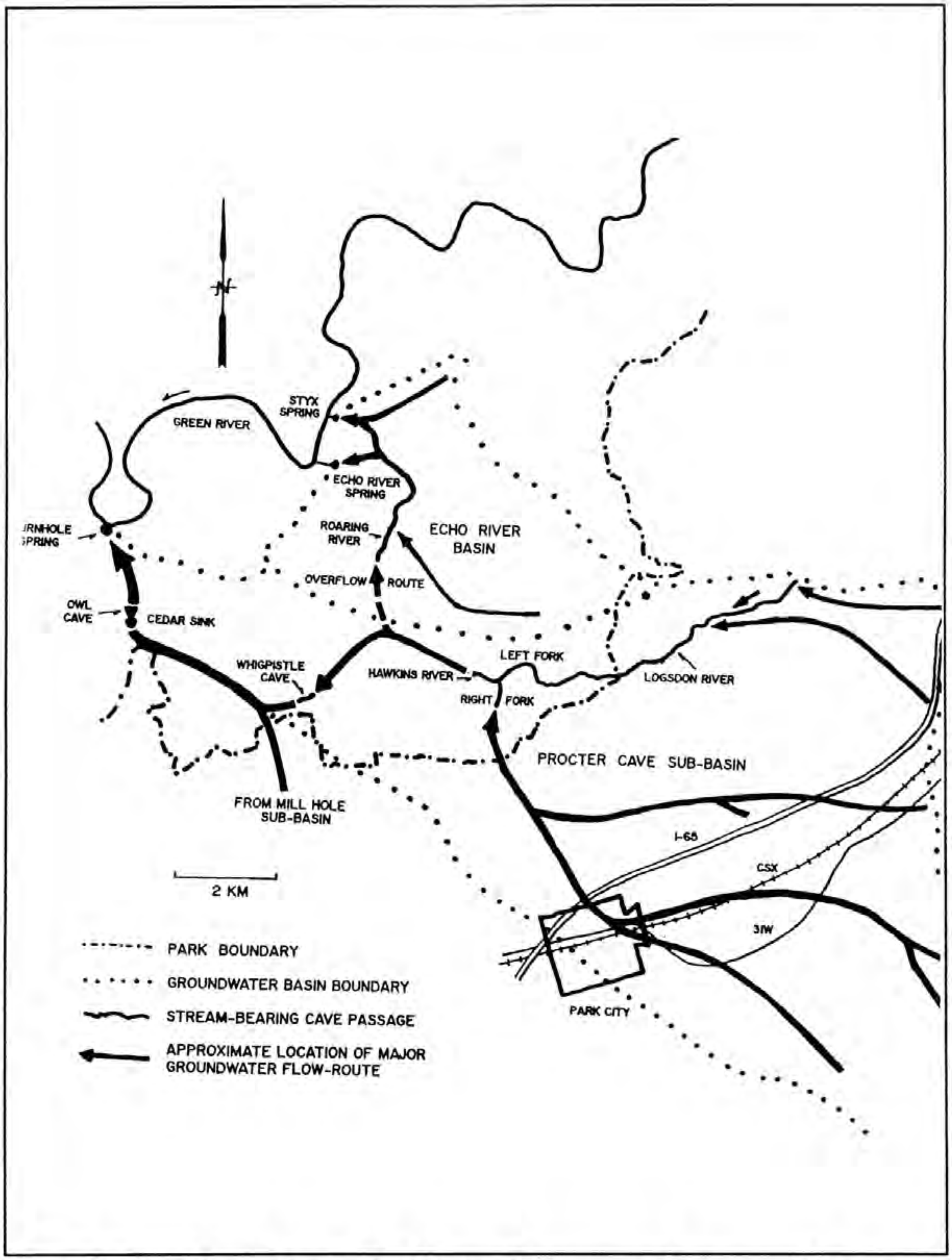


Figure 5. Groundwater flow in the Mammoth Cave area (Meiman and Ryan, 1993).

FIELD TRIP ROAD LOG

Day One

Bowling Green to Mammoth Cave National Park

Kenneth W. Kuehn

Mileage Interval	 Total	Description
0.0	0.0	Turn left from the parking lot of Howard Johnson's Hotel onto US31W-Bypass. Proceed 0.8 miles to a stoplight at the intersection with US31W/US68, KY80. A map of the local roads with today's stops appears as Figure 6 and regional topography is shown in Figure 7.
0.8	0.8	Turn right (north) on to US31W/US68, KY80.
2.3	3.1	Junction KY1402 at stoplight. Continue straight.
0.3	3.4	Access road to Interstate Highway, I-65. Bear left, continuing north on US31W/US68, KY80.
3.0	6.4	Continue straight past stoplight at junction KY526. Note the terra rossa soil exposed by recent excavations on your right (east) side.
0.4	6.8	Junction US68, KY80 goes right (east). Continue straight (north) on US31W.
2.6	9.4	Junction KY743 on left (north). A now continuous view of the Dripping Springs Escarpment begins on that side (Figure 8).
3.8	13.2	Junction KY101 (north) on left. To our right (south) a geomorphic surface known as the Bristow Plain is visible. This area of low relief and very few sinkholes has developed where the Lost River Chert in the upper St. Louis Limestone mantles the surface. In the subsurface, the Lost River Chert is a significant perching layer for groundwater in some areas.
0.7	13.9	Junction KY101 (south) on right. Continue straight on US31W.
0.5	14.4	Warren/Edmonson County Line.
0.6	15.0	**STOP 1. Liberty Hill Church at Dripping Spring, KY**. Pull off onto paved access road on left just as main road, US31W, begins to curve right. From this location, we can look southwest along strike of the Dripping Springs Escarpment which rises approximately 150 to 200 hundred feet above the sinkhole plain. The Girkin Formation is exposed in the slope and the elevated surface is capped by Big Clifty Sandstone and younger units. This stop is stratigraphically below the Lost River Chert, and within the St. Louis Limestone. The large sinkhole has relief of about 50 feet and is used as a stockpond (Figure 9).

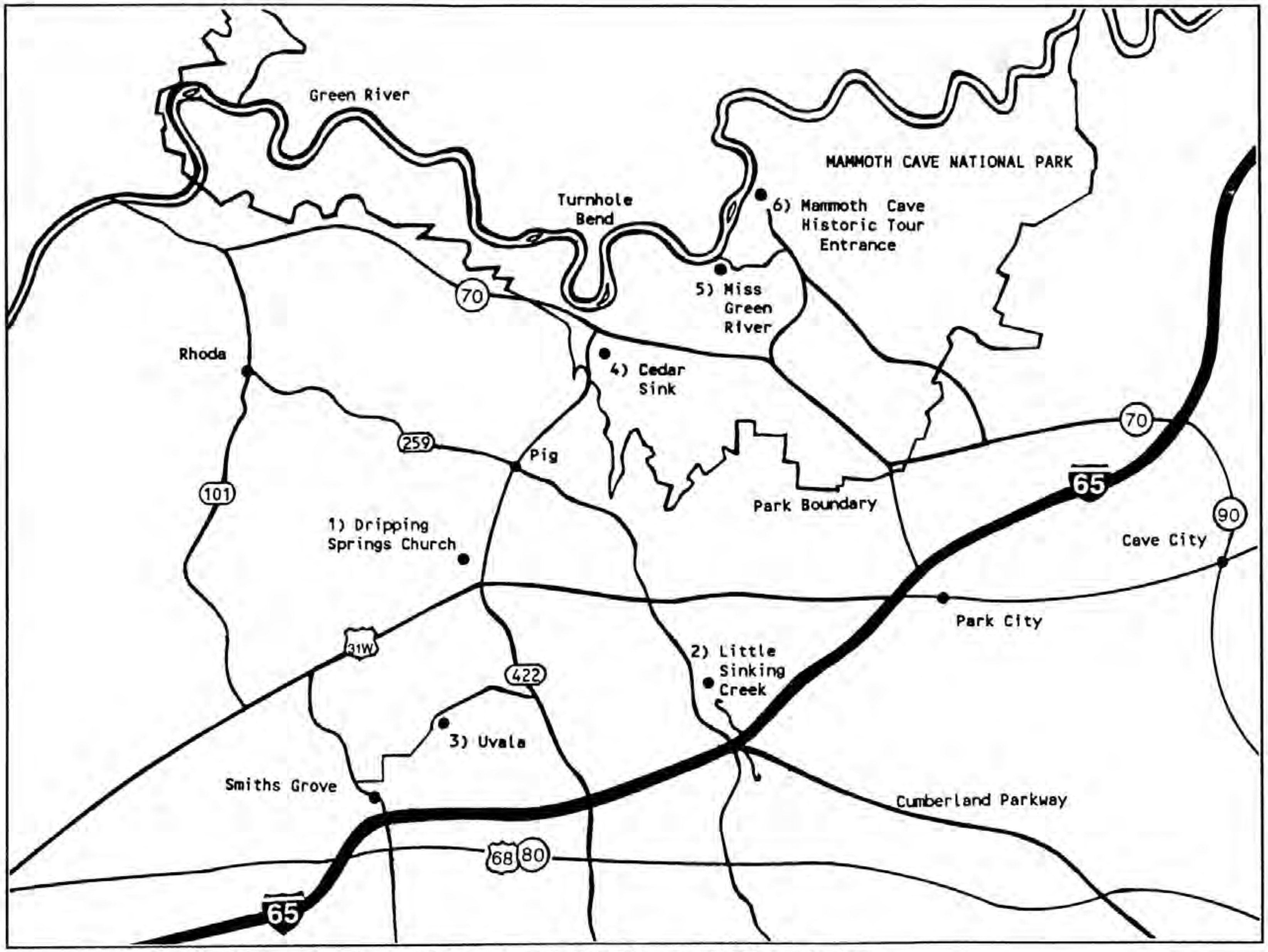


Figure 6. Generalized map showing field trip stops in the Mammoth Cave Region.

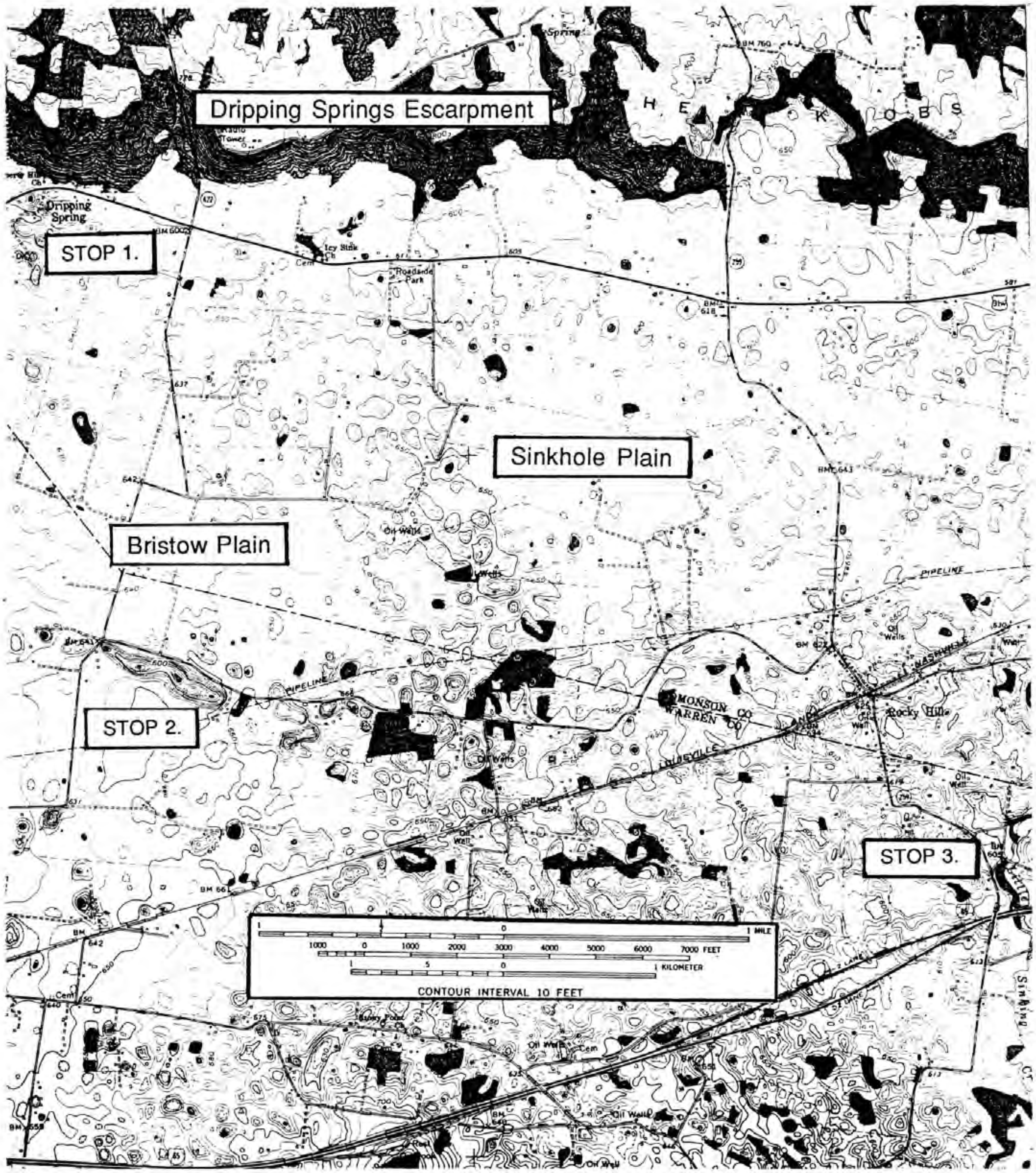


Figure 7. Portion of the Smiths Grove, KY topographic quadrangle map showing some key geomorphic elements of the Mammoth Cave Region

