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Welcome to Karst 2011!

The organizers and sponsors of the 2011 International Conference on Karst Hydrogeology and Ecosystems extend a warm welcome to you. With a location in the midst of one of the world’s greatest karst landscapes, Western Kentucky University has a rich history of karst scientific research, and has been pleased to host a series of international karst conferences over the last several decades, including the 8th International Congress of Speleology in 1981, and joint conferences of international karst commissions in 1998, 2003, and 2007. This one is to serve as a joint conference of the Karst Commissions of the International Association of Hydrogeologists, the UNESCO/IUGS International Geoscience Program Project IGCP/SDA 598 (Environmental Change and Sustainability in Karst Systems), and the Union Internationale de Spéléologie Commission on Karst Hydrogeology and Speleogenesis.

Once treated as some kind of esoteric backwater by the ‘mainstream’ science community, karst science continues to emerge, with at least three events driving this over the last few decades. A wealth of direct observation has been accumulated by both cavers and scientists who have created an extensive database by exploring and surveying thousands of kilometers of cave conduits, and their contents, around the world. This accumulated information has made it clear that the nature and function of a particular karst aquifer/landscape system depend on site-specific interactions of climate, lithology, structure, and topography, and that no “one size fits all” model can adequately describe karst hydrologic phenomena in general. Secondly, advances in technology have made new tools available for the study of karst. These include new methods of ground water tracing using fluorescent dyes and other materials, and geophysical methods that can assist in the location of conduits. The advancement of computer technology has provided important new insights into geochemical interactions within karst waters and their aquifer frameworks, as well as aquifer and flow path evolution. Lastly, there has been a virtual explosion of interest in karst hydrology due to environmental problems associated with karst, having both human and ecological dimensions. Growing populations on carbonate rock areas have increasingly had to attempt to find solutions to problems of water supply, both of water quality and quantity. Flooding has become more common with urbanization in karst regions, and sinkhole collapses and dam integrity present engineering challenges.

While of course research presentations form a core activity of any scientific conference, another aspect is also critical, and forms the basis of whether this meeting will ultimately be a success: that is, the potentially synergistic, informal communication and connections that take place among the participants outside of the lecture halls, during breaks and meals, and in the field. If there is a single motivation that we have for working to organize such a meeting, it is getting a group of folks together at one place, from around the world, who might otherwise never have gathered together. In the past many such “chance” meetings have led to wonderful and productive relationships, experiences, and cooperative efforts. Do take the time to chat with your colleagues, and otherwise all of us hope that your time here in Kentucky is productive, rewarding, and fun!
Sponsor Information

Hoffman Environmental Research Institute
www.hoffmanworld.org

Crawford Hydrology Laboratory
www.dyetracing.com

UNESCO/International Geoscience Union
www.igcpkarst.com

Western Kentucky University
Office of Research

Western Kentucky University
Office of Sponsored Programs
www.wku.edu/Dept/Support/SponsPrg/grants/

Western Kentucky University
Applied Research and Technology Program
www.wku.edu/artp

National Cave and Karst Research Institute
www.nature.nps.gov/nckri/

International Association of Hydrogeologists
www.iah.org

Edwards Aquifer Authority
www.edwardsaquifer.org
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Jonathan Oglesby
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Lindsay Rice
Natalie Schieber
Mark Sghiatti
Chasity Stinson
Rick Toomey
Sean Vanderhoff

Contact Information

Baymont Inn
165 Three Springs Rd
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1.270.842.3200

Komfort Cab Service
1.270.782.9410

Hampton Inn
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Bowling Green, KY 42104
1.270.842.4100

Emergency Contacts
Lisa Lynn Haynes
1.270.745.3252

Wendy DeCroix
1.270-745-4556

Bowling Green Emergency Services
Fire, Ambulance, Police- Dial 911
### Full Conference Schedule

**WEDNESDAY, 8 June 2011**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Location</th>
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<tbody>
<tr>
<td>7:00 am - 7:45 am</td>
<td>Hotel Shuttles (Baymont Inn/Hampton Inn parking area to WKU Snell Hall/Chestnut Parking Lot) Runs every 15 minutes</td>
<td>Hotel Shuttles</td>
</tr>
<tr>
<td>7:00 am - 8:00 am</td>
<td>Conference Registration</td>
<td>Snell Hall Lobby</td>
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</table>
| 8:00 am - 8:20 am | Opening Ceremony: Dr. Gordon C. Baylis, Vice President for Research  
Mr. Pat Reed, Superintendent of Mammoth Cave National Park | Snell Hall 3110           |
| 8:20 am - 10:00 am | Technical Session: Karst Geomorphology                                | Snell Hall 3110           |
| 10:00 am - 10:20 am | Break: Refreshments in Snell Hall                                    | Snell Hall 3110           |
| 10:20 am - 11:40 am | Technical Session: Engineering and Modeling in Karst Terrains         | Snell Hall 3110           |
| 11:40 am - 1:20 pm | Lunch Break                                                           | Shuttles will run to local areas |
| 1:20 pm - 2:40 pm | Technical Session: Isotope Geochemistry in Karst Settings             | Snell Hall 3110           |
| 2:40 pm - 4:40 pm | Technical Session: Cultural and Educational Aspects of Karst Environments | Snell Hall 3110           |
| 4:40 pm - 5:00 pm | Break: Refreshments in Snell Hall                                    | Snell Hall 3110           |
| 5:00 pm - 6:00 pm | Business Meeting: International Union of Speleology (UIS) Speleogenesis Commission | Snell Hall 3110           |
| 6:00 pm - 7:00 pm | Break: Shuttles will run between WKU, hotels, and Lost River Cave     | Shuttles will start departing at 9:30pm |
| 7:00 pm - 9:30 pm | Welcome Party: Lost River Cave and Valley                             | Shuttles will start departing at 9:30pm |
### THURSDAY, 9 June 2011

<table>
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<tr>
<th>Time</th>
<th>Activity</th>
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<tr>
<td>8:00 am</td>
<td>Hotel Shuttles will meet at Baymont Inn/ Hampton Inn parking area</td>
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<td>8:00 am - 8:30 am</td>
<td>Board Vans for Local Fieldtrips</td>
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<tr>
<td>8:30 am - 5:30 pm</td>
<td><strong>All Day Local Conference Fieldtrips</strong></td>
</tr>
</tbody>
</table>
| Option 1: Mammoth Cave Trip  
Option 2: Pennyroyal Plateau Surface Trip |
<p>|               | *Box lunches will be provided for both trips.                             |
| 6:00 pm - 9:30 pm | <strong>Cookout: Hamilton Valley</strong>                                             |
|               | <strong>Guest Speaker: Mr. Roger Brucker</strong>                                    |
|               | <em>Follow the Water: Discoveries in the Longest Cave</em>                      |
|               | <strong>Shuttles will depart for hotels at 9:30pm</strong>                           |</p>
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<thead>
<tr>
<th>Time</th>
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<td>Hotel Shuttles (Baymont Inn/Hampton Inn parking area to WKU Snell Hall/Chestnut Parking Lot) Runs every 15 minutes</td>
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<tr>
<td>8:00 am - 10:00 am</td>
<td>Technical Session: <strong>Karst Hydrochemistry</strong></td>
<td>Snell Hall 3110</td>
</tr>
<tr>
<td>10:00 am - 10:15 am</td>
<td>Break: Refreshments in Snell Hall</td>
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<tr>
<td>10:15 pm - 11:15 pm</td>
<td>Business Meeting: <strong>UNESCO/IUGS IGCP Project 598</strong>: &quot;Environmental Change and Sustainability in Karst Systems: Relations to Climate Change and Anthropogenic Activities&quot;</td>
<td>Snell Hall 3110</td>
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<tr>
<td>11:15 am - 11:30 am</td>
<td>Break: Refreshments in Snell Hall</td>
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<tr>
<td>11:30 am - 12:30 pm</td>
<td>Business Meeting: <strong>Karst Commission of the International Association of Hydrogeologists (IAH)</strong></td>
<td>Snell Hall 3110</td>
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<tr>
<td>12:30 pm - 2:00 pm</td>
<td>Lunch Break</td>
<td>Shuttles will run to local areas</td>
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<tr>
<td>2:00 pm - 4:20 pm</td>
<td>Technical Session: <strong>Karst Hydrogeology</strong></td>
<td>Snell Hall 3110</td>
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<tr>
<td>4:20 pm - 4:30 pm</td>
<td>Break: Refreshments in Snell Hall</td>
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<tr>
<td>4:30 pm - 5:30 pm</td>
<td><strong>Panel Discussion</strong>: International Karst Cooperation</td>
<td>Snell Hall 3110</td>
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<tr>
<td>5:30 pm - 7:00 pm</td>
<td><strong>Poster Session</strong>: Karst Topics</td>
<td>KY Museum (on campus)</td>
</tr>
</tbody>
</table>
| 7:00 pm - 9:30 pm     | **Closing Banquet**: Kentucky Museum  
**Guest Speaker**: Dr. Nick Crawford  
"Urban Development Upon Karst: Problems and Solutions for Bowling Green, Kentucky"  
Shuttles will start departing for hotels at 9:30pm |                        |
Sessions Schedule

WEDNESDAY, 8 June 2011

I. TECHNICAL SESSION: Karst Geomorphology  (Snell Hall 3110)

8:20am  Geophysical Investigations of Anthropogenic Karst Phenomena in Southwestern New Mexico  
Lewis Land and George Veni

8:40am  Karst Development and Hydrogeology of Wonosari Basin  
Eko Haryono, Erik Febriarta, and Subekti Damayanti

9:00am  Estimation of Soil Erosion Risk in Chahe Town, Guizhou Province using GIS and Remote Sensing  
Wei Huang and Michael Day

9:20am  Geological Structure and Underground Drainage of an High-Alpine Karst Aquifer System, Wetterstein Mountains, German Alps  
Ute Bellmann and Nico Goldscheider

9:40am  Regional Features of Hypogene Speleogenesis in the Prichernomorsky Artesian Basin (North Black Sea Region)  
A.B. Klimchouk, E.I. Timokhina, and G.N. Amelichev

II. TECHNICAL SESSION: Engineering and Modeling in Karst Terrains  (Snell Hall 3110)

10:20am  Karst Impacts on Dam Safety Risk Assessment in the US Army Corps of Engineers  
Kenneth E. Henn, III

10:40am  Characterizing Groundwater Flows in Small-Scale Karstic Voids using Single Borehole Tracer Dilution Tests  
Lou Maurice, Tim Atkinson, Ann Williams, and John Barker

11:00am  Analytical Modeling of Karst Processes on the Basis of Petrographic Mapping  
Arthur Palmer and Margaret Palmer

11:20am  Modeling Tracer Test Result in Karst Conduit: A Case Study at Guancun Subterranean River  
Jiang Guanghui, Wu Jichun, Guo Fang, Yu Shi, and Lin Yushi
III. TECHNICAL SESSION: Isotope Geochemistry in Karst Settings  (Snell Hall 3110)

1:20pm  Influence of Land Use Patterns on Dissolved Inorganic Carbon and $\Delta^{13}$C$_{\text{DIC}}$ for Epikarst Springs  
Mingzhu Lin, Daoxian Yuan, Shiyou Xie, Min Cao, Peng Wang, and Xiaoping Zhou

1:40pm  A Process Model of Cave Dripwater $\Delta^{18}$O Values: A Test of Reconstructing Decadal Variability in Speleothem Climate Records  
S.A. Truebe, T.R. Ault, and J.E. Cole

2:00pm  Nutrient Supply and Chemolithoautotrophy as a Possible Driver of Stygobiont Diversity and Aquifer Evolution: The Edwards Aquifer of South-Central Texas  
Benjamin T. Hutchins, Benjamin F. Schwartz, and Annette S. Engel

2:20pm  Assessing Recharge Elevations for Karst Springs of the Kaweah River, Sequoia and Kings Canyon National Parks, California  
Benjamin Tobin and Benjamin Schwartz

IV. TECHNICAL SESSION: Cultural and Educational Aspects of Karst Environments (Snell Hall 3110)

2:40pm  Investigating the Role of Guided Show Cave Experiences in Karst Understanding  
Leslie A. North and Philip van Beynen

3:00pm  Digging Deeper into a Bowling Green, Kentucky, Karst Legend: The Uncle Henry Story  
Margaret M. Gripshover

3:20pm  People, Politics, and a Park: The Unvarnished Story of the Creation of Mammoth Cave National Park  
Katie Algeo

3:40pm  The Groundwater to the Gulf Collaboration  
Robin Gary

4:00pm  Evaluating Karst Disturbance in Puerto Rico: Examining Methodologies and Future Implications  
Jason S. Polk, Brandon Porter, and Leslie A. North

4:20pm  Assessment of Internationally Shared Karst Aquifers: Example of Dinaric Karst Aquifer System  
N. Kukurić, H. Treidel, and A. Merla
FRIDAY, 10 June 2011

V. TECHNICAL SESSION: Karst Hydrochemistry  (Snell Hall 3110)

8:00am  Sulfide Oxidation and Evaporative Concentration: Competing Mechanisms in the Semi-Arid Karst of Northeastern Brazil
Augusto S. Auler

8:20am  Significance of Free-Surface Flow Representation for Numerical Modeling of Karst
Thomas Reimann, Rudolf Liedl, Tobias Geyer, and Martin Sauter

8:40am  Water Chemistry Variations and Source Mixing of a Distributary Spring System: the Carroll Cave – Toronto Springs System
Benjamin V. Miller, Robert N. Lerch, and Chris G. Groves

9:00am  Carbon Dioxide Degassing Flux from Two Geothermal Fields in Tibet, China
Shen Licheng, Wu Kunyu, Xiao Qiong, and Yuan Daoxian

9:20am  Carbonate Rock Dissolution Rates in Different Landuses and their Carbon Sink Effect
Zhang Cheng

9:40am  Methodology for Evaluating Flow and Hydrochemistry of Autogenic Recharge in Kentucky’s Mississippian Plateau
Chris Groves, Jason Polk, Ben Miller, Sean Vanderhoff, Carl Bolster, and Warren Campbell

VI. TECHNICAL SESSION: Karst Hydrogeology  (Snell Hall 3110)

2:00pm  Characterisation of Fluids and Evaluation of their Effects on Karst Development at the Discharge Zone of the Buda Thermal Karst, Hungary
Anita Erőss, Judit Mádl-Szőnyi, and Anita É. Csoma

2:20pm  Hydrogeology and Geomorphology of Carbonatic Conglomerates in the Folded Molasse Zone of the Northern Alps
Nico Goldscheider and Nadine Goeppert

2:40pm  Interconnection of the Edwards and Trinity Aquifers, Central Texas, USA
Marcus O. Gary

3:00pm  Hydrogeological Investigations and Sinkhole Research on Forested Karst Landscapes on Coastal British Columbia, Canada
Tim Stokes, Paul Griffiths and Carol Ramsey
3:20pm  Storm Event Impacts on Epikarst Storage and Transport of Organic Soil Amendments in Kentucky  
Sean M. Vanderhoff, Jason S. Polk, Chris G. Groves, Benjamin Miller, and Carl Bolster

3:40pm  Impact of Land Use and Climate Changes on Long-Term Discharge of Springs  
Neven Kresic, Jiang Guanghui, and Tim Glover

4:00pm  Karst Issues in Jamaica  
Angella Graham

I. POSTER SESSION: Karst Hydrogeology  
(KY Museum)

1. Physico-Chemical Formation during Storm Events in an Underground River of a Typical Karst Watershed, SW China  
Yang Pingheng, Yuan Daoxian, Jiang Yongjun, He Qiufang, and Shen Licheng

2. Overview of Quantitative Characterization Methods to Estimate Water Fluxes in Karst Hydrogeologic Investigations  
Earl A. Greene and Charles J. Taylor

3. The Influence of Allogenic Water on Karst Process - A Case Study in the Maocun Subterranean River in Guilin, China  
Huang Fen and Tang Wei

4. Karstification in Breccia and Flysch (Mount Nanos, Slovenia)  
Martin Knez and Tadej Slabe

5. Hydrogeological - Environmental Issues and Causes of Karst Water Systems in Northern China  
Liang Yongping, Wang Weitai, Zhao Chunhong, and Zhang Cheng

6. Long-Term Trends of Precipitation, Streamflow, and Barton Springs Discharge, Central Texas  
Robin Gary, Brian Hunt, Steff Lazo-Herencia, and Brian Smith

Bryan Booth

8. Occurrence of Hypogenic Caves in Coastal Re-Entrants and Gullies  
Patricia Kambesis and John Mylroie
Jonathan Oglesby

10. Localized Hydrology of Autogenic Recharge in Kentucky’s Mississippian Plateau  
Ben Haaff, Chris Groves, and Jason Polk

11. Protecting Karst Systems and Groundwater in Rural China through Community Outreach and Science Education  
Jason S. Polk, Leslie A. North, Guo Fang, and Chris Groves

12. Dam and Reservoir Construction on Coastal Plain Carbonates: Site Study from Smith County, Mississippi  
John E. Mylroie, Darrel W. Schmitz, Jim May, Will D. McBryde, and Jason A. Mcilwain

Business Meetings Schedule

WEDNESDAY, 8 June 2011

5:00pm-6:00pm  Business Meeting: International Union of Speleology (UIS) Speleogenesis Commission  
(Snell Hall 3110)

FRIDAY, 10 June 2011

10:15am-11:15am  Business Meeting: UNESCO/IUGS IGCP Project 598: "Environmental Change and Sustainability in Karst Systems: Relations to Climate Change and Anthropogenic Activities"  
(Snell Hall 3110)

11:30am-12:30pm  Business Meeting: Karst Commission of the International Association of Hydrogeologists  
(Snell Hall 3110)

4:30pm-5:30pm  Panel Discussion: International Karst Cooperation  
(Snell Hall 3110)
Option 1: Pennyroyal Plateau Surface Trip: The South-Central Kentucky Karst

Led By:
Dr. William B. White
Dr. Bette White
Dr. Chris Groves
Dr. Jason Polk

Guide By:
Dr. William B. White

Professor Emeritus of Geochemistry
Materials Research Institute
The Pennsylvania State University
University Park, PA 16802

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TABLE OF CONTENTS

The Geologic and Hydrologic Setting
Field Trip 1. The Turnhole Drainage Basin
Field Trip 2. The Historic Section of Mammoth Cave
Field Trip 3. The Eastern Section of Mammoth Cave

PREFACE

This guidebook was prepared for Karst Hydrology, a one-week course taught at Western Kentucky University as part of their summer course program in cooperation with Mammoth Cave National Park. As such it emphasizes features discussed in the course and is led by the course instructor. Field Trips 2 and 3 are in Mammoth Cave. For the course, these are evening trips led by the instructor with the approval of the Park. Although these trips follow the tourist routes mostly, there are side excursions into several unlighted parts of the cave.