Figure 8. View looking southwest from Stop 1 along the Dripping Springs Escarpment.

Figure 9. Sinkhole pond near Liberty Hill Church at Stop 1.

		Turn left from access road and continue north on US31W.
0.6	15.6	Turn right (south) onto KY422, Upper Smiths Grove Road.
1.0	16.6	Turn right at 'T' junction.
0.8	17.4	**STOP 2. Uvala.** Stop sign at junction with Rocky Hill Road. Turn left (east) and park along shoulder. This will be a brief picture stop. South of the road, trending east-west, is a uvala which extends nearly 2900 feet, and has a maximum relief of more than 90 feet on the east end, and is illustrated in Figure 10. It was formed by coalescing of sinkholes through solution and collapse of the limestone bedrock.
		Continue east along Rocky Hill Road, observing the high density of sinkholes and increased relief of this classic karst terrain developed on the St. Louis Limestone.
3.2	20.6	Turn right (south) onto KY259 at the stop sign. The Rocky Hill Baptist Church on the right denotes this intersection.
0.2	20.8	Cross L&N railroad tracks in Rocky Hill, KY.
0.5	21.3	Sharp left on KY259.
0.1	21.4	Pass sign for Estes Farm.
0.2	21.6	Turn left through gap in guard rail onto single lane paved road.
0.1	21.7	**STOP 3. Little Sinking Creek** (Figure 11). Park where road turns to the right, observe stream channel across fence on the left (north) side of the road. We are now located on the boundary between the sinkhole plain and the Glasgow Upland to the south and east, which has developed on the St. Louis Limestone and older units. These older units are capable of supporting limited surface flow. This stop is significant because the area forms the headwaters for the Turnhole Bend Groundwater Basin in Mammoth Cave National Park. We will have a discussion of the Mammoth Cave Biosphere Reserve and nonpoint-source pollution at this stop.
0.2	21.9	Follow road around to the right, again meeting KY259. Turn right (north) at junction KY259 returning toward Rocky Hill, KY.
1.2	23.1	Junction Rocky Hill Road on left, continue straight (north) on KY259.
1.5	24.6	Stop sign at intersection of KY259 and US31W. Cross US31W, continuing north on KY259. Begin climbing Dripping Springs Escarpment. The Girkin Formation crops out on the hillside to the right (east).
3.3	27.9	Turn right (north) onto KY422. Welcome to Pig, KY! The General Store on the right denotes this intersection. This section of KY422 is also called

Figure 10. View down long axis of uvala near Rocky Hill, KY at Stop 2.

Figure 11. Stop 3. Little Sinking Creek, at the headwaters of the Turnhole Spring Groundwater Basin.

the Park Boundary Road.

1.1 29.0 Mammoth Cave National Park boundary (Figure 12)

29.6 **STOP 4. Cedar Sink.** Pull off into parking area on the right. Cedar Sink itself represents the throat of a much larger closed karst valley of several miles in extent (Figure 13). This valley comprises Cedar Spring Valley, Woolsey Valley, and Smith Valley. In this area the Big Clifty caprock has been breached exposing the Girkin Formation and resulting in a relief between 100-200 feet below the main plateau surface. The bottom of the sink lies another 100 feet below and exposes the top of the Ste. Genevieve Limestone. In this 'karst window' we will observe the same water flowing on the surface that sank more than six miles to the south at our previous stop, Little Sinking Creek. We will hike to the north side of Cedar Sink and enter Owl Cave where we will discuss cave-forming processes. Cedar Sink will be shown to have formed as a result of the collapse of huge cave passages.

Figure 12. Entrance to Mammoth Cave National Park along KY 422.

Return to the parking area via Cedar Sink Trail. Continue north on KY422.

0.5 30.1 Turn right (east) onto KY70 at 'T' junction.

3.2 33.3 Turn left onto the Visitors' Center Access Road, following the signs for 'cave tours'.

2.3 35.6 Turn left (west) onto Mammoth Cave Ferry Road. Follow signs for the ferry and for boat tours. We are descending the Echo River Valley en route to the Green River. The road passes through basal Big Clifty Sandstone, the entire Girkin Formation and into the top of the Ste. Genevieve Limestone.

1.2 36.8 **STOP 5. Green River.** We will enjoy a leisurely lunch while boating on the 'Miss Green River', travelling almost 3.5 miles downstream toward Turnhole Bend. Green River is the region's major baselevel stream. The water that entered the basin at Little Sinking Creek (STOP 3), and we saw again in the Karst window at Cedar Sink (STOP 4),

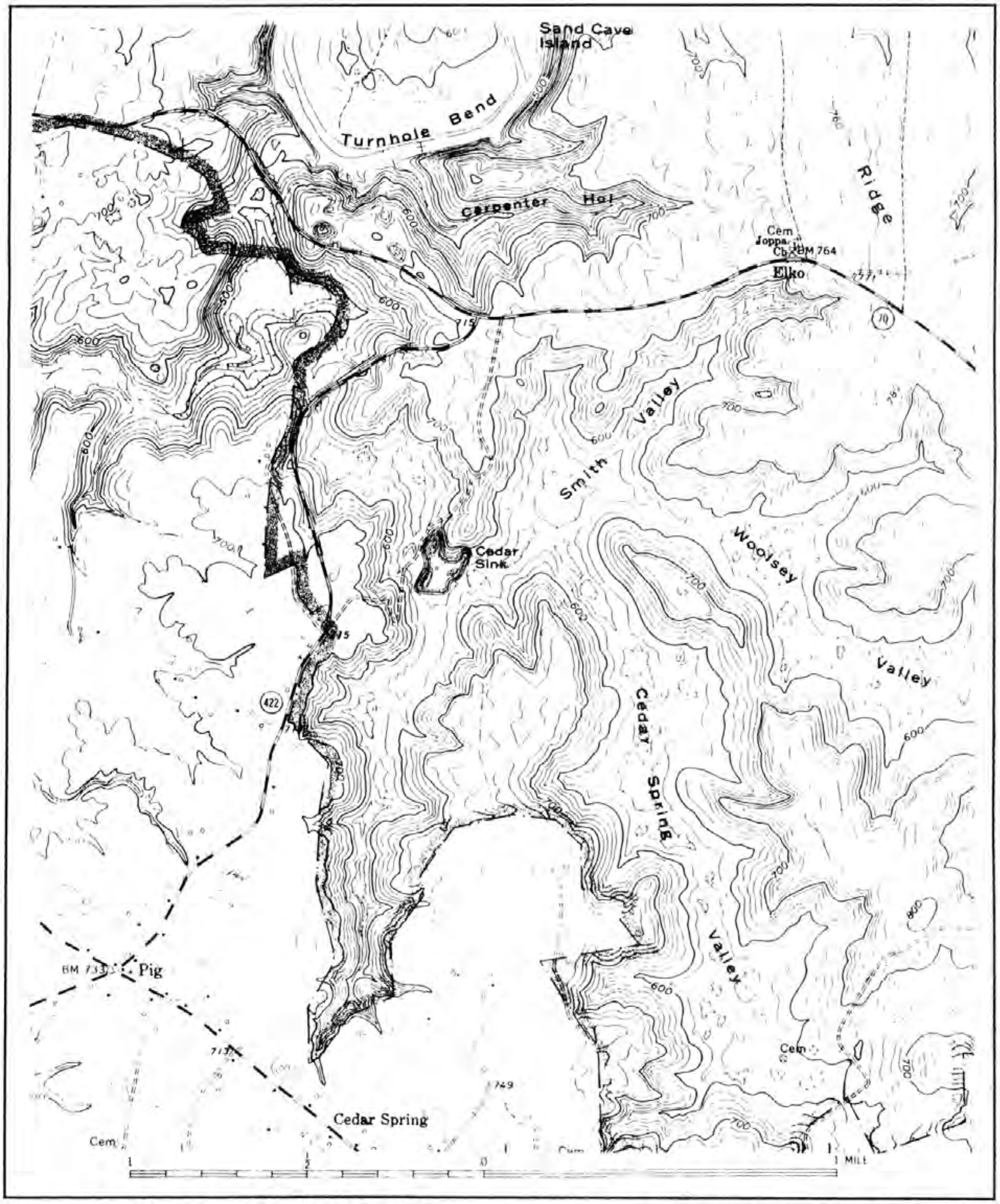


Figure 13. Portion of the Rhoda, KY topographic quadrangle map showing Cedar Sink (Stop 4) and its relation to surrounding karst valleys.

		flows into the Green River from springs at Turnhole Bend after travelling (map distance) nearly 8 miles. The bluffs along our route expose Ste. Genevieve and Girkin lithologies. Turnhole Bend takes its name from the fact it afforded the large paddlewheelers that once made their way along the Green, a 'wide spot in the road' for coming about.
		Return east up the Mammoth Cave Ferry Road to its end at the Visitors' Center Access Road.
1.2	38.0	Turn left (north) and proceed to Visitors' Center parking lot area.
0.7	38.7	Arrive at the Mammoth Cave National Park Visitors' Center. We will spend a few minutes here to examine maps and literature, and to prepare to enter the cave.
		STOP 6. Mammoth Cave Walking Tour. Our geological tour of Mammoth Cave will be led by Joe Meiman and Chris Groves.
		Refer to the detailed guide to our tour on the following pages.
0.0	38.7	After the cave trip, leave the Visitors' Center Parking Area and return south down the access road 4.2 miles till it ends in a 'T' at KY70.
4.2	42.9	Turn right (west) onto KY70.
3.2	46.1	Turn left (south) onto KY422, the Mammoth Cave Boundary Road, continuing past Cedar Sink, returning to the General Store and intersection with KY259 at Pig, KY.
2.2	48.3	Intersection of KY422 and KY259 at Pig, KY. Continue straight (south) on KY422.
2.9	51.2	Turn right (west) onto US31W at the intersection (it is not marked).
0.6	51.8	Pass the Liberty Hill Church (STOP 1) on your right as the road curves to the left (south). Continue south on US31W to Bowling Green by reversing our initial steps to STOP 1 this morning.
15.0	66.8	Arrive at Howard Johnson's Hotel.
		End of Field Trip - Day One.