The trip descriptions are presented in such a way that they also can be used as a stand-alone guidebook for general usage. Field trip 1 is a surface driving tour with stops either within the Park or along public highways. Field trips 2 and 3 can be followed by taking the Historic Tour and the Grand Avenue Tour provided by the National Park Service. However, for the in-cave tours, the features discussed in this guidebook may not be specifically pointed out by the tour leaders. And, of course, the off-trail portions would not be visited.

NOTE. Many of the stops on the surface field trip and all of the cave field trips are in Mammoth Cave National Park. Defacement, damage, or specimen collecting is strictly forbidden. Any such incidents are treated as Federal crimes and are prosecuted accordingly. Especially for the students in the Karst Hydrology course, being able to wander freely through Mammoth Cave is a great privilege. This privilege should not be abused.

ACKNOWLEDGEMENTS

There have been many contributors to our knowledge of the Mammoth Cave Area but the outstanding ones, many of whose illustrations are used in this Guidebook, are Arthur and Margaret Palmer and the late James F. Quinlan.
THE GEOLOGIC AND HYDROLOGIC SETTING

INTRODUCTION

The South-Central Kentucky Karst, also known as the Mammoth Cave Area is a world-class example of a shallow, intensely karsted, carbonate terrain. The area has been the subject of scientific investigations since the early 1800’s and has accumulated a vast literature. For the purposes of providing additional background information for those on field trips, the following sources may be helpful: Bedrock geology – Weller (1927); review from a geomorphological viewpoint – White et al. (1970); detailed consideration of many aspects of the hydrology – White and White (1989); detailed guidebook to the region and to Mammoth Cave – Palmer (1981); guidebook to the regional hydrology – Quinlan and Ewers (1981).

The South-Central Kentucky Karst extends both south and north of the Mammoth Cave area, but the portion visited on these field trips is displayed on U.S. Geological Survey Mammoth Cave, Rhoda, Park City, and Smiths Grove 7.5 minute quadrangles. The bedrock geology has been mapped by the U.S. Geological Survey also at the 7.5 minute quadrangle scale. The maps are GQ-351 (Mammoth Cave), GQ-219 (Rhoda), GQ-183 (Park City), and GQ-357 (Smiths Grove).

THE PHYSIOGRAPHIC SETTING

The Mammoth Cave area is located in a wide band of Mississippian limestone that extends from southern Indiana, around the eastern and southern edge of the Illinois Basin into western Kentucky (Fig. 1). Immediately to the east is the broad structural high of the Cincinnati Arch along which the Mississippian limestones are eroded away. The structural high brings up Ordovician limestones in the Blue Grass Region to the north and in the Nashville Basin to the south. Further east, the Mississippian limestones reappear along the western margin of the Appalachian plateaus. To the northwest the limestones dip below the upper Mississippian and Pennsylvanian clastic rocks of the Illinois Basin.

The main features of the South-Central Kentucky Karst appear in Figure 2. From southeast to northwest: The Glasgow Upland, a rolling topography mostly on shales and shaley limestones so that surface drainage is preserved. The Sinkhole Plain, an area lacking surface streams but pocked with sinkholes formed on the Mississippian St. Louis and Ste. Genevieve Limestones; the Dripping Springs Escarpment, a dissected and irregular escarpment about 300 feet in elevation; the Mammoth Cave (or Chester) Plateau, the dissected, sandstone-capped ridges south of Green River, that contain the major cave systems; the Hilly Country, more rugged topography north of Green River underlain by clastic rocks.

STRATIGRAPHY
The overall stratigraphic column is shown in Figure 3 and a more detailed column for the limestone in Figure 4. Both columns are the work of A.N. Palmer.

![Figure 1](image1)

**Fig. 1.** The regional scale setting for the Mammoth Cave area (Black spot in lower center). From Weller (1927).

![Figure 2](image2)

**Fig 2.** The physiographic features of the South-Central Kentucky karst. From White et al. (1970).
Fig. 3 Regional stratigraphic column for south-central Kentucky. Palmer (1975).
Fig. 4. Detailed stratigraphy of the karstic limestones. Palmer (1975).
The Salem Formation (usually called the Salem-Warsaw Formation) is a combination of calcareous shales and shaley limestones. It is an aquiclude that forms the ultimate hydrologic base in the region.

The St. Louis Limestone underlies the southern and eastern portion of the Sinkhole Plain. It contains numerous chert beds which act to perch the underground flow resulting in underground streams that flow down-dip along the chert beds.

The Ste. Genevieve Limestone occupies the portion of the Sinkhole Plain closest to the Dripping Springs Escarpment. The Lost River Chert that occurs near the bottom of the Ste. Genevieve is also an important perching bed. Very large sinkholes develop in the Ste. Genevieve.

The Girkin Limestone makes up the top of the section and outcrops along the Dripping Springs Escarpment and in the walls of the karst valleys on the dissected Mammoth Cave Plateau.

The Big Clifty is the resistant sandstone that holds up the ridges of the Mammoth Cave Plateau. The contact between the Big Clifty and the underlying Girkin limestone is an unconformity. In places, the sandstone rests directly on the limestone; in others there occurs about five feet of the black Fraileys Shale. At the top of the Big Clifty is a carbonaceous zone containing abundant pyrite (FeS₂).

Above the Big Clifty is the Haney Limestone. The Haney is only about 40 feet thick but contains a perched aquifer that drains through a series of small springs. Those on Flint Ridge have been tapped for use as water supplies. Although the feeder systems for the Haney Springs are solutionally widened fractures, response of the springs to storms is rapid; the water chemistry is highly undersaturated and highly variable.

At the top of the section is the Caseyville Sandstone and Conglomerate, equivalent to the Pennsylvanian Pottsville Formation of the Appalachians. There is a major unconformity between the shales and siltstones that make up the uppermost Mississippian beds and the Pennsylvanian. A deep channel was cut into the Mississippian formations during the erosional period of the unconformity and the channel filled with the Caseyville Conglomerate. Thus on Flint Ridge, the Caseyville gravels lie directly on top of the Big Clifty Sandstone. Quartz pebbles from the Caseyville Conglomerate are an important component so the cave sediments.

**STRUCTURE**

The regional dip is to the northwest toward the Illinois Basin. Superimposed on the regional dip is a great deal of subdued local structure. Most important of these structures, from the viewpoint of cave development, is a monoclinal fold more or less coincident with the Dripping Springs Escarpment (Fig. 5). The presence of this fold has kept the position of the escarpment essentially fixed because it locks the edge of the resistant Big Clifty Sandstone.
Fig. 5. Structure contours for the Mammoth Cave Area. From Quinlan and Ewers (1981).
The influence of the monoclinal fold can be seen in the cross-section through the Sinkhole Plain and the plateau (Fig. 6). The down-fold of the structural monocline has preserved the Big Clifty Sandstone and taken the St. Louis Limestone of the Sinkhole Plain below base level. Without the monocline, erosion would have pushed back the sandstone at least as far as the Green River. The Girkin and Ste. Genevieve Limestones would have been highly dissected and the long cave system, if they had developed at all, would have been broken into many smaller fragments.

![Cross-section through the Mammoth Cave Region](image)

**Fig. 6.** Cross-section through the Mammoth Cave Region based on USGS 7.5 minute quadrangle topographic and geologic maps.

Small faults are common. These typically have displacements of few feet to a few tens of feet. The faults seem to have very little influence on ground water flow or cave development. There are also broad and very gentle folds that appear in the structure contour maps but are difficult to impossible to discern on the ground.

**DRAINAGE**

The base level streams for the region are the westward-flowing Green River and the Barren River. Critical to the development of large caves is the position of the Green River. It
has cut a deep canyon through the Mammoth Cave Plateau, down-dip from the recharge areas on the Sinkhole Plain. The Green River is the ultimate base level for all drainage through the Mammoth Cave Region. There is a drainage divide along the southern and eastern borders of the Sinkhole Plain. South of the divide, surface streams are tributary to Beaver Creek, a tributary of the Barren River. North of the divide, surface streams flow on the Salem Warsaw and lower St. Louis where they flow northward underground beneath the Dripping Springs Escarpment, to eventually discharge in a series of big springs along the Green River.

Although there are no surface streams crossing the Sinkhole Plain, the underground drainage has been mapped into well-defined ground water basins using dye-tracing techniques (Fig. 7). Each of the large springs on Green River has a distinct catchment. The Turnhole Spring, the objective of this field trip, is one of the largest. Turnhole Spring is on a prominent meander bend and is also the last major discharge into the Green River in the downstream direction. Not far below Turnhole Spring, the river bed is on sandstone and no further karstic outlets are possible. On the Sinkhole Plain, this is reflected in a drainage divide that crosses the Plain between the swallet of Little Sinking Creek and the swallet of Sinking Creek. Little Sinking Creek is part of the recharge area for Turnhole Spring while the water from Sinking Creek flows to the west to resurge at Graham Spring near Bowling Green.

MAMMOTH CAVE

The breaching of the sandstone caprock allowed the Mammoth Cave Plateau to be dissected into plateau fragments separated by intervening karst valleys. Once the sandstone was breached, the drainage quickly migrated to the subsurface. Although the valleys are tributary to the Green River, the valley floors are a sequence of closed depressions separated from the river by high saddles. Creation of the karst valleys also truncated high level cave passages. As a result, the historically known caves are located under the ridges and connecting them together to form the Mammoth Cave System required long and challenging exploration.

From west to east, the main ridges are: Joppa Ridge, Doyel Valley, Mammoth Cave Ridge, Houchin's Valley, and Flint Ridge. Further east, the plateau is more highly dissected but fragments such as Northtown Ridge, Toohey Ridge, and Fisher Ridge remain and are relevant to the expanding Mammoth Cave System. A topographic map of Mammoth Cave Ridge (Fig. 8) shows the locations of the entrances to what was historically Mammoth Cave. It also shows the closed depressions formed where the caprock was breached.

Mammoth Cave, as explored from the Historic Entrance, was known to the early Kentucky pioneers in the late 18th Century and to the local Native Americans some thousands of years earlier. Exploration proceeded erratically first by saltpetre miners and later by the guides after Mammoth Cave was opened as a tourist attraction. The most useful publically available map of Mammoth Cave was constructed by Max Kämper in 1908. Long buried in the files of the Mammoth Cave Estate and later the National Park Service, this remarkable map was printed for distribution by the Cave Research Foundation and is available at the gift shop of the Mammoth Cave Hotel or from Cave Books, CRF’s publishing arm. Kämper’s map shows about 35 miles of passage. Little was added to Mammoth Cave following Kämper’s exploration until the 1920’s when George Morrison opened the New Entrance and soon after the Frozen Niagara
Entrance. These provided access to a portion of the cave beyond the boundaries of the Mammoth Cave Estate.

Fig. 7. Ground water basins in the Mammoth Cave Area. Based on a much more detailed map by Quinlan and Ray (1981) (reproduced in White and White, 1989).
Fig. 8. Topographic map of Mammoth Cave Ridge showing the various entrances to Mammoth Cave and an overlay of some of the principal main trunk cave passages. Note that the locations of the Carmichael and Violet City entrances are reversed, an error on the original topographic map. From White et al. (1970).

This was the situation in the Mammoth Cave Region when the modern period of exploration began in the 1950’s. There was Mammoth Cave, to which had been added the New Discovery Section in 1938. Under Joppa Ridge was Proctor Cave operated as a show cave at one time but now part of the National Park. On Flint Ridge was Great Salts Cave, with a natural entrance known to the Native Americans, and now part of the National Park. There was Colossal Cave, once a show cave operated by the L&N Railroad, now also part of the National Park. There was Crystal Cave, discovered by Floyd Collins in 1917, and operated as a private show cave and there was Great Onyx Cave, also a private show cave.

Exploration of National Park Caves was not permitted in the 1950’s. The first foray was through the privately-owned Floyd Collins Crystal Cave and it took the form of a grand expedition with a week-long camp set up within the cave (Lawrence and Brucker, 1955).
Because the private caves were about to be sold to the National Park Service, some formal arrangement was needed and the result was the Cave Research Foundation. CRF negotiated access to not only Crystal but other Flint Ridge caves and intensive survey operations were soon underway. Rather quickly Crystal Cave, Colossal Cave and Salts Cave were connected forming the Flint Ridge Cave System. These passages appear on a map folio by Denver Burns and Roger Brucker that was published by CRF in 1964. The next major connection was in 1972 when a low-level passage was found extending beneath Houchins Valley and connected the Flint Ridge System to Mammoth Cave (Brucker and Watson, 1976). Progress was rapid in the 1970’s and 1980’s. Proctor Cave, previously isolated on Joppa Ridge, was found to contain a major stream – Logsdon River – that proved to be the long suspected master drain that pirated recharge that had previously flowed through Mammoth Cave and took it to Turnhole Spring. A new cave – Roppel Cave – was discovered outside the Park on Toohey Ridge. Upstream Logsdon River was linked to Mammoth Cave and Roppel was spliced in as well (Borden and Brucker, 2000). The result, as of 2009, is an integrated sequence of cave passages representing several major drainage lines and their evolution over at least three million years of time.

There are many cave fragments have not been connected to the Mammoth Cave System. As of early 2009, the caves in the immediate area with surveyed lengths greater than five miles are:

<table>
<thead>
<tr>
<th>Cave/Mammoth System</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammoth Cave</td>
<td>367.00 miles</td>
</tr>
<tr>
<td>Fisher Ridge System</td>
<td>111.86 miles</td>
</tr>
<tr>
<td>Whigpistle-Jackpot-Martin Ridge</td>
<td>34.27 miles</td>
</tr>
<tr>
<td>Hidden River System</td>
<td>21.10 miles</td>
</tr>
<tr>
<td>Crump Spring Cave</td>
<td>10.74 miles</td>
</tr>
<tr>
<td>James Cave</td>
<td>10.25 miles</td>
</tr>
<tr>
<td>Vinegar Ridge Cave</td>
<td>8.41 miles</td>
</tr>
<tr>
<td>Lee Cave</td>
<td>7.82 miles</td>
</tr>
</tbody>
</table>

These data are from Robert Gulden’s “Long Cave List”.

After 50 years of effort and countless miles of survey, there is still no generally available map of Mammoth Cave. The 1964 CRF folio describes much of the Flint Ridge portion of the system although passage detail is sparse. But for Mammoth Cave proper, there is only the 1908 Kämper map. At the 2007 NSS Convention, Marengo, Indiana, CRF arranged to have the draft map of the entire system spread out on the floor of the gymnasium. Viewers in their socks could walk (or crawl) across the map finding some sections in elegant detail while other sections appear only as survey lines.
FIELD TRIP 1

THE TURNHOLE DRAINAGE BASIN

The objective of this field trip is to get a sense of the layout and size of karst drainage basins in the Mammoth Cave Region. To do this, we begin at the drainage outlet and follow the drainage upstream to the drainage divide, then downstream again along the main Turnhole Drainage.

Mileages have been scaled from topographic maps, not logged in the field, so allowances need to be made.

POINT OF ORIGIN: THE PARK CITY INTERCHANGE ON I-65

0.0 Follow the access road, KY route 255, toward Mammoth Cave National Park.

1.3 Diamond Caverns, a privately-owned show cave on the right.

2.3 Intersection with KY route 70. Bear left on route 70, the main entrance road into Mammoth Cave National Park. We are driving on the sandstone caprock along Joppa Ridge.

3.9 Intersection at Sloan’s Crossing. Turn right toward Park headquarters. We descend from Joppa Ridge and cross the high saddle that marks the downstream end of Doyel Valley. To the right is Doyel Valley, a deep karst valley with multiple closed depressions. We then climb up onto Mammoth Cave Ridge.

5.5 Cross-road. Continue straight toward Park Headquarters.

6.2 Cross-road. Turn left on the road to Mammoth Cave Ferry. We descend from Mammoth Cave Ridge into the valley of the Green River.

7.4 Turn right into the parking lot for Echo River and the Mammoth Cave Ferry.

STOP 1. Green River and Echo River Spring

Green River flows in a narrow V-shaped valley with a pool stage elevation of 420 feet. It is the base level for all of the drainage from the ridges and the Sinkhole Plain as far south and east as the drainage divide. The river is flowing on a thick pad of alluvium with the bedrock channel at least 30 feet below the river bottom. As a result, the springs discharge from rise pools with the orifice between the alluvial fill and the bedrock valley wall. Because of the narrow valley, flood stage can be as much as 60 feet above pool stage.

A trail from the parking lot leads about a quarter mile to Echo River Spring. The spring emerges from beneath a limestone ledge but the feeder tube is at considerable depth below the surface orifice. Divers have penetrated the spring and it does indeed connect, through more
than 3000 feet of submerged passage, with Echo River in Mammoth Cave. The spring discharge is peculiar. Intense storm activity on the Sinkhole Plain will cause the discharge to suddenly increase. The present-day catchment for Echo River Spring is limited to a few square miles on the Mammoth Cave Plateau. Flow markings in the high level passages in Mammoth Cave indicate a much larger paleocatchment, taking up much of the ancestral Sinkhole Plain. High recharge in this ancestral catchment, now draining to Turnhole Spring, activates abandoned cave passages and causes the water to spill over into the Echo River Basin, increasing its discharge. The drainage in Echo River Spring can also reverse. Rising water levels in Green River can cause river water to flow up the spring channel and into the spring orifice. Because of the low gradients within the conduit system, water may back up several miles into the cave system.

Leave parking lot, drive back up onto Mammoth Cave Ridge and backtrack.

10.8 Intersection at Sloan’s Crossing on Joppa Ridge. Turn left.

10.9 Pull into parking area at Sloans Crossing Pond. Follow path to the pond.

STOP 2. Sloan’s Crossing Pond.

Sloan’s Crossing Pond was at one time a small open lake perched on the Big Clifty Sandstone. Today, vegetation is crowding in. Little water remains and that little is brown and thick with decayed plant material and humic substances. The Big Clifty can act as an aquifer and it was possible to dig shallow wells suitable for farm water supplies. Dig too deep, of course, and the well would penetrate the underlying cavernous Girkin Limestone with the true water table several hundred feet down.

Continue east on the Joppa Ridge road.

13.4 Intersection with route 255. Turn right, south, on route 255.

13.7 Pull off next to road cuts on right where the highway has sliced through Cedar Hill.

STOP 3. The Epikarst.

The soil profile on non-carbonate rocks usually has an organic-rich A-horizon at the top, a more clay-rich B-horizon below, and a thick rubble transition zone, or C-horizon, consisting of partly weathered rock fragments that gives way to solid bedrock below. In carbonate terrain, the C-horizon is often missing. There is a sharp contact between the soil and unweathered bedrock visible in this and other roadcuts and outcrops. The soil/bedrock contact is the zone of most intense weathering. Rainfall, soaking through the O- and A-horizons dissolves carbon dioxide from the soil atmosphere to values 10 to 100 times the atmospheric background. CO₂-rich water with a pH between 4 and 5 reaches the underlying limestone and dissolves the rock. However, dissolution of the bedrock is not uniform. It is concentrated along joints, bedding plane partings and any other weaknesses in the rock. The result is an extremely irregular rock-surface with deep solution trenches along joints and
elaborate sculpturing of the rock surface. This zone of soil-filled crevices and bedrock pinnacles is known as the *epikarst*.