Guide to the Historic Tour Area of Mammoth Cave

Chris Groves and Joe Meiman

The Cave's Original Entrance

Much of the geological interpretation in the cave, especially the detailed stratigraphy we will be discussing, comes from the extensive work of Art and Peg Palmer, and Art's book *A Geological Guide to Mammoth Cave National Park* (1981) is very highly recommended to anyone interested in pursuing the subject further.

We will enter the cave through the original, Historic Entrance. A map of our route through the cave appears as Figure 14. Although the cave was reputed to have been "discovered" by a local hunter named Houchens in the late 1700's (either while chasing or being chased by a wounded bear, depending on who tells the story), it is clear that ancient residents of Kentucky used the cave as early as 4,000 years ago, according to dated artifacts from the cave system (Watson, 1969). These early vistors entered the cave for a variety of reasons, including the mining of sulfate minerals such as gypsum, epsomite, and mirabilite, using the cave for shelter, and perhaps even for sport spurred by the same curiosity that drives cave explorers today. According to archeologist Patty Jo Watson, who has made detailed studies of the cave, the Indians were terrific cave explorers. They visited several miles of passages, leaving an incredible treasure- house of artifacts which have been preserved in the dry, stable conditions in the upper passages. These artifacts have painted a fascinating picture of their culture, their activities, and even the food they ate, which seems to have included their captured and killed enemies.

The cave was first shown commercially in 1816, and since then has been open for tourists on a continual basis. Sporadic exploration of the cave system occurred throughout the 1800's and early 1900's. All of the cave passages we will be visiting were known by about the 1870's, the ones beyond Bottomless Pit having been discovered about that time by the famous guide (and slave) Steven Bishop. Steven reportedly crossed over the gaping chasm on a cedar pole with a paying customer who had wanted to go where "no man had gone before." He went on to make a number of fabulous discoveries along this route, including Echo River with its bizarre blind fish, Relief Hall, and the area he was to call his greatest find, Mammoth Dome.

The modern era of exploration in the park began in the late 1940's with a small group of cavers who started a systematic exploration of the caves on Flint Ridge, just to the east of Mammoth Cave. As time went on, these caves became integrated one by one and it was revealed that another great cave system, rivalling Mammoth Cave in extent, lay under that ridge. By and by the growing group of cavers formed the Cave Research Foundation, an organization devoted to the exploration and scientific study of the area's caves which was able to cooperate with the National Park Service, who until then had not supported cave exploration to any degree. By the late 1960's the Flint Ridge Cave system reached a surveyed length of over 90 miles, and a new challenge loomed before the explorers: if a way beneath the large karst valley separating

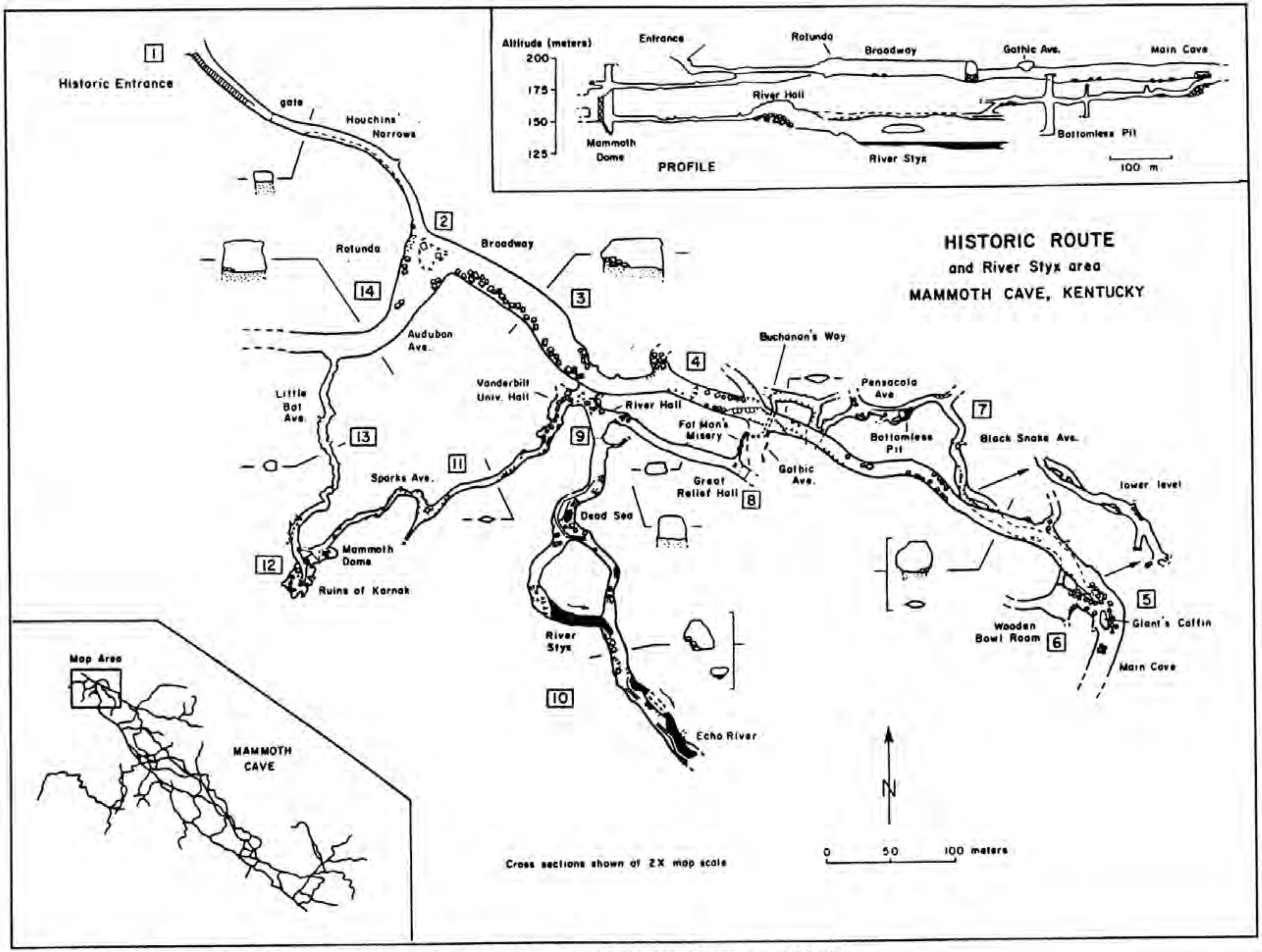


Figure 14. Map of the Historic Tour section of Mammoth Cave (Palmer, 1981).

the two great cave systems could be found, the two caves might possibly be connected making a cave system that would for all time be unrivalled as the world's longest.

After a great deal of effort and difficult exploration by a number of dedicated cavers, a group of seven entered Flint Ridge on the morning of September 8, 1972. After a long, grueling trip through several miles of low, wet passages beneath Houchen's Valley, they emerged early the next morning from a low passage into Echo River and onto the tourist trail in Mammoth Cave. The "Everest" of speleology had been conquered, and since that day the Flint Ridge-Mammoth Cave system has been the world's longest. At the time of the connection the cave was 144 miles long--today the cave is just over 348 surveyed miles in length, and no end is in sight. In fact, a very large exploration breakthrough in nearby Fisher Ridge Cave occurred early in 1993, and that cave, now over 74 miles long by itself, comes to within 1,000 feet of the Mammoth System. Although a connection is not imminent at this time, it is interesting to note that the combined length of these passages exceeds 422 miles. Other large, nearby caves also are being explored and surveyed, and will very possibly be integrated into the main system as time goes on. How long will the cave ultimately be? No one can say, but it is clear that the once wild claim of a 500 mile long cave system may not be so wild after all.

As we descend the hill we will pass the contact between the Big Clifty Sandstone, and walk onto the highest of the three limestone units within which the cave is formed, the Girkin Limestone. It is within the lower Girkin that we enter the cave. A detailed stratigraphic section of these units (Palmer, 1981) is shown in Figure 15.

Rotunda

After passing through the entrance area known as Houchen's Narrows, the Rotunda is the first large room encountered in the cave, and is in fact one of the largest rooms in the system, although a few are considerably larger. This is also stratigraphically one of the higher passages in the cave. The walls here are carved primarily from the Paoli Member of the Girkin Limestone. The recessed niche of silty gray limestone near the floor towards Audubon Avenue (the large passage winding away to the right) is the P1 unit of of the Paoli, which forms the base of the Girkin.

The excavated area in the center of the room is the remains of a large saltpeter mining operation that went on in the cave during the War of 1812. The dirt in the cave was leached for the compound calcium nitrate, which was then mixed with wood ashes to form potassium nitrate. This saltpeter was used in the manufacture of gunpowder. Although mining ended here just after the War of 1812, other caves in the southeast U.S. were utilized as a major source of saltpeter during the Civil War, when the Confederate Army was unable to get gunpowder from Europe. The artifacts here are completely original, as the cave has been preserved just as it was at the end of the mining activities.

What a horrifying experience it must have been for the miners in the cave during the New Madrid earthquakes of the winter of 1811-12! George (1992) has collected a series of stories handed down about the event, and although no deaths were reported in the cave, there was apparently considerable concern as the miners went running from the cave, screaming for their lives. The manager of the mining operation was unfortunately fired not long

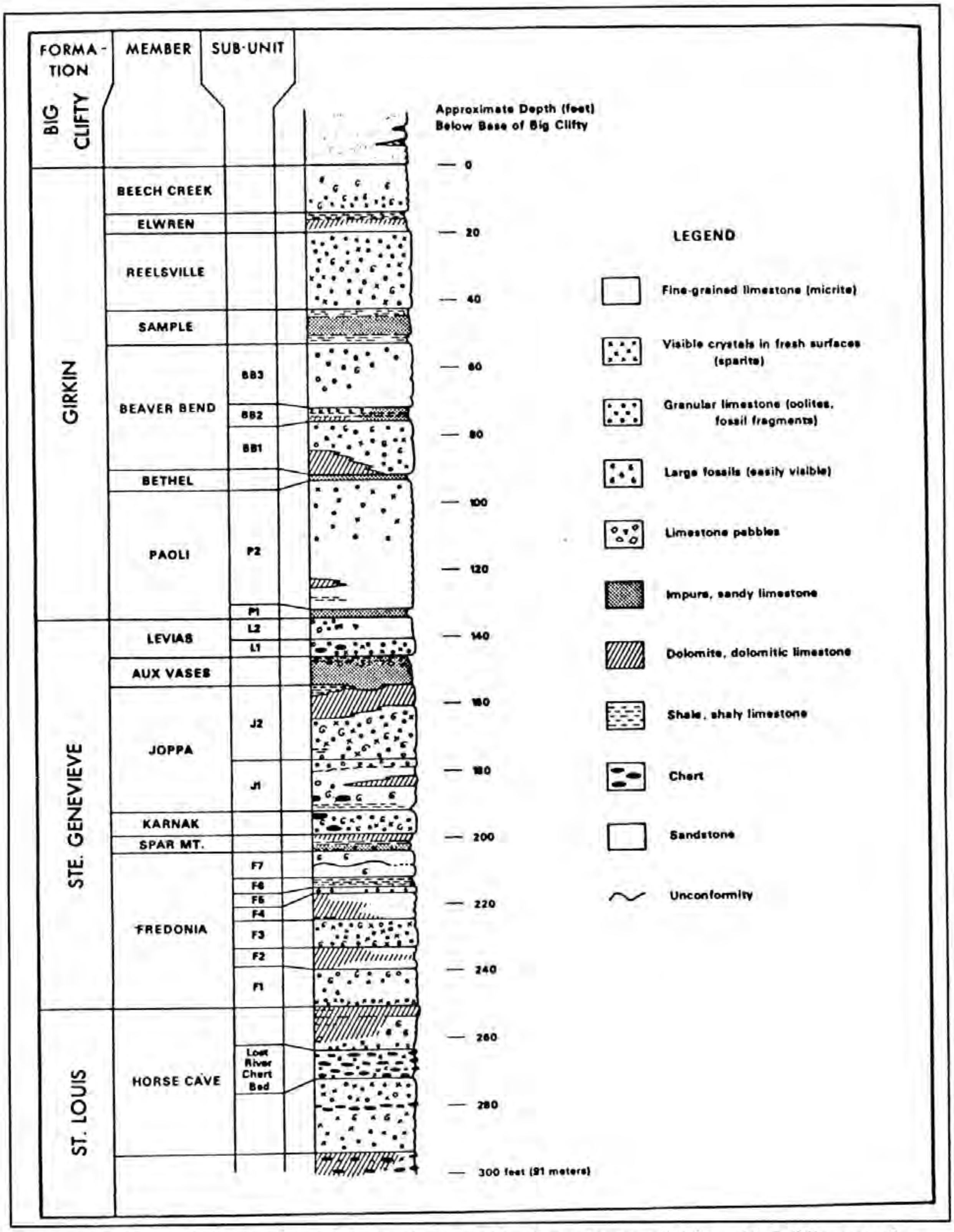


Figure 15. Detailed stratigraphic section for the limestones within which Mammoth Cave has formed (Palmer, 1981).