Walk the outcrop and examine the great variety of solutional sculpturing of the bedrock surface.

This roadcut in the Girkin Limestone illustrates why construction in karst terrain is such a hazardous business. If we were to scramble up into the woods beyond the top of the cut, the land surface would be uniform with no surface expression of the bedrock below. Imagine a house with one corner of the foundation resting on one of the limestone buttresses but with another corner resting on a soil-filled cavity. Complete sinkhole collapse is not necessary. Differential settling due to soil compaction is enough to seriously damage the house.

Continue south on route 255. Cross beneath I-65.

16.1 Intersection of route 255 with U.S. route 31W in Park City. Turn left.

16.3 Blinker light. Turn right on KY route 255, cross the railroad tracks, then turn right again past the small park that marks the ruins of Bell’s Tavern. Bell’s Tavern was once the main stopping point for visitors to Mammoth Cave. From here they could take either a stage coach or the Mammoth Cave Railway to cover the 10 miles between the main line of the L&N and the cave. At the edge of town, route 255 turns south again and we follow it across the Sinkhole Plain.

Park City is on the Ste. Genevieve Limestone. About one mile south of Park City is the contact between the Ste. Genevieve and the underlying St. Louis Limestones. Sinkholes are the prominent landscape feature in all direction on both the lower Ste. Genevieve and upper St. Louis. This is classic sinkhole plain topography.

Note the range of sizes and shapes of sinkholes. Many are gently sloping bowls, completely grass-covered. Some are deeper and steep sided. Some have soil piping collapses on the bottoms of the sinkholes. Some hold water to form sinkhole ponds. The residuum from the weathering of the limestone is very clay-rich and it can form an impermeable layer on the bottoms of the sinkholes sufficient to retain water even during the dry season. However, sinkhole ponds are ephemeral features. An abrupt piping failure of the clay liner and the sinkhole pond can drain in minutes or hours.

19.0 Sharp turn to the south just beyond Mount Vernon Church. This spot marks the approximate position of the line of swallets of the small streams that flow northward. We remain on the St. Louis Limestone, but the lower parts of the section have many chert layers generating a regolith that will support surface streams.

21.6 Intersection of route 255 with U.S. route 68 at a cross-road called Bon Ayr. Turn right, west, on route 68.
Fig. 9. Cross-section sketch of a drainage line from the headwaters to the Green River. Note that the (hypothetical) active cave passage cuts across the stratigraphic section. The swallets are in the St. Louis Limestone, Turnhole Spring is in the upper part of the Ste. Genevieve.
Driving along route 68, we are in the headwaters of the Turnhole Spring and Graham Spring drainage basins (Fig. 9). The drainage divide with Beaver Creek is several miles to the south. The small surface streams seen from the highway are tributaries of Sinking Creek or Little Sinking Creek. There is, in fact, a divide a half mile south of the highway, but it is a divide between Little Sinking Creek which flows to Turnhole Spring on the Green River and Sinking Creek which flows to Graham Spring on the Barren River at Bowling Green. There are many ponds and swamps in this upland area.

26.2 Village of Hays. Turn right onto KY route 259 north toward Rocky Hill.

The general trend of the structure is ENE – WSW. Because route 68 is an east-west road, we have been climbing through the stratigraphic sequence and so just east of Hays came back into an area of intense sinkhole development. Route 259 winds between and through sinkholes of various sizes.

28.2 Cross I-65 on an overpass.

28.6 Turn right onto gravel road. This is the second gravel road north of I-65. Drive to the valley bottom and park.

STOP 4. Blind Valley of Little Sinking Creek

The sinking streams on the southeastern margin of the Sinkhole Plain typically have carved shallow valleys such as this one. Little Sinking Creek is flowing to the north on an alluvial pad on the valley floor. It sinks against the blind footwall of the valley a quarter mile north of the road. There is no cave entrance, only a huge pile of logs and other debris that have washed into the swallet. Because of the debris clog, the swallet has a limited carrying capacity and during high flow water backs up into the valley. In past field trips, we have found mud several feet up the trees and fence posts where we are parked (Fig. 10).

Continue on the gravel road, turn right along the creek, then right again. This will bring us back onto route 259 at the first turn-off north of I-65. Turn right on route 259 to complete the loop.

29.8 Village of Rocky Hill. Cross the railroad tracks.

30.0 At the north edge of the village, turn left onto Smiths Grove – Rocky Hill road.

From Hays to Rocky Hill and also along this road are some of the largest sinkholes on the Sinkhole Plain (Fig. 11). These are all developed in the St. Louis Limestone. On the left near the end of the road is a sequence of large sinks that may represent a collapsed cave roof (Fig. 12). A mile to the south, on the outskirts of Smiths Grove is Crump Cave, at 20 – 30 feet wide, the largest fragment of trunk passage found beneath the Sinkhole Plain.

33.2 Intersection. Turn right, north.
Fig. 10. Two views of the blind valley of Little Sinking Creek. Above: during dry weather. Below: the flooded valley during high runoff. The line of fence posts and the road in the foreground are where we normally park.

34.7 Intersection with US Route 31W. Cross highway and continue north up the Dripping Springs Escarpment and onto the Mammoth Cave Plateau.

Highway 31W is just north of the contact between the St. Louis and Ste. Genevieve Limestones. Within a mile and a half, as we climb the escarpment, we cross the Ste. Genevieve, the Girkin, the Big Clifty Sandstone, and the Haney Limestone to emerge on the plateau on the Hardinsburg Sandstone.
Fig. 11. Segment of the Smiths Grove 7.5 minute USGS Quadrangle map. The valley of Little Sinking Creek is lower right. Note density of sinkholes.
Fig. 12. Large compound sink in St. Louis Limestone at western end of Sinks Grove – Rocky Hill road.

37.5 Cross road at village of Pig. Continue straight ahead.

38.7 National Park Boundary

39.1 Pull into Cedar Sink parking area.

STOP 5. Cedar Sink

We have descended into Smith Valley, a karst valley formed when the sandstone caprock of the plateau was breached. We are near the top of the Girkin Limestone with the contact with the overlying Big Clifty a short distance up the hill. The trail to Cedar Sink more or less follows contour along the wall of the valley for about ¾ mile. The trail is through a cedar break with few landmarks. The old trail led directly to Cedar Sink but it has been rerouted by the Park Service. Now we turn before we reach the edge of the sink and hike uphill along the remnants of a road that once was Kentucky Route 70. Then the trail circles the southern edge of the sink and eventually brings us to a platform overlooking the sink.

Cedar Sink is a vertical-walled collapse sink that is vaguely kidney-shaped (Fig. 13). From the overlook we are looking straight down into the south end of the sink. Looking ahead, there is a northern arm and a northeastern arm with a spur of ridge sticking out between them.
Fig. 13. Map of Cedar Sink. From work of James F. Quinlan.

From the overlook, continue down the trail and down an iron stairway to the bottom of the sink. There is a wet-weather spring at the south end of the stream channel to the left of the Park Service trail. What is seen here depends on the weather. The stream channel is an overflow route and is dry some times of the year. At other times there is a strong flow of water.
in the channel. Even during dry periods, standing water can be seen a short distance down the spring orifice. A trail up the far bank brings one to the gated entrance to South Cave, an isolated fragment with about half a mile of passage.

Continuing downstream on the Park Service trail brings us to a platform at the north end of the stream channel. Overflow water sinks against the wall at the end of the channel. The main flow does not appear at the surface and is somewhere below and off to the side of the surface channel. The contact between the Girkin and Ste. Genevieve Limestones is on the cliff just above the level of the platform. The platform is the end of the Park Service trail. Beyond the platform, the old trail into Cedar Sink can be seen. This trail descends over a series of limestone ledges and was deemed too dangerous for public use, thus the new circuitous route. Cedar Sink has a bottom area of about 7 acres and has much better soil than found on the ridge tops. It was farmed before it became part of the park. Farmers led their mules down over the ledges of the old trail.

There is a trail continuing north along the floor of the sink. This trail is treacherous because it skirts several closed depressions with standing water and would be very slippery in wet weather. It ultimately climbs the north arm of Cedar Sink and ends at Owl Cave. The entrance, now gated, is high on the wall of the sink but opens near the ceiling of the huge fragment of cave passage. From the entrance, a steep talus slope drops down all the way to stream level. A large stream flows across the bottom of Owl Cave, left to right, both entering and leaving through completely submerged passages. Owl Cave has been useful as an observation point for water draining to Turnhole Spring. Of the water in the Turnhole master drain that reaches Cedar Sink, about ⅔ to ¾ of the flow bypasses the collapse on the west side and crosses Owl Cave.

Backtracking along the Park Service trail from the terminal platform, watch for an obscure trail to the left just before beginning the climb out of the sink. This trail takes us past the East Window – a closed depression which usually has standing water – to the northeast arm of Cedar Sink.

The trail brings us to a broad bench beneath a huge crescent-shaped overhang. The overhang has the appearance of a cave passage that has been bisected along its axis leaving only the inner half of the passage. A badly degraded stalagmite in a wall alcove lends some support to this idea. There is a deep depression below the bench with an obvious cave entrance at the bottom (during those times when the depression is not completely flooded). The entrance opens into a tubular passage of standing height. In a few hundred feet it leads to a large chamber with a stream flowing across the floor. This is the remaining ⅓ to ¼ of the Turnhole drainage that bypassed Cedar Sink on the east side. A short distance upstream from this entrance is another entrance to a passage extending under the bench. This is one of the entrances to Smith Valley Cave with several miles of surveyed passage.

One hypothesis for the origin of Cedar Sink is that there was an S-bend in the ancestral master trunk. The weakening of the ceiling with the breaching of the caprock and the formation of Smith, Cedar Spring, and Woolsey Valleys caused this master trunk to collapse. The northeast overhang and Owl Cave are the only remaining fragments. Continuous flow in
the master drainage line further undermined the sink and triggered further collapse. It should be said that not everyone accepts this hypothesis.

Return to the main trail, turn left, climb up the iron stairs, and follow the main trail back to the parking lot. Drive north, continuing along the way we have been going.

39.8 Intersection with Joppa Ridge Road, KY route 70. Turn left, west.

40.3 Pull into the Turnhole Overlook parking lot.

**STOP 6. Turnhole Spring**

There are two trails from the parking lot, one leads up over the hill to an overlook; the other, from the lower end of the parking lot descends into a small side valley and down to Green River.

Fig. 14. Turnhole Spring seen from the air in winter. Sandhouse Cave is at the base of the cliff to the right of the spring. The switchbacks of the overlook trail can be seen at the upper right. The trail to Sandhouse Cave can be seen at the lower right. Photo by Gordon Smith.
Fig. 15. Map of Turnhole Spring and Sandhouse Cave. From the work of James F. Quinlan.

The upper trail leads from the parking lot to the top of the ridge where the sandstone caprock is intact. There are several deep, vertical sided sinkholes along the trail. These are examples of "caprock protected sinks". The limestone was dissolved below the caprock, allowing the sandstone to collapse. The remaining sandstone forms vertical walls of the sinks.
The trail then descends the other side of the ridge as a series of switchbacks leading to an overlook into the Green River Valley. The rise pool of the Turnhole Spring can be seen below (Fig. 14).

Downhill from the parking lot, route 70 crosses a tributary valley on a causeway, itself built on the saddle that separates the karst valley to the south from the Green River. A trail leaves the lower corner of the parking lot, drops through the woods to the bottom of the valley and then follows the valley to Green River. At the river, a trail at the top of the river bank takes us to Sandhouse Cave. Sandhouse Cave is essentially a large shelter that extends back under the limestone bluff. There are massive sand banks that have washed out of the overflow spring at the back of the cave where there is usually a standing pool of water and sometimes an outflow. The Quinlan map (Fig. 15) shows the details. Up-river from Sandhouse Cave, we can walk a short distance along the river bank to the edge of the Turnhole rise pool.

Very little is known about the Turnhole Spring itself. The feeder conduit, like most of the Green River springs, is 30 feet below the water surface. Attempts to dive the spring have been frustrated by logs and other debris that have fallen into the spring pool. Dye traces, mostly by the late James Quinlan and his group have show quite clearly that the Turnhole Spring is the outlet for drainage for a very large area extending to the Glasgow Upland drainage divide. Some relatively small fragments of the upstream tributaries are known in caves of the Sinkhole Plain although not enough to discern the drainage pattern. The master trunk has two known major tributaries. The one draining the Sinkhole Plain is seen once in Mill Hole, another large collapse sink near the Dripping Springs Escarpment and appears briefly as Hawkins River in the cave system. Much of the tributary that has beheaded the other drainage basins along the Dripping Springs Escarpment is Logsdon River which has been explored for many miles. The underground rivers sump near their junction and are seen once again at Cedar Sink from which the trunk stream is sumped again all the way to the Turnhole Rise.

From the final stop, the class will return to Bowling Green. Backtrack to the Cedar Sink road, turn right, and follow it out of the Park, through Pig, and down to 31W. Turn right on 31W. To reach the interstate, make a left on route 101, follow it through Sinks Grove to the Sinks Grove interchange at the south edge of town. Or continue on 31W into Bowling Green. Those wishing to go north can follow the Joppa Ridge Road, route 70, to Cave City and the I-65 interchange there.
FIELD TRIP 2

THE HISTORIC (WESTERN) SECTION OF MAMMOTH CAVE

POINT OF ORIGIN: THE HISTORIC ENTRANCE IN MAMMOTH CAVE NATIONAL PARK

It is clearly difficult to write a road log for a cave trip. What follows is a walk through the cave. Specific points of interest are noted but not the distances between them.

The Historic Entrance. The natural entrance to Mammoth Cave is formed by the collapse of the underlying passage. The stairs descend over the debris pile formed by the collapse. This is the only natural entrance to the historic Mammoth Cave and one of the very few natural entrances anywhere in the system.

Houchins Narrows. The entrance passage to Mammoth Cave is a broad avenue just over walking height. On the outside, this passage was clearly the one that collapsed to form the entrance sinkhole. If we were to follow the trail around the hill from the Historic Entrance, we would come to the entrance to Dixon Cave. Dixon Cave is the continuation of Houchin’s Narrows beyond the collapse to the paleo-spring mouth on the wall of the Green River Valley. But the fragment of trunk passage that makes up Dixon Cave is much higher than Houchin’s Narrows, leading to the suspicion that we are walking on a thick sediment sequence that filled the passage upstream from the collapse.

The Air Shaft. Near the end of Houchin’s Narrows is an obscure opening on the left wall. When the new Mammoth Cave Hotel was built in the 1960’s, the architects had the bright idea of air-conditioning the new hotel with cave air. The hotel is directly above this point. The shaft was drilled and the project proceeded. Then, in the early 1970’s, it was discovered that the air in Mammoth Cave has exceptionally high radon levels. The data presented by Yarborough and Ahlstrand (1977), in units of working levels, are:

<table>
<thead>
<tr>
<th>Cave</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammoth Cave</td>
<td>1.24</td>
<td>0.39</td>
<td>0.73</td>
</tr>
<tr>
<td>Crystal Cave</td>
<td>1.49</td>
<td>0.83</td>
<td>1.12</td>
</tr>
<tr>
<td>Great Onyx Cave</td>
<td>1.22</td>
<td>0.68</td>
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</tr>
</tbody>
</table>

Working levels are defined by NIOHS as the exposure to uranium miners, working standard 40 hour weeks, breathing air containing 100 picocuries of $^{222}$Rn per liter. For comparison, the EPA action level for radon in homes is 4 picocuries/liter. The air conditioning project was abandoned before later wide-spread concern about the necessity of preserving the cave environment. The shaft is now sealed although the caprock breach allows drip water to enter the cave.
The Rotunda. Houchin’s Narrows leads into the Rotunda, one of the largest rooms in the cave. The walls expose the Paoli member of the Girkin Limestone. The Rotunda represents a downstream bifurcation in the drainage channel. To the left is the Main Cave (or Broadway) in the upstream direction. To the right is Audubon Avenue in the downstream direction. Whether the downstream forks carried flow at the same time to two different ancestral springs on Green River or whether they operated sequentially is not known.

In the center of the Rotunda are the remains of the early 1800’s saltpetre workings. The soils in the dry upper levels of Mammoth Cave contain quantities of what is probably calcium nitrate as well as other water-soluble salts. The soil was piled in hoppers and leached with water. The leachate was pumped outside where it was drained through wood ashes to exchange the calcium by potassium. This liquor in turn was evaporated in boiling kettles, then cooled and KNO₃ (saltpetre) crystallized out. It was a quite sophisticated exercise in early 19th Century chemical engineering, because it was necessary to crystallize the nitrate salts while leaving the sodium and magnesium sulfates in solution. The saltpetre was shipped off to use in the manufacture of gunpowder for the War of 1812 (George, 2005).

On the far side of the Rotunda is a stack of fresh-looking breakdown slabs. Although active breakdown in caves is uncommon, breakdown does occur. The slabs fell on a bitter cold January night when the cave was drawing in air. Although this breakdown as been ascribed to the freezing of water in joints and bedding plane partings, this section of the cave is very dry. Further, breakdown has occurred in other parts of the system since the caves have been explored. Inelastic creep can occur in suspended limestone beds due to micro-cracking. It is entirely possible that these beds, cantilevered over the open expanse of the Rotunda, were on the edge of failure. The freezing air that entered the cave might have been only the final trigger.

We begin our walk, upstream, along the Main Cave. Note the rectangular cross-section. This passage has been extensively modified by breakdown so that the original solution surfaces are obscure.

The Kentucky Cliffs. High on the left wall of the Main Cave is a recess partly blocked by a laid wall. This recess is the top of the Corkscrew, a twisting sequence of canyons and breakdown that descends to River Hall.

The Methodist Church. We have been following a walkway built by the Park Service to decrease dust and lint generated by the thousands of visitors through the part of the cave. Remnants of the wooden pipes used by the saltpetre miners are visible along the trail. The stairs descend into a widening of the passage known as the Methodist Church.

Carefully study the passage shape. The lower portion of the Main Caves goes straight ahead as two superimposed elliptical tubes partly filled with sediment. But the upper portion makes a hard left turn and vanishes into a pile of breakdown.

Gothic Avenue. From the Methodist Church, we walk up a hill of sediment and come to a row of saltpetre vats. There is another large passage, Gothic Avenue, high on the right hand wall. This passage crosses the Main Cave but is immediately choked with sediment at a place called
Backsliders Alley. Is this passage the upper component of the Main Cave that was lost in breakdown at the Methodist Church? If so, it requires a hard S-bend in the missing passage segment.