Figure 16. Damage to saltpeter mining artifacts from a large rockfall in January of 1994.

after the earthquake, because although he indicated his willingness to continue the job, he was never again willing to set foot in the cave. There is also evidence that the mining works were substantially damaged in the event.

In January of 1994, during the extreme cold snap that gripped the central U.S., a large slab of the Beaver Bend Member of the Girkin came loose from the roof, crashing down on the tourist trail and crushing part of the saltpeter works (Figures 16 and 17). The slab was about seventy feet long by twenty feet wide, and about a foot thick, which led to an estimate of close to 100 tons. Fortunately, the cave was closed at the time because of the winter storm outside, which had closed the entire park as well as Kentucky's highway system. The cause of the fall seems to be related to the cold weather, as it reached a low of -16°F during the period, with temperatures in the Rotunda falling well below zero with a strong wind blowing in through Houchen's Narrows. Speculation has suggested that either freeze-thaw wedging in the bedding plane above the slab, or contraction of the limestone slab itself, is responsible for the fall. This is the only very large rockfall to occur within the developed part of the cave during the 178 years of continuous show-cave operation here.

Booth's Ampitheater

As we wind down Main Cave to the left off of the Rotunda, we begin to slip down into the Ste. Genevieve Limestone, walking in the paleo-upstream direction (Figure 18). Note that we are only seeing the highest parts of these passages, which are filled with up to 80 feet of sediment in places (Palmer, 1981). Booth's Ampitheater (Figure 19) has formed at the intersection of Main Cave with Gothic Avenue above. Gothic Avenue is the oldest known passage in Mammoth Cave Ridge. It began to form some time prior to one million years b.p., by draining water from the ancestral Houchen's Valley towards the Green River (Palmer, 1981).

The localized, dark black deposits near the ceiling have resulted from years of "torch throwing", where guides would fling tied bundles of kerosene soaked rags onto high ledges for unusual illumination. The practice was discontinued in 1991, for environmental

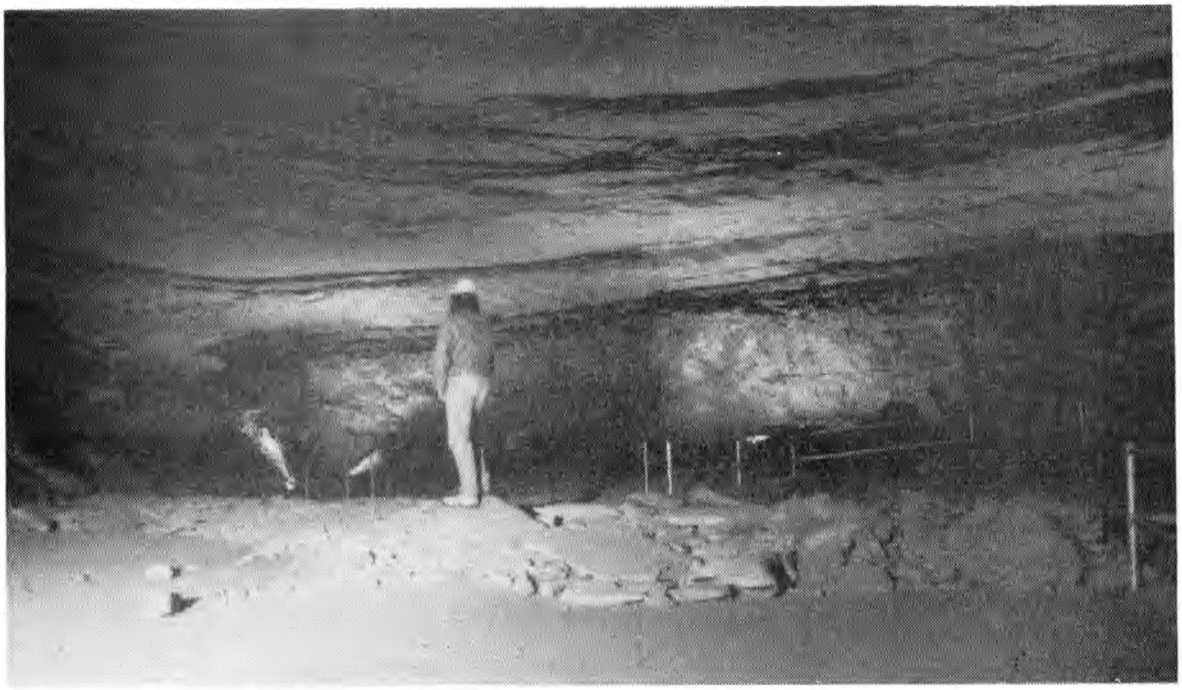


Figure 17. View of 100-ton slab that fell in the Rotunda during January of 1994.

Figure 18. View looking in the paleo-upstream direction, Main Cave.

Figure 19. Booth's Amphitheater, at the intersection of Gothic Avenue and Main Cave. Gothic Avenue is the oldest passage within the Mammoth Cave Ridge.

reasons. The walls in this part of the cave, in fact, are rather dark in general, which may be the result of soot from thousands of years of cane-reed torches used by the aboriginal visitors to the cave (Watson, 1969) who mined sulfate mineral crusts in this area. Organic acids have been shown to be present in the coating as well (Quinlan and Traverse, 1967). The dark material seems to preferentially occur on gypsum crusts.

Giant's Coffin

At this point on the trip we will turn into a smaller passage on the right at Dante's Gateway, descending down through the Fredonia Members of the Ste. Genevieve. Giants's Coffin is the very large breakdown block behind which we will begin our descent. As we make our way down, we will pass through a more complex configuration of smaller passages, which formed during the early or middle Quaternary Period (Palmer, 1981). Erosion of the Mammoth Cave Plateau was by this time exposing limestone in new areas, so that water from the surface could enter the aquifer at many new discrete locations. These smaller yet more abundant active flowpaths have resulted in smaller yet more abundant cave passages, with an increase of passage complexity.

The roughly horizontal elliptical tube passage that we travel along for a bit is Black

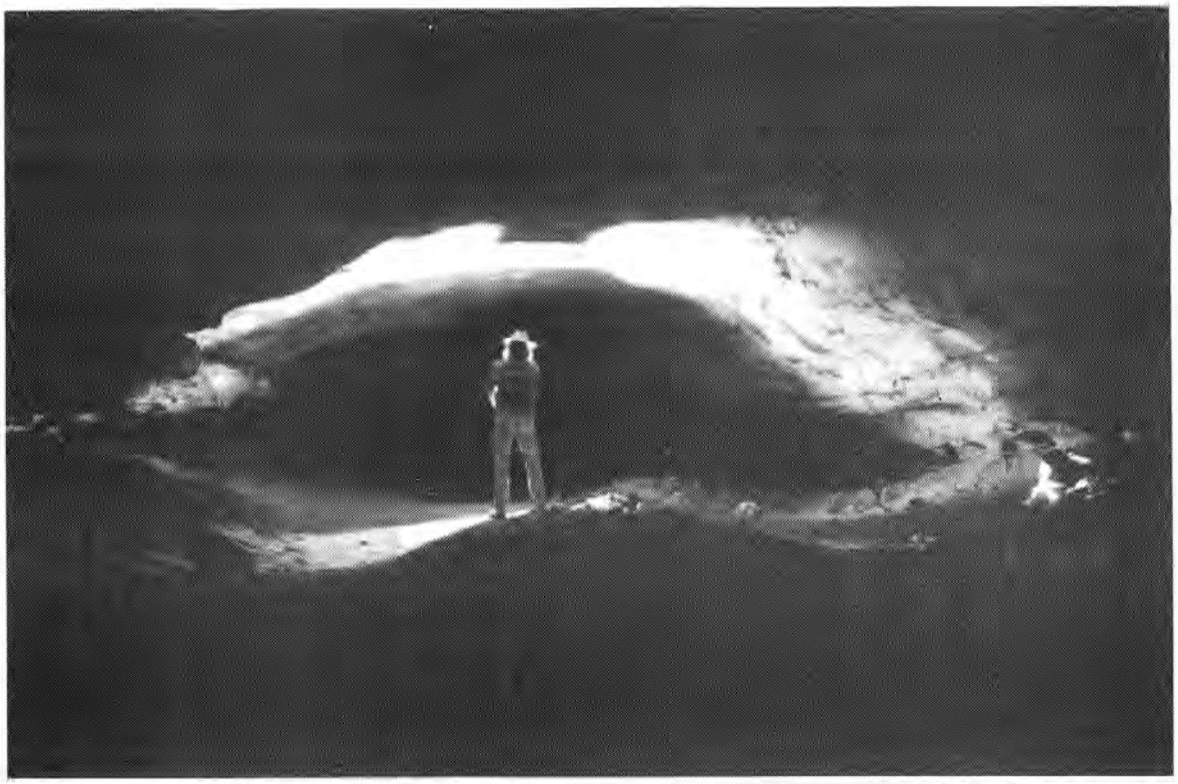


Figure 20. Black Snake Avenue, a passage whose elliptical shape suggests that it was often filled completely with water during its formation.

Snake Avenue (Figure 20), and its tube shape suggests that it was formed largely under phreatic or pipe-full conditions. Since the Green River experienced a relatively stable period during this time, such passages are very common in the cave system at this level. Some of these tubes stretch unbroken for miles in various parts of the cave.

Black Snake Avenue eventually winds close to the edge of Mammoth Cave Ridge, and inthis area we will pass a number of dome-pit complexes. On the surface, at points along the edge of the Big Clifty Sandstone, water can make its way into the subsurface. Since this water is typically quite undersaturated with respect to limestone, it can bore these shafts, which only coincidentally intersect the horizontal passage along which we are moving. If the conditions are relatively wet, water can be seen at the bottom of Bottomless Pit. We are getting lower in the cave--the water at the bottom of this shaft is level with the Green River, thus the local baselevel.

Great Relief Hall

After passing through Fat Man's Misery (Figure 21) we reach Great Relief Hall. This will be a short rest and rest room break. Emerging from Fat Man's Misery. we come into the passage that Steven Bishop called Relief Hall. Since the addition of rest rooms by the Park Service, it has been known as

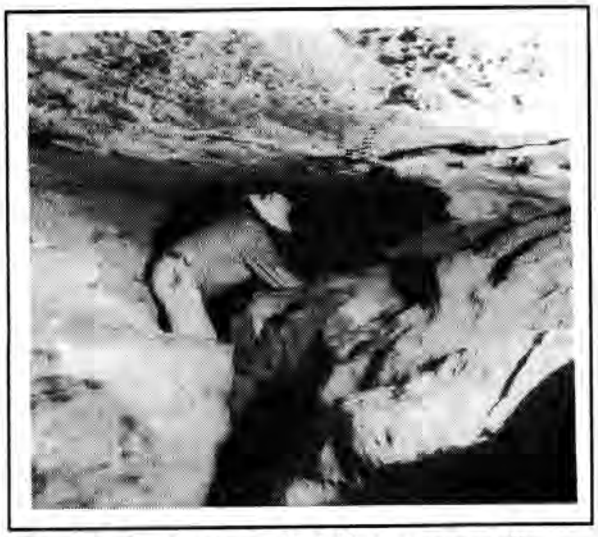


Figure 21. Fat Man's Misery, a small, keyhole-shaped passage.