The time of deposition of the sand and quartz pebbles can be determined by cosmogenic isotope dating. Figure 16 shows the dates from Mammoth Cave determined by Granger et al. (2001). The sediment plug in Backsliders Alley was deposited 2.27 million years ago. This is not necessarily the age of the passage but it certainly dates from the time when the passage was part of the active ground water flow system.

Fig. 16. Cosmogenic isotope dates for clastic sediments in the Mammoth Cave System. From Granger et al. (2001).

**Broadway or The Main Cave.** The Main Cave is a master drain that in late Pliocene or very early Pleistocene time carried the runoff from the ancestral Sinkhole Plain to the ancestral Green River, at that time flowing at an elevation of about 600 feet, 200 feet higher than the present day bedrock channel. At this time the caprock on the Mammoth Cave Plateau was intact. We are in the downstream trunk of the drainage where there were no local inputs and therefore very few side passages on the Main Cave.

Palmer (1989) divided the Mammoth Cave System into “levels” or tiers. These cut across the dip of the bedding and are related to past base levels (Fig. 17). The Main Cave corresponds to the B-level. There are corresponding passages at the same elevation in the Flint Ridge Section of the system.
Fig. 17. Some of the major passages in the Mammoth Cave System demonstrating the development of passages at specific "levels" or tiers. From Palmer (1989).

**Wandering Willie’s Spring.** Wandering Willie was a blind boy who played the violin in the 1800’s. He spent the night in the cave and was found in the morning, sleeping beside this small pool of water. Except for the air shaft, this is the only water seen in this part of the cave. The source of the pool is a small vertical shaft cut into the side wall of the passage. It is fed by a small meandering canyon visible along the ceiling. Like other vertical shafts to be seen later, this feature is much younger than the passage that it intercepts.

**Giant’s Coffin.** Giant’s Coffin is a breakdown block that has slide out of the right side wall of the passage and in so doing almost obscures a small canyon passage that drops away behind it. At this point we leave the Main Cave and begin our descent to the lower levels. Ahead, the Main Cave continues for another mile and a half, finally ending in massive breakdown at Violet City. An entrance has been excavated at the top of the breakdown pile that brings visitors to the surface near the Carmichael Entrance.

**Wooden Bowl Room.** Descending a short slope behind the Giant’s Coffin brings us to a low room with a sandy floor. Ahead is a crawlway – Lost Avenue – connecting with a tangle of passages that developed below the Main Cave. To the left is Ganter Avenue. This is a complex of mostly canyons and medium size passages that extends for more than a mile to connect to Silliman Avenue beyond Echo River. The sequence forms the long sought escape route that would have allowed early visitors to return from the far reaches of the cave if the Echo River should flood while they were on their tour. Rapid rises in Green River back-flooding into the cave made this threat a real possibility. To the right, a steep stone stairway takes under a ceiling ledge and down to the next sequence of passages.
Fig. 18. Map showing the Main Cave and the underlying route through the Deserted Chambers, Bottomless Pit, and Fat Man’s Misery to Great Relief Hall. This is a separate survey by G.H. Deike and W.B. White made in 1962.
The Deserted Chambers. Going lower in the system is also going forward in time. When the caprock was breached, and the surface valleys developed, drainage from these valleys formed a very complicated sequence of tubes. The Deserted Chambers are a sequence of braided tubes, somewhat intertwined around each other. It is likely that these developed along separate bedding planes but as the passages grew they merged into each other. We are going the opposite direction from our route in the Main Cave and are actually beneath the Main Cave. This demonstrates that the breakdown and fill in the Main Cave cannot be very deep because these passages are only 30 - 40 feet below the Main Cave and there is no evidence at all of the existence of a huge passage directly overhead. The Deserted Chambers correspond to Palmer’s level D and are developed in the upper Fredonia member of the Ste. Genevieve Limestone.

Bottomless Pit.

Fig. 18. Bottomless Pit. (Left) As seen by H.C. Hovey in 1896. (Right) As seen by James Knudstad in 1970.

Bottomless pit (105 feet deep) cuts across the horizontal tubular passages of the Deserted Chambers almost blocking the passage. It is here that Stephen Bishop shinnyped across on a cedar pole in 1837 to discover vast reaches of cave beyond. However, Bottomless Pit is only one of a group of vertical shafts formed at the edge of the sandstone caprock. We passed Sidesaddle Pit a little ways back. To the right, just before Bottomless Pit, Darnall’s Way and Lively Avenue lead to Gorin’s Dome, another impressive shaft. Behind Bottomless Pit,
accessed through a left-hand lead off the Deserted Chamber are Scylla and Charybdis, two other shafts.

Vertical shafts are recent features, related to the present position of the sandstone caprock. They form from unsaturated water from the caprock percolating vertically through the vadose zone. Mostly the water enters through small canyons at the top and exits through small drains at the bottom. Their relationship to the horizontal passages is mostly fortuitous. We now have more or less three categories of passage: master trunks, valley drains, and shaft drains.

**Pensico (or Pensacola) Avenue.** Beyond Bottomless Pit, the tubular passage that we have been following, goes off to the right as a single walking-height tube called Pensico (or Pensacola) Avenue. Although fairly extensive, it is ultimately blocked by fill. The tourist trail descends a short flight of steps to the next lower level, a sequence of wide tubes almost blocked with fill. Indeed a substantial amount of excavation was required just to provide a walking path for the tours. Again the tube goes off to the right as a sediment-choked passage called Buchanan’s Way. A cosmogenic isotope date for the sediments in Buchanan’s way is 0.80 million years so we are down to the D-level of the cave and only half way through the Pleistocene. We are in a dolomitic limestone, the F2 beds of the lower Ste. Genevieve Fredonia member.

**Fat Man’s Misery.** It requires an amazing sequence of random passage connections and just plain dumb luck to find a really long cave. We are about to enter one of them. Caves consist of fragments of drainage conduits, usually truncated by collapse or blocked by fill. Long caves are constructed by finding interconnections between these fragments. Bottomless Pit didn’t stop Stephan Bishop but Buchanan’s Way might have if the 0.8 million year massive sedimentation event had dumped just a little more fill or if a local drain hadn’t flushed some of it out.

Fat Man’s Misery is a narrow meandering canyon just large enough for human passage – or at least for typical tourist passage. The walls are covered with small scallops indicating a stream flowing at high velocity. There is the remnant of a small tube at the top of the passage where it was initiated along a bedding plane before developing into a canyon.

**Great Relief Hall.** Fat Man’s Misery opens as a small side passage near the ceiling of a large tube called Great Relief Hall. This is also where the Park Service decided to install an underground rest room. Behind the rest room, the conduit continues a few hundred feet until it is blocked with fill. Downstream, the conduit opens near the ceiling of River Hall. Great Relief is in the lower Ste. Genevieve Limestone where the formation is beginning to get cherty. Look for large chert nodules dissolved out in relief on the passage ceiling.

**River Hall.** At River Hall we are again in large trunk passage. The ceiling is at the very base of the Ste. Genevieve Limestone and the lower portion of the passage in the upper St. Louis. The walls and ceiling are sculptured with medium-size scallops showing flow velocities in the fraction of a foot/second range but the large cross-section gives a very large volumetric flow. In the downstream direction, to the right as you enter the passage, the conduit is lost beneath
breakdown and fill. In the opposite direction, the passage leads to River Styx, Echo River, and deep into the cave.

**River Styx.** The main base level drain through Mammoth Cave Ridge consists of two superimposed passages. Sometimes they are directly superimposed forming a high canyon. In other places they are separate – a high level dry passage and a low level stream passage. These are the E and F levels in Palmer’s notation. When we leave River Hall, a small passage behind a rock column on the left is Carlo’s Way. It leads to the bottom of Bottomless Pit and beyond. Crawling through drains and climbing or descending the shafts has been a useful way of finding connections within Mammoth Cave.

The first feature is the Dead Sea, an apparently stagnant pool at the bottom of a steep-walled mud pit. We skirt this on a catwalk on the right wall. The Park Service has had a love-hate relationship with the river passages. They flood nearly every spring putting a layer of mud and silt over trails and walkways and making a mess of the lighting system. The old wooden bridges and walkways were rotted and dangerous so the Park closed the lower levels for a while. Then they launched into an ambitious engineering project of building the aluminum walkways that we are now using. But again, the project was interrupted by floods and mud and was not completed.

Beyond the Dead Sea, the passage splits. We cross the bridge and climb the stairs to the upper level. In the loop-around passage to the right is a waterfall, Charon’s Cascade. After some distance in the walking-height upper passage we descend again and are on a walkway looking down into the River Styx. The water elevation is essentially the same as that of the Green River and rises and falls with the Green. Beyond the walkway, we climb again and then descend a set of stairs. What happens next depends on water level. At low water we can descend the stairs almost to the Styx and follow the aluminum walkway for some distance until around a corner it just ends. This is where the engineering project was abandoned and the only way onward is to wade. At high water, of course, we see the stairs descending into a muddy pool.

Having gone as far as the water will allow or reaching the end of the walkway there is no alternative but to turn around and return to River Hall. Echo River is still some distance beyond the end of the walkway.

**Vanderbilt University Hall.** To continue our loop tour, we exit River Hall by stairs that climb over a breakdown pile. On a large breakdown block are several brass markers showing the levels to which various flood have risen. The 1962 flood and several others filled River Hall to the roof and reached nearly to the top of the stairs.