Great Relief Hall.

We are moving lower within the Ste. Genevieve and as we walk towards River Hall we eventally come into the top of the St. Louis. Great Relief Hall is formed within the Fredonia Member of the Ste. Genevieve.

River Hall

At this point we reach the lowest major level of the Mammoth Cave System; it is at this level that the cave is still forming on a regular basis. At River Hall we will rest and then take a trip down the passage towards the left which leads to Echo River. This trail is not currently maintained by the Park Service for tours. As this passage is flood prone, there may be sediments of various descriptions on the trail.

In River Hall, the contact between the Ste. Genevieve and the underlying St. Louis is visible at the top of a prominent ledge near the ceiling (Palmer, 1981). Throughout the passage to Echo River we will be at this contact, but sediment on the walls obscures much of the lithologic detail.

Dead Sea

The rather complex levels of passages we've traversed over the past hour and a half can also be seen at the current baselevel of the Mammoth System (Figure 22). The Dead Sea, representing the baselevel, continues as a pipe-full canyon passage to Echo River Spring while at a slightly higher elevation, River Styx flows to the Dead Sea and finally to Styx Spring. Prior to rapid downcutting of the Green River during the Pleistocene, all flow was through River Styx. Following the entrenchment of the Green River, flow was diverted to Echo River Spring, and thereafter, reached River Styx only during flood events. Post-Pleistocene backfilling of the Green's channel caused an increased regional base-level, approximating that prior to the Pleistocene. Today, the pre-Pleistocene route of River Styx and the Pleistocene route of Echo River are both active as flow distributaries.

Mammoth Dome

As we work our way back up to the higher levels of the cave, we will make up most of that elevation within a great vertical shaft complex known as Mammoth Dome. In the walls here, almost the entire section of the Ste. Genevieve Limestone is exposed, from the basal contact with the St. Louis seven feet below the floor of the lowest balcony (Palmer, 1981) to the uppermost part of the Joppa Member where we will emerge from the dome into Little Bat Avenue.

This dome is one of the largest of the hundreds known in the cave system. These

Figure 22. View of the Dead Sea, which represents the lowest major level within Mammoth Cave. Water levels here closely match that of the Green River.

shafts often provide routes connecting the different horizontal levels. Explorers and surveyors working in the cave system must become proficient at moving up and down ropes to negotiate these places. Sometimes the drains at the bottom of these shafts can be explored to lower levels, but quite often these drains are very wet and possibly filled with breakdown or silt.

Upon reaching the top of the dome via the fire-tower steps, we pass through Little Bat Avenue (which was once the drain for water flowing from the upper level *to* Mammoth Dome) and eventually pop back into the Girkin Limestone at Audobon Avenue. A short hike to the right brings us back to the Rotunda, where we began our trip.

Introduction to the Lost River Karst Groundwater Basin, Bowling Green, Kentucky, and Associated Environmental Problems

Nicholas C. Crawford

Bowling Green, with a population of approximately 50,000, is located on the classic Pennyroyal sinkhole plain of South Central Kentucky (Figure 1). The city is drained almost entirely by cave streams and is a focal point for the convergence of ground water flowing beneath the sinkhole plain of Warren County, Kentucky. Almost all drainage from the sinkhole plain for about 15.5 miles northeast (Quinlan and Rowe, 1977) and 13 miles south (Crawford, 1985) issues from Graham Springs and the Lost River Rise to flow into the Barren River at Bowling Green. Because of its location, the city has serious problems associated with karst hydrology. Today's field trip will emphasize the considerable effort being made to solve karst problems in the Bowling Green area by the Center for Cave and Karst Studies at Western Kentucky University as well as various federal, state, and local agencies.

Lost River Groundwater Basin

The Lost River Groundwater Basin includes most of Warren County south of Bowling Green. Dye traces have revealed that the Lost River begins in uplands about 10 miles south of the city where several small streams sink and flow into the underlying St. Louis Limestone. These subsurface streams unite to become the Lost River which flows north under the city (Figure 23).

The Lost River flows across the bottom of several karst windows, the largest being located at the southern edge of Bowling Green where the stream rises at the Lost River Blue Hole, flows across the Lost River Karst Window and into the mouth of Lost River Cave. From the Lost River Karst Window the river travels through large cave passages under the southwest portion of the city to the Lost River Rise (Figure 24). We will view the Rise at STOP 6 and the Lost River Blue Hole, Karst Window, and Lost River Cave at STOP 8.

The Lost River drainage system has formed in the Mississippian Ste. Genevieve and St. Louis Limestones in the vicinity of two chert confining layers. The stream begins near the town of Woodburn south of Bowling Green as surface streams invade the subsurface upon breaching the Lost River Chert Bed. It then flows north perched primarily on the Corydon Member of the St. Louis Limestone and in places the Lost River Chert Bed (Crawford, 1988). The Lost River Chert Bed is named for the famous Lost River of southern Indiana. It appears that this prominent 10 to 20-foot zone of bedded, light gray, fossiliferous chert extends from southern Indiana to the Bowling Green area and probably as far south as the Mississippian sinkhole plain of the Highland Rim of Tennessee. It is somewhat ironic that the Lost River Chert (of southern Indiana) plays such an important stratigraphic role in the development of the Lost River Cave system of southern Kentucky. At every location between the headwaters and the Rise where the Lost River is visible, it is flowing upon either the Lost River Chert or the Corydon Chert. It is interesting that structure and stratigraphy have influenced groundwater flow and thus cavern development to a much

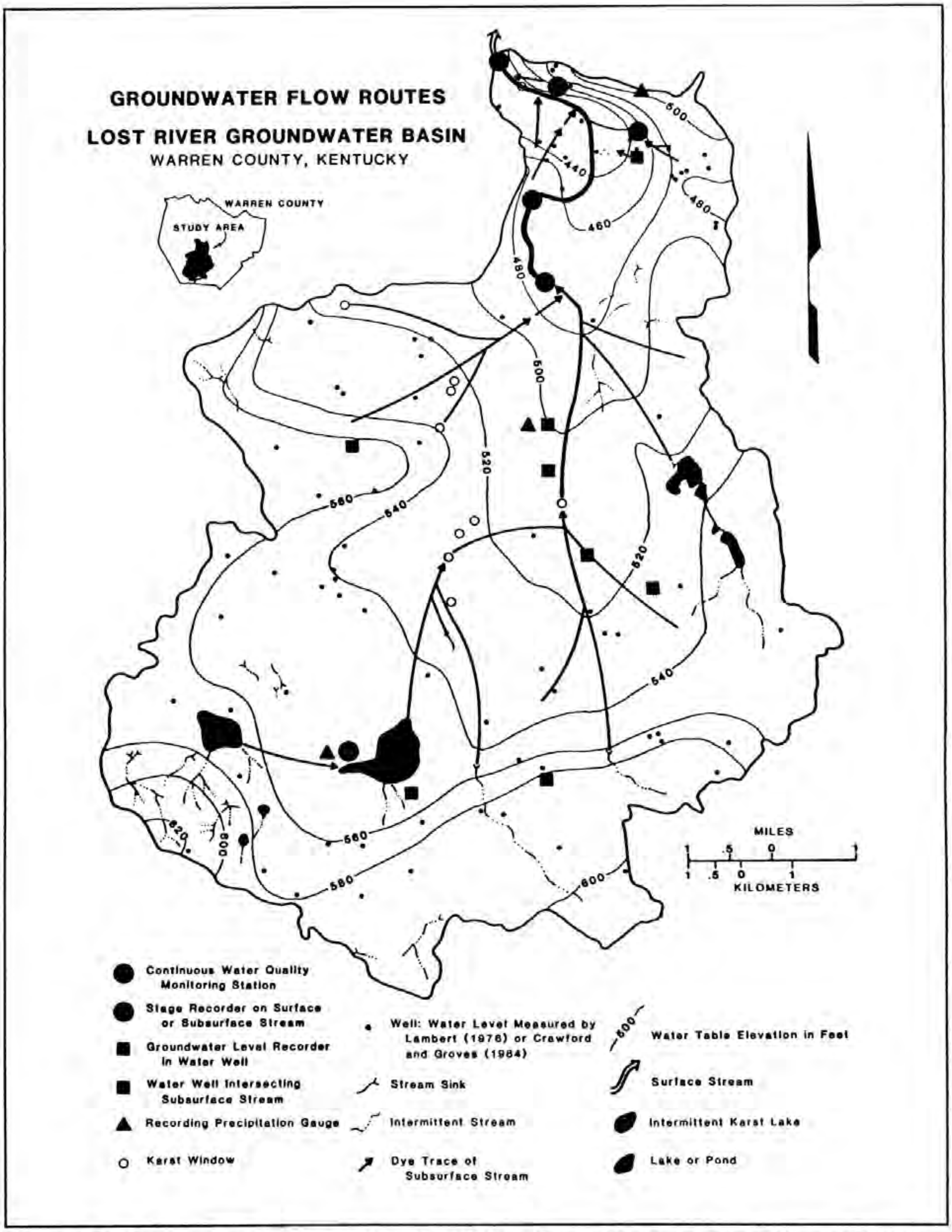


Figure 23. Groundwater flow routes, Lost River Groundwater Basin, Warren County, Kentucky.

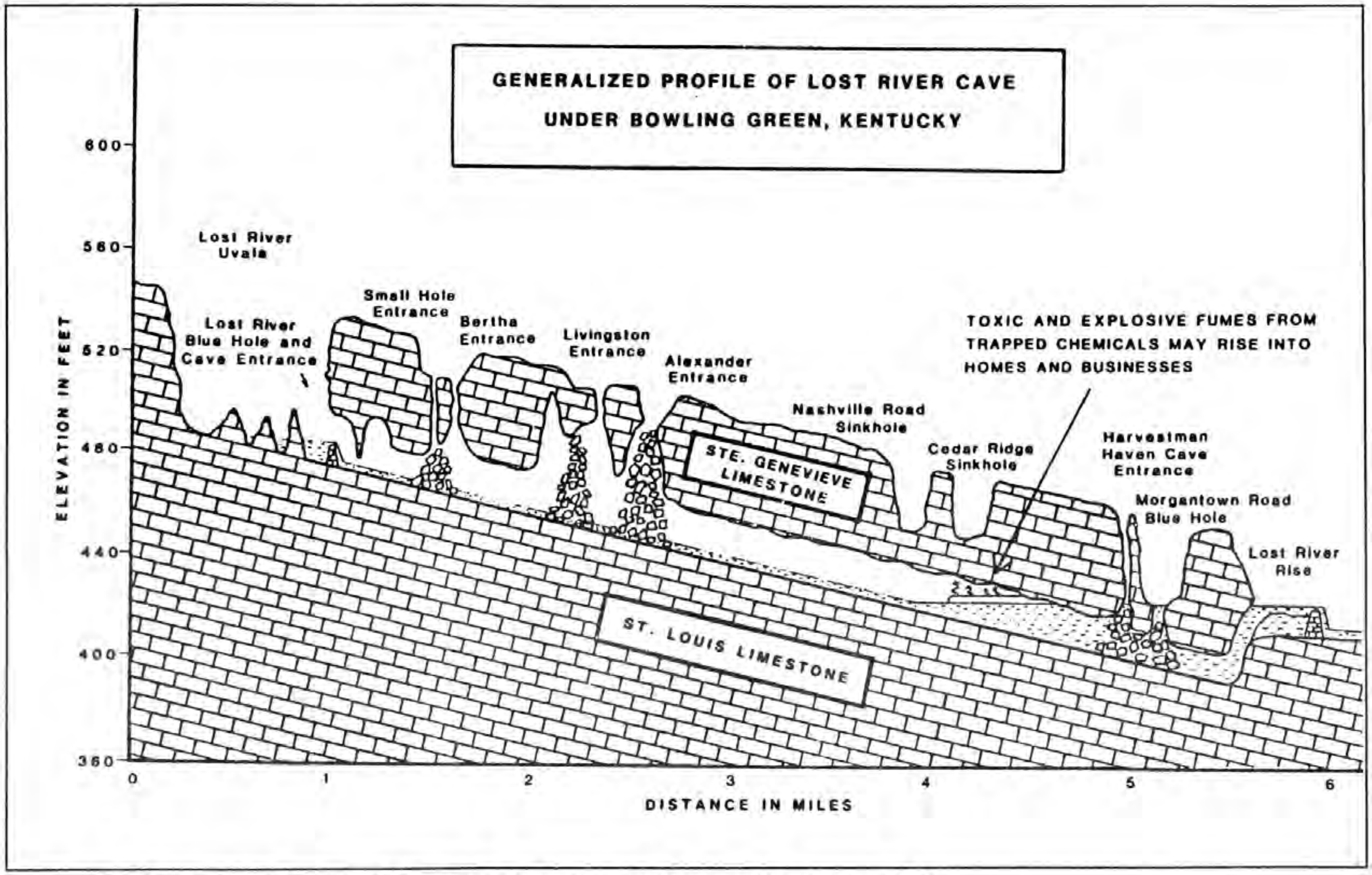


Figure 24. Generalized profile of the Lost River Cave under Bowling Green, KY.

greater extent in the Bowling Green area than in the Mammoth Cave area only 25 miles to the northeast.

Groundwater Contamination of Karst Aquifers in the Bowling Green Area

Shallow carbonate aquifers in karst areas are extremely vulnerable to groundwater contamination from human and animal wastes, agricultural land use, urban storm water runoff, leaking underground storage tanks, and a variety of industrial activities. Storm water runoff may wash contaminants into the aquifer as it sinks directly into caves without any filtration through the soil. Contaminants may also percolate through thin soils into the cave drainage system below. Once contaminants reach the fast-flowing underground streams, they may be carried for miles through the aquifer in only a few hours.

The caves under Bowling Green often have a fetid order, and places exist where septic tank effluent is dripping or even pouring from the ceiling, where oil covers the passage floor, and where various kinds of trash have collected. Scum, sometimes two inches thick can be found at stream sumps and in perched pools above cave streams. Cave passages often have a strong odor of gasoline, oil, and other volatile organic chemicals (VOCs).

Water which has had contact with human and animal waste is one of the most serious pollutants in underground streams in the Bowling Green area. High fecal coliform and fecal streptococcus counts indicate that groundwater has had recent contact with human and animal waste. Runoff from heavy rain washes past livestock wastes from farm land south of the city into subsurface streams at swallets. Waste from dogs and cats is a problem in urban areas. Heavy rains also flush septic tank effluent from the soil down into underlying conduits in the limestones. Water samples with fecal coliform counts of over 40,000 colonies per 100 milliliters have been taken at the Lost River Blue Hole and the Lost River Rise at Lampkin Park during relatively high discharges following heavy rains. Dye traces of septic tanks by Crawford (1979) have revealed surprisingly rapid flow from septic tanks into underground streams. Rhodamine WT dye was detected at the Lost River Karst Window only ten hours after it was flushed down the toilet of a house 0.8 miles away.

In addition to septic tank effluent from the suburbs, human waste enters the Lost River from many homes in the older areas of town which were never connected to city sewers. The city did not require that they connect when the sewer pipes were laid years ago, and the city does not have complete records of which homes are on sewer and which are not. All homeowners are sent a sewer bill based upon water usage each month regardless of whether they are connected or not. Many homeowners have not had septic tank problems because the effluent sinks into the limestone rather than appearing at the surface when the system fails. Consequently, they assume that their septic tank is working correctly and that there is no need to pay a plumber to connect their home to the sewer. Houses change owners frequently, and it is likely that some homeowners who pay their sewer bill each month believe that they are connected to the sewer, when in fact, they are injecting their waste directly into the karst aquifer.

The effects of urban storm water runoff in Bowling Green have been investigated by monitoring the water quality of the Lost River before (Blue Hole monitoring station) and after (Lost River Rise monitoring station) it flows under Bowling Green. A third monitoring station was constructed exclusively for studying urban storm water runoff at Bypass Cave swallet. Our findings indicate that urban storm water runoff flowing into Bypass Cave at times exceeds the surface water criteria for public water supplies in the following areas: a) coliform bacteria, b) oil and grease, c) chromium, d) lead, and e) iron. Grab samples taken during the first flush indicate that ammonia, BOD_5 and total dissolved solids are also high enough to be considered pollutants. In addition, suspended solids appear to be a significant pollutant. The Bypass Cave swallet and monitoring station will be visited as STOP 4 today.

Groundwater contamination problems are particularly serious when they involve toxic or explosive chemicals. Not only are the chemicals a threat to water supplies and aquatic life, but upon vaporizing they may become concentrated in the cave atmosphere and rise into homes on the surface. Intermittent problems with toxic and explosive fumes have occurred in Bowling Green for at least twenty-three years with homes and buildings in various parts of the city affected.

Leaking underground storage tanks are believed to be the major source of fumes in the caves. The Bowling Green area has an estimated 500 buried tanks, most of them containing gasoline and belonging to auto service stations. Gasoline floating on a subsurface stream can travel several miles from the site of a leak or spill in a few hours, rapidly filling cave passages with explosive fumes. The fumes may rise up solutionally-enlarged joints, faults, bedding plane partings, and caves into basements and crawl spaces. They may also rise into homes built over sinkholes, up water wells, and storm water drainage wells, and even up abandoned wells and natural openings used for waste disposal (STOP 1). Detailed investigations of the fumes problem has ultimately led to the development and installation of novel ventilation systems for mitigation. We will observe one of these at the Dishman-McGinnis Elementary School (STOP 5).

Sinkhole Flooding and Related Problems

The flooding of sinkholes in karst regions is a part of the natural hydrologic system. Flooding occurs during periods of intense rainfall, usually of short duration: 1) when the quantity of storm water runoff flowing into sinkholes exceeds their outlet capacities, and they cannot drain into underlying caves fast enough to prevent ponding, 2) when the capacity of the cave system to transmit storm water is exceeded, and the water must be stored temporarily in sinkholes since it cannot be stored on flood plains like surface streams, 3) when high water table results from a 'backwater effect' on groundwater flow caused by surface or subsurface streams being at flood stage. Unfortunately, in the Bowling Green area, houses have been built in these natural storage areas (sinkholes). The problem has been greatly aggravated by increased runoff resulting from urban development and by sinkhole filling by developers and landowners (Crawford, 1984).

The worst flooding problems in Bowling Green occur in large, shallow sinkholes with broad catchment areas. Often individuals who build or purchase homes in such areas fail to recognize them as sinkholes and never consider the chance of flooding, especially since the nearest surface stream may be miles away. Unfortunately, many people believe that a sinkhole must be a steep-walled depression, a 'hole in the ground'. At STOP 2, the steep-walled depression we will visit near Batsel Avenue is easily recognizable as a sinkhole, but most of the people who built homes on Covington Street did not realize that they were building in the upper portion of that same sinkhole. People normally do not build in the bottoms of deep, easily recognizable sinkholes, and some towns built upon sinkhole plains have relatively minor sinkhole flooding problems for this reason. Bowling Green has mostly large, shallow karst depressions, and consequently flooding is a major problem (Crawford, 1984).

Bowling Green is rapidly growing towards the southeast, or upstream in terms of the subsurface Lost River. Urban expansion in that direction will increase the flood crest of the Lost River as more storm water runoff is directed underground. This may increase the depth of flooding in sinkholes downstream, and sinkholes which have not flooded in the past may flood in the future. An intensive investigation is needed of the effects of increased runoff on areas which are lower in elevation and downstream in terms of the flow paths through the carbonate aquifer upon which the city is built. Flood retention reservoirs to retain increased storm water runoff resulting from changes in present land use are required by the City-County Planning Commission and should help to reduce this potential problem.

In addition, the City has installed hundreds of storm water drainage wells to permit surface water to sink into the ground more easily (Crawford and Groves, 1984). These are normally placed at or near sinkhole bottoms, along drainage ditches, or ephemeral streams leading to sinkholes, and in storm water retention basins. Drilled wells vary in diameter from 6 to 12 inches, and are generally less than 100-feet deep. They are usually cased to bedrock with standard steel well casing, although galvanized culverts are sometimes used. The annular space between the hole and the casing is virtually never sealed with concrete, and no attempt is made to seal the casing at the regolith-bedrock contact. As a result, about 40 sinkhole collapses have occurred adjacent to or near Bowling Green's drainage wells. It is hypothesized that a large crack often exists where the casing rests on the irregular bedrock surface, and water flowing from the well saturates the surrounding regolith. The saturated regolith is piped into the well as the water level drops below that of the crack. The result is the formation of a regolith arch which expands during floods until it collapses all the way to the surface (Figure 32). We will observe a drainage well with an associated collapse at STOP 7 today. At STOP 3, the Glendale Baptist Church, we will observe a uniquely constructed trash rack designed to keep a drainage well functioning properly during flood events.

We hope this brief introduction has been informative and has increased your awareness of the problems associated with human activities on the sinkhole plain. We will discuss specific details at the stops today as time and weather allow. A general map of the City showing our stops today appears as Figure 25.

Figure 25. Map of Bowling Green, KY, showing locations of field trip stops.

FIELD TRIP ROAD LOG

Day Two

Bowling Green, Kentucky

Nicholas C. Crawford and Kenneth W. Kuehn

Mileage		Description
Interval	Total	
0.0	0.0	Turn right from Howard Johnson's parking lot onto US31W-Bypass. Proceed to first stoplight.
0.05	0.05	Turn left (east) at stoplight onto Cemetery Road, KY234.
0.05	0.10	Turn right into Fairview Plaza Shopping Center immediately past Kenny Roger's Restaurant.

STOP 1. Fairview Plaza Shopping Center. At this stop we will investigate flooding in the parking lot (Figure 26) as well as the problem of fumes rising from the cave system.

Figure 26. Fairview Plaza parking lot (Stop 1). The sign reads "impassable during high water".

Twice during the spring of 1981 people were evacuated from homes on the opposite side of Cemetery Road from the Fairview Plaza Shopping Center parking lot because gasoline fumes reached explosive concentrations in their basements. A trench was dug in a futile attempt to find the cave stream and obtain a sample of the gasoline and trace it to an underground tank at a nearby service station. The backhoe excavated many large rocks mixed with the terra rossa soil. Since the rocks were Lost River Chert (flint), it was fortunate that the cave and gasoline were not located.

A check of drainage wells in the vicinity uncovered high levels of gasoline fumes coming from two storm water drains in the parking lot, it is possible that they could have produced an explosion which might have travelled through the cave system destroying houses some distance away. In Louisville, Kentucky in 1981 an automobile with a faulty catalytic converter emitted sparks over a manhole causing an explosion in the sewer system which travelled for eleven blocks with estimated damages exceeding forty-three million dollars.

On four occasions during the spring of 1981 people had to leave their homes in three different areas of Bowling Green because of gasoline fumes in their basements. Gasoline floating on a subsurface stream can rapidly travel several miles from the site of a leak or spill. Obviously any kind of accidental leak or spill of a potentially explosive substance should be a matter of concern to the people of Bowling Green.

Exit the parking lot by turning right (east) onto Cemetery Road.

0.5 0.6 Turn right onto Hampton Avenue.

0.3 0.9 Turn right at stop sign Covington Street.

0.2 1.1 Turn left onto Batsel Avenue. Park at fenced area.

STOP 2. Batsel Avenue Sinkhole. Storm water flooding in the Batsel Avenue area is typical of sinkhole flooding in Bowling Green. Although sinkhole ponding is generally less than three feet when the sink overflows it is sufficient to flood homes and streets. For the most part people have not built homes and businesses at the bottom of obvious sinkholes in Bowling Green. Problems occur primarily in large and shallow karst depressions which are often not even evident as sinkholes on topographic maps with a 10-foot contour interval. Figure 27 illustrates the three-hour, 100-year flood contour for the sinkhole and indicates that more than one dozen existing homes can be affected.

0.05 1.15 Turn right at stop sign onto Wakefield Street.