At the top of the stairs are two irregular breakdown chambers, Bandit’s Hall and Vanderbilt University Hall. At the back of Bandit’s Hall is the bottom of the Corkscrew, the winding way that leads to the Main Cave at the Kentucky Cliffs.

**Sparks Avenue.** From the breakdown rooms, we enter Sparks Avenue, a complex of winding tubes nearly filled with sediment. Sparks Avenue is at about the same elevation as Buchanan’s Way and these sediments are likely also deposited in the 0.8 million year sedimentation event.
We pass Silvan Avenue, a low passage to the left. The floor rises and Sparks Avenue becomes narrow and more canyon-like with many ceiling pockets. Small scallops indicate high flow velocities. The passage enlarges and we enter Mammoth Dome on a balcony.

**Mammoth Dome.** We enter Mammoth Dome on the active side. To the left from the balcony, the bottom of the dome is a rubble strewn floor 20 to 30 feet below but the top of the shaft reaches high overhead. Water streams down the back wall and the rock is shiny and appears to be actively dissolving. A stair leads to the floor of the main dome – the Ruins of Karnak – consisting of very complex assembly of shafts. The wall of Mammoth Dome farthest from the active cutting edge has extensive deposits of travertine. The water chemistry tells the story.

![Fig. 19. CO₂ pressures and saturation indices from a selection of waters calculated from chemical analyses of water samples.](image)

Shaft waters are derived from the sandstone caprock and are typically highly undersaturated. These are the waters streaming down the active shaft that will rapidly dissolve more limestone. The other side of the Mammoth Dome complex is also the older part of the dome. The caprock has retreated and this part of the dome now lies under a limestone hillside. Waters that have their origins in overlying karst soils are typically supersaturated and will precipitate calcite speleothems. So we have the interesting situation where one side of a shaft complex is actively enlarging while the other side is filling with travertine.
We leave Mammoth Dome by the stairway up the “fire tower” erected in the middle of the dome. Near the top is a spectacular view of the active shaft.

**Little Bat Avenue.** At the top of Mammoth Cave, the trail ascends through a narrow slot that only fortuitously intersects the sidewall of a medium-size tube known as Little Bat Avenue. This slot was known to the saltpetre miners of the early 1800’s and was called Crevice Pit. To the left, Little Bat Avenue ends in breakdown in a short distance. Outside, on the wall of the Green River Valley is White Cave. White Cave has about the same dimensions as Little Bat Avenue and also ends on the opposite side of the same breakdown. Little Bat Avenue was a later stage drain that carried the residual water from the Main Cave. The White Cave entrance would have been a spring.

Little Bat Avenue is a meandering tube containing very little sediment. It connects with Audubon Avenue up a slight grade that takes us to floor level of a very large passage.

**Audubon Avenue.** Native Americans traveled long distances in Mammoth Cave and in Great Salts Cave, the two large and obvious natural entrances. Remnants of their passing – burnt fragments of cane torch, bit of moccasin, and other debris have been found as much as a mile or more from the entrances. They were apparently mining gypsum which might have been used as a pigment and water soluble salts such as epsomite and mirabilite which have medicinal properties. See Watson (1974) for many details. The Park Service has constructed a display of Native American materials from the cave in Audubon Avenue.

To the left, this huge passage breaks into several distributaries all of which end in breakdown. The passage ends against the Green River bluffs but with no connection to the surface.

From here we turn right, return to the Rotunda, turn left into Houchins Narrows, and exit the cave.
FIELD TRIP 3

THE EASTERN SECTION OF MAMMOTH CAVE

POINT OF ORIGIN: THE CARMICHAEL ENTRANCE

The Grand Avenue Tour enters Mammoth Cave through the Carmichael Entrance about midway along Mammoth Cave Ridge (see Fig. 8). The access road to the Carmichael Entrance is open only to official vehicles. The entrance is within the circle of the access road, in the base of a closed depression recessed into the wall of Doyel Valley on the south side of Mammoth Cave Ridge. A little higher on the side of the ridge, in the woods across the road from the Carmichael Entrance, is the Violet City Entrance.

The Carmichael Entrance. The Carmichael Entrance opens into the blasted tunnel in solid limestone that descends a long flight of stairs to open into Sandstone Avenue. The tunnel crosses the Girkin Limestone and into the upper Ste. Genevieve in Sandstone Avenue. To the left, the passage ends against a pile of breakdown. To the right, the passage rapidly opens up because of its collapse into a lower level.

Croghan Hall and the Rocky Mountains. The enlarged passage is known as Croghan Hall. It looks like the Main Cave (without the soot) because we are indeed in level B, an extension of the Main Cave beyond its terminal breakdown at Violet City. Straight ahead is a breakdown slope known as the Rocky Mountains. Beyond, the passage is blocked by breakdown but at the very end is a pit, the Maelstrom. This point marks the end of the longest tour available from the Historic Entrance in the 1800’s. We are about 4 miles from the Historic Entrance had we come by way of Echo River. The collapsed passage to the right is Franklin Avenue which continues about a quarter of a mile to another collapse. Beyond the collapse, the passage continues as Big Avenue in the New Discovery Section. The tourist trail descends the breakdown to the left and into Cleaveland Avenue.

Cleaveland Avenue. Cleaveland Avenue is as close to a perfect elliptical tube as can be found anywhere in the system (Fig. 20). It is a low gradient passage extending for more than a mile along a single bedding plane parting at an elevation of 550 feet, the C level. The sediment age is 1.34 Myr. In plan view (Fig. 21) the passage is seen to wrap around the nose of a small anticline maintaining constant elevation by following the structure contours.

Gypsum and Crystal Wedging Breakdown. Cleaveland Avenue extends across Mammoth Cave Ridge and is dry throughout its length. The passage walls are decorated with gypsum crystals. These were apparently spectacular in the early days before many of the crystals were broken and taken as souvenirs by early tourists. The crystals grow from tiny quantities of fluid seeping from the pores in the limestone. The source of the gypsum is the oxidation of pyrite that occurs dispersed in the limestone and also in the bed directly above the Big Clifty.
Sandstone. Which (or both) of these sources actually provides the gypsum seen in the cave has not been resolved.

Throughout Cleaveland Avenue we will see small masses of breakdown stuck to the ceiling by gypsum crystals. The gypsum forms by chemical reaction in the immediate wall rock of the cave passage. Because gypsum has a higher molar volume than the calcite it replaces, there is an expansion that tends to spall off bits of the limestone. For more on gypsum activated breakdown, see White and White (2003).

![Image](image.png)

**Fig. 20.** Cleaveland Avenue, a low gradient elliptical tube developed along a prominent bedding plane.

Dissolution and mineralization of cave passage in Mammoth Cave depend on both the presence and the chemistry of infiltrating water (Fig. 22). Undersaturated water from the plateau that enters the cave at the edge of the caprock is aggressive and is responsible for the vertical shafts and related passage. Passages beyond the caprock receive water that has percolated through a limestone soil so these are the parts of the cave that contain calcite speleothems. The dry passage, under the caprock, preserve the more soluble gypsum formed from seeping solutions. In very dry (very dry = relative humidity in the range of 80 – 90%) passages, there are other water-soluble sulfate minerals such as epsomite (MgSO₄·7H₂O) and mirabilite (Na₂SO₄·10H₂O) as well as some more exotic minerals. At Donna’s Garden, one of the few side passages to Cleaveland Avenue, a drill hole in the ceiling admits water and creates a wet spot in the otherwise dry passage. The cave soils near here often sprout clear crystals in the winter which are trampled back into the dirt during the summer visitor season. The small amount of moisture is sufficient to transport the water-soluble salts.

**Snowball Dining Room.** We are walking upstream along Cleaveland Avenue and at Snowball Dining Room, the passage branches. The main branch is Marion Avenue which continues for a
considerable distance behind the service area. There is an elevator to the surface near the beginning of Marion Avenue. Our route takes the right hand branch.

Fig. 21. Map of Cleaveland and Marion Avenues showing their wrap-around the structure contour of a minor anticline. From Palmer (1981).
Fig. 22. Relation of gypsum and calcite deposition to position of the caprock.

Mary's Vineyard and the Pass of El Ghor. The right fork from Snowball Dining Room is an irregular passage that completes the crossing of Mammoth Cave Ridge. Water dripping into the passage has opened high ceiling channels and coated the walls with cave coral – thus the name “Mary’s Vineyard” (or Martha’s Vineyard). Just beyond Mary’s Vineyard, the passage is cut by a canyon, the Pass of El Ghor. To the left, El Ghor, with a fairly high gradient, reaches Silliman Avenue and after a mile and a half, Echo River. The steps to the right take us through the canyon and into the underlying tube known here as Boone Avenue.

Boone Avenue. Boone Avenue skirts along the northern edge of the Mammoth Cave Plateau and, unlike most passages seen thus far, is wet and muddy throughout its length. It is a very complex passage. We are walking in the lower tube – a roughly elliptical passage about walking height and 5 – 10 feet wide. Above is a canyon, above that an upper tube, and above that an upper canyon. These components of the passage do not follow the same track. In some places the ceiling is just overhead. In others the passages are lined up and the ceiling is high above us.

Farther along Boone Avenue the passage has been cut by some small vertical shafts which enlarge and change the passage shape. Beyond, the trail climbs out of the lower tube, through the lower canyon and into the upper tube. We have shifted passages in a very unobvious manner and the passage retains the name of Boone Avenue (Fig. 23).
Fig. 23. Map of the superimposed tubes and canyons in the Boone Avenue-Martel Avenue complex. Map surveyed by G.H. Deike and W.B. White about 1962.
**Thorp’s Pit** The continuation of Boone Avenue above the stairs