0.35 1.5 Turn right at stop sign onto Lehman Avenue.

0.1 1.6 Turn left at stop sign onto Covington Street.

0.6 2.2 Stoplight at intersection of Covington Street and Scottsville Road (US231). Proceed straight onto Smallhouse Road.

0.5 2.7 Turn right onto Roselawn Way.

0.2 2.9 Turn right into parking lot of Glendale Baptist Church. Follow parking lot around, stopping behind the church.

STOP 3. Glendale Baptist Church. Glendale is the only area of the city where a water shed systems approach has been made in an attempt to solve sinkhole flooding problems. An intensive investigation of the hydrogeology of the Glendale area was made involving four stage recorders and a recording

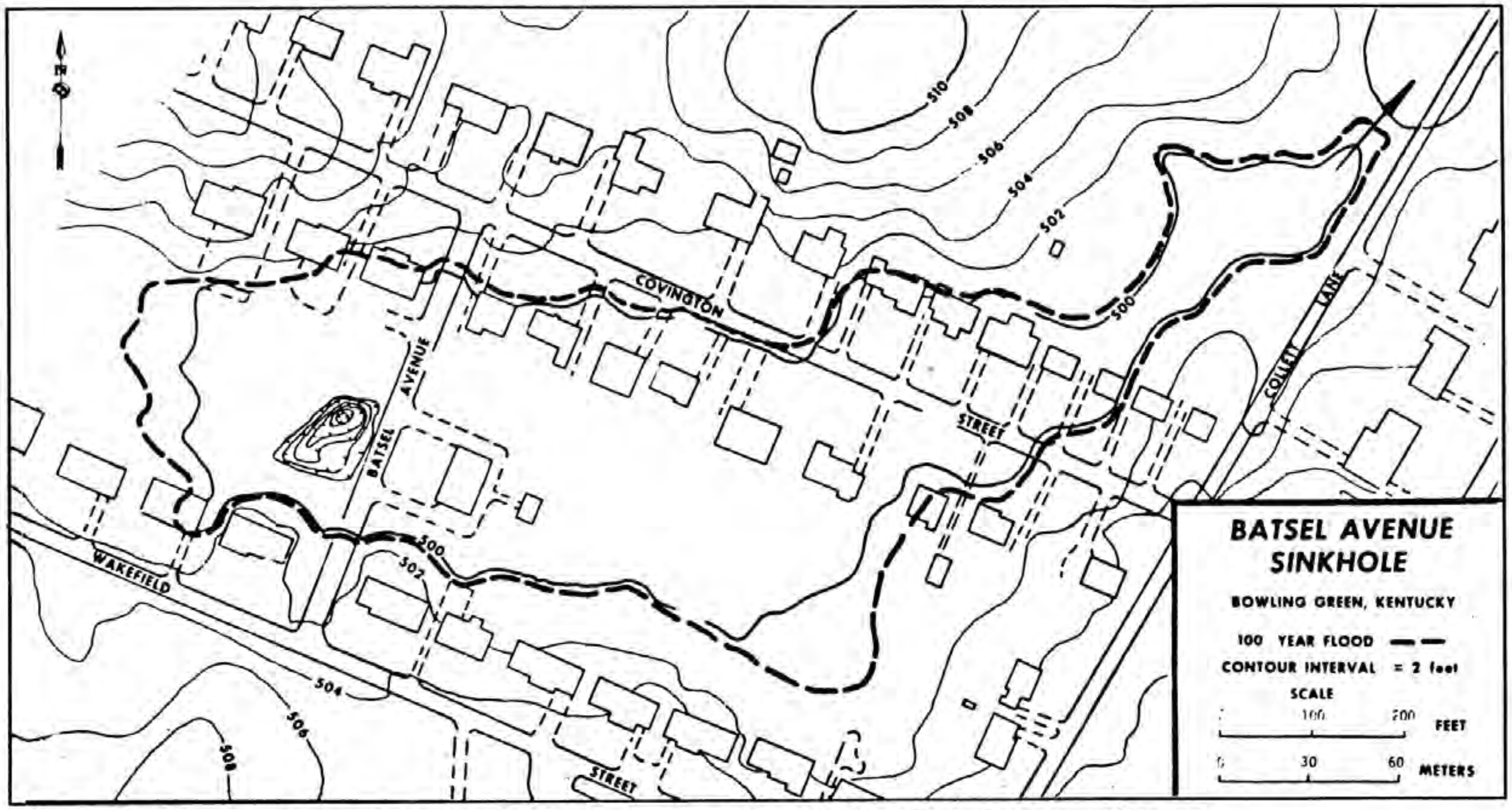


Figure 27. The three-hour, 100-year flood contour for the sinkhole at Batsel Avenue (Stop 2).

rain gauge which were maintained for one year. Sinking streams were dye traced, and cave streams were located and surveyed.

The hydrogeologic investigation in the Glendale are revealed the following three levels of horizontal water movement:

1) Surface runoff, corresponding with surface topography, generally flows south and then west.
2) Shallow caves, believed to be perched upon chert layers only 16 to 32 feet underground. Most of the storm water runoff from the area sinks to the deeper and larger Lost River.
3) The water table as determined from 29 drainage wells is generally about 48 to 65 feet below the surface, with a gradient to the southwest towards the Lost River.

The investigation led to the discovery of Buckberry Cave 1400 feet northwest of Nahm Sink. A dye trace revealed that water flowed from Nahm Sink to a stream discovered in Buckberry Cave. The capacity of Nahm Sink was determined to be approximately 7 cfs before overflow. Observations indicated that a constriction between Nahm Sink and Buckberry Cave was responsible for the flow capacity of the sink. Another constriction occurred due to the collection of water-borne debris on the trash rack protecting the concrete culvert leading to Nahm Sink. An ingenious, self-cleaning, arrow-shaped trash rack (Figure 28) designed by Daugherty and Trautwein, Inc. was constructed, the storage capacity of the sink was increased by excavation, and a pipe was laid to direct the overflow of Nahm Sink to the stream in Buckberry Cave.

Leave the church parking lot onto Roselawn Way.

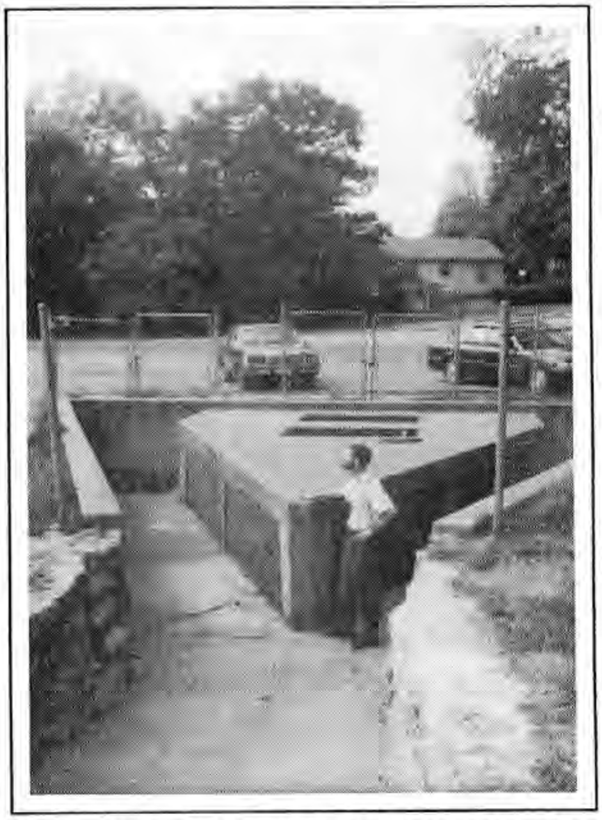


Figure 28. Specially designed trash rack protecting a drainage well in the parking lot of the Glendale Baptist Church (Stop 3).

0.1	3.0	Stop sign at Cabell Drive proceed straight.
0.2	3.2	Turn right onto Rhodes Drive at stop sign.

0.3	3.5	Veer to left, staying on Rhodes Drive at 'V'.
0.05	3.55	Turn right at stop sign onto US31W-Bypass.
0.05	3.6	Turn right into parking lot, just past O'Charley's Restaurant. Park in rear of lot near fenced area.

STOP 4. Bypass Cave. Storm water runoff from an intensively developed commercial area had been directed by storm sewers into the mouth of Bypass Cave. The cave has not been protected by a silt trap or trash rack, and debris has washed far into the cave. The cave often smells of gasoline, and on one occasion a gas detector was used to check the cave after nearby residents had to evacuate their homes because of gas fumes in their basements. A weir, stage recorder, and automatic water sampler were placed at the cave entrance and an investigation of urban storm water pollution was conducted (Figure 29). Results of this study indicate that storm water flowing into Bypass Cave at times exceeds the surface water criteria for public water supplies in the following areas:

1) coliform bacteria, 2) oil and grease, 3) chromium, 4) lead, and 5) iron.

Turn left from the parking lot onto US31W-Bypass proceeding south to stop light.

Figure 29. V-notch weir and recording instruments at the entrance to Bypass Cave (Stop 4).

0.2	3.8	Turn right at stoplight onto US231 (University Drive).
0.4	4.2	Stoplight at junction US68/KY80. Proceed straight. WKU's baseball and football stadiums are on the right.
0.5	4.7	Turn left at stoplight, onto Old Morgantown Road. Cross L&N railroad tracks.
0.3	5.0	Turn left into the unnamed access road to Dishman-McGinnis

Elementary School. The road is just past Johnson Drive on the left and Westland Drugs on the right.

STOP 5. Dishman-McGinnis Elementary School. In January of 1984 fumes began to rise from contaminated cave streams into several homes and buildings in Bowling Green's Forest Park Subdivision. Initial investigations were made by the Bowling Green Fire Department and Kentucky Fire Marshal's Office. In May, 1984 Crawford was asked by the State Fire Marshal and by the Bowling Green City Commissioners to investigate and prepare a proposal for dealing with the problem. The homes, buildings, drainage wells, and sinkholes with fumes in the Forest Park area were identified and it was recommended that EPA be asked to deal with the problem.

EPA Region IV began an investigation in cooperation with the Centers for Disease Control (CDC) in June, 1984. Air samples collected from bedrooms, crawl spaces, and basements of 125 homes in the Forest Park area were analyzed as were urine samples of residents from twenty homes. During the investigation the problem continued to worsen as fumes forced the partial evacuation of Parker-Bennett Elementary School in November, 1984 and Dishman-McGinnis Elementary School in January, 1985. Fumes were reported in over fifty homes, three commercial buildings, two schools, one church, eighteen drainage wells, four sinkholes,and nine caves. The most severe problems were in the Forest park area above the Lost River Groundwater Basin. After the initial investigation of the fumes problem in May, 1984, it was recommended that a backhoe be used to excavate down to bedrock at the place where the fumes were the strongest at each affected home or building, predicting that a bedrock crevice could be found leading down into the cave system. A pipe could then be installed into the crevice, and a fan with an explosion-proof motor could then be used to pull the fumes from the crevice and vent them into the atmosphere above the home. The negative pressure created by the exhaust fan would prevent the fumes from entering the home or building. Unfortunately, no government agency was willing to provide the money or assume the responsibility until November, 1984 when fumes forced the evacuation of three classrooms in Parker-Bennett Elementary School and threatened closure of the entire school. The Bowling Green City School Board provided the money, and a crevice was found immediately as predicted. The ventilation system worked quite well and the school did not miss a single day of classes.

In January, 1985 fumes in Dishman-McGinnis Elementary School were quickly ventilated also (Figure 30). After the Centers for Disease Control issued a health advisory for

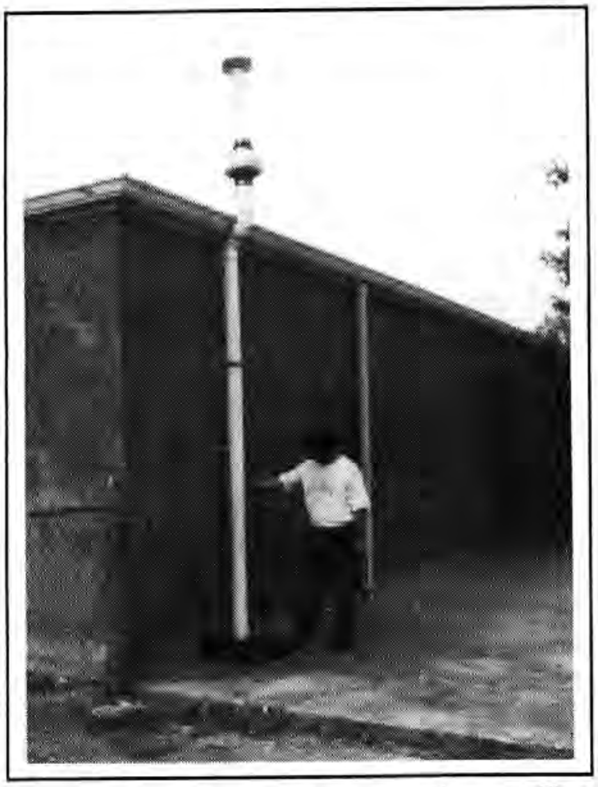


Figure 30. Ventilation system for gasoline fumes rising from the karst aquifer at Dishman-McGinnis Elementary School (Stop 5).

Bowling Green in March 1985, EPA used the same technique to ventilate fumes from affected homes or buildings. In every case a bedrock crevice was easily found with very little digging.

Return via the access road to Old Morgantown Road and turn left (west) onto it.

0.6 5.6 Turn right at the stop sign which marks the end of Old Morgantown Road and the junction of US231 (Morgantown Road).

0.2 5.8 Turn right into the second entrance road to Lampkin Park. A sign (Fields 3 & 4) denotes this turn.

0.1 5.9 Park in the paved lot on the right. Walk past the gate in the road and follow the gravel trail to the Lost River Rise.

STOP 6. Lost River Rise. The Lost River is approximately 65 feet wide and about 6 feet deep as it flows from under the ledge of a large crescent-shaped spring alcove. An underwater survey of the Lost River Rise revealed that water flows up from a cave passage 6-10 feet high and more than 100 feet wide located forty feet below the surface of the spring. The monitoring station at the rise consists of a trailer containing a stage recorder, Schneider Robot Water Quality Monitor, pump and automatic water sampler (not in operation at this time).

Return to Morgantown Road (US231) and turn right (west) onto it.

0.4 6.3 Turn left (south) at the stoplight onto KY880 (Hobson Lane).

1.4 7.7 Stoplight at the intersection of KY880 and US68/KY80. Proceed straight.

0.8 8.5 Turn right (south) at the stoplight at intersection of KY880 and US31W. The Bowling Green Mall is on your right.

0.1 8.6 Turn right into the Bowling Green Mall parking lot at the 'Big Lots' sign. Park at the end of the

the mall next to the Heilig-Meyers Furniture Store.

STOP 7. Sinkhole collapse-Bowling Green Mall. Here we will observe a small sinkhole collapse in the parking lot which has been active for about 10 years (Figure 31). A possible connection between this collapse and the nearby storm water drainage well will be discussed. Such wells, when installed by the city, are cased only to the soil-bedrock interface, and not into the bedrock itself. A diagram that illustrates this type of installation and associated problems appears in Figure 32.

0.3 8.9 Turn left at the stoplight onto Cave Mill Road, which is just past Crescent Bowl on the left. Park in gravel area immediately on the right.

STOP 8. Lost River Uvala, Blue Hole Rise, and Lost River Cave. The Lost River Uvala has formed by the collapse of the roof of Lost River Cave and extends in virtually a straight line for approximately 0.8 miles. It is probable that the cave formed along a joint swarm. The Lost River rises at the Blue Hole and flows about 400 feet into the massive entrance of Lost River Cave (Figure 33). The stream is

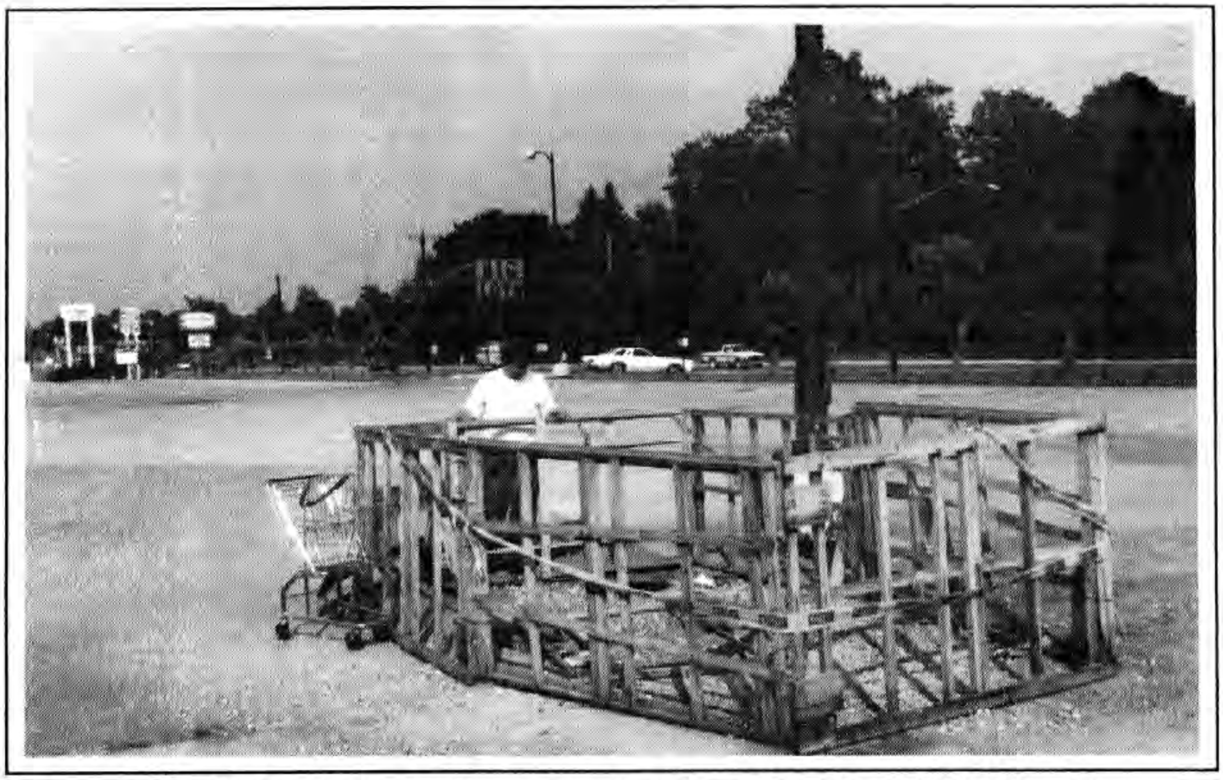
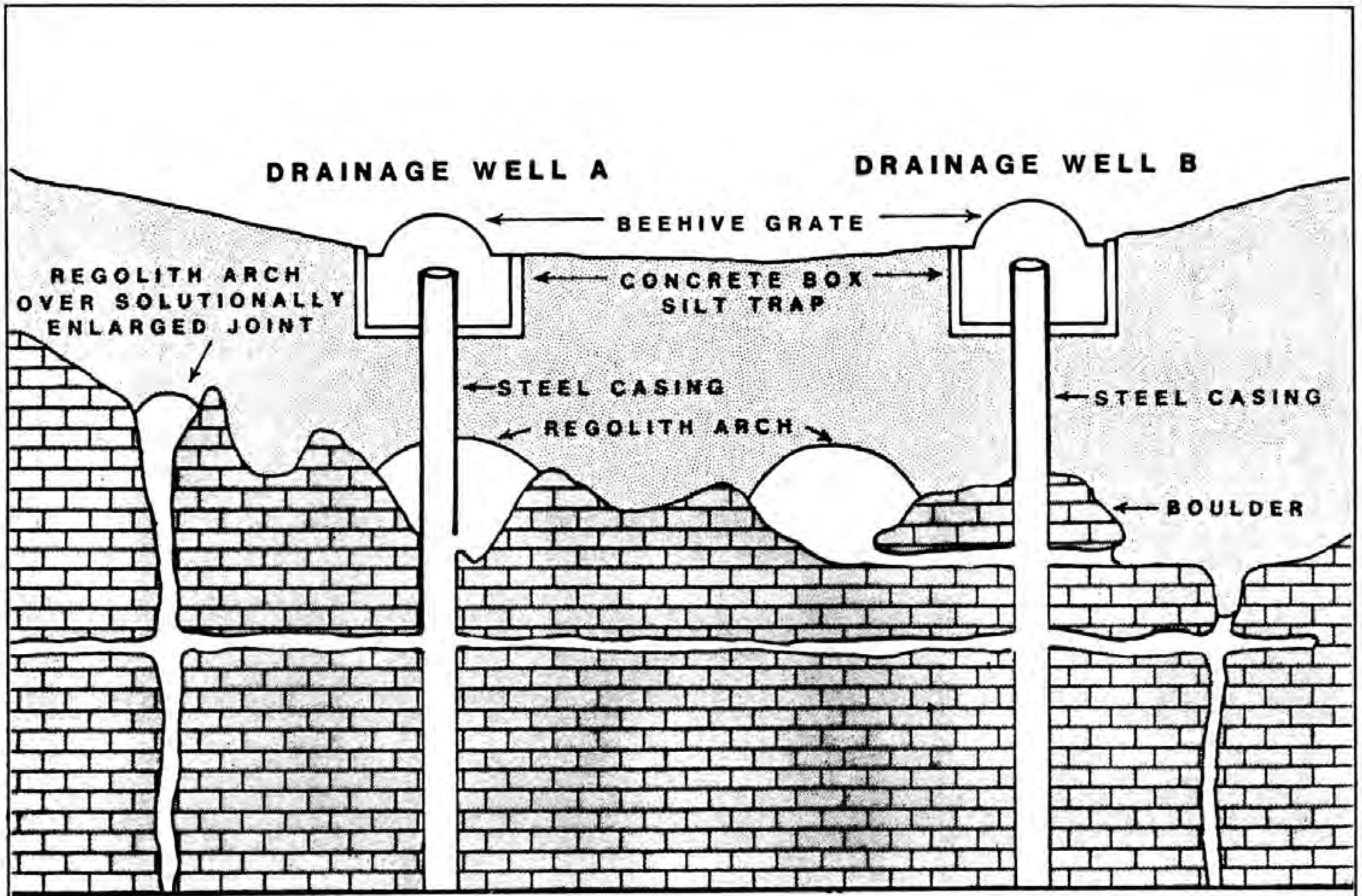


Figure 31. **Sinkhole collapse in the parking lot of Bowling Green Mall (Stop 7).**



Hypothesized development of regolith arches under and near drainage wells. Water flows out of drainage well A along a crack where the casing is resting on bedrock and saturates the surrounding regolith. As the water level in the well drops below the crack, piping of saturated regolith into the well creates a regolith arch. Drainage well B was only cased to a boulder above bedrock. During floods as water flows from the perched water above the bedrock into the well piping creates a regolith arch.

Figure 32. Hypothesized development of regolith arches under and near drainage wells.

perched upon the Lost River Chert in the accessible portion of the cave as it flows under Bowling Green.

Lost River Karst Window is a National Landmark and has long been of historic interest. A water-powered mill was built inside the massive cave entrance as early as 1796, and a night club occupied the entrance between 1933 and 1955. The dam, power house, bridge, and dance floor were built in the early 1930's.

The Lost River Karst Window is an important monitoring station for the investigation of karst flooding and water quality. The site has a stage recorder, an automatic water sampler, and a Schneider Robot Water Quality Monitor contained within a monitoring trailer (not in operation at this time).

Return to the stoplight at Cave Mill Road and US31W. Turn right (north) onto US31W.

3.7 12.6 Follow US31W straight (north), returning to the Howard Johnson's Hotel which will be on your left.

End of Field Trip - Day Two.

Figure 33. Lost River Cave, Bowling Green, KY (Stop 8).

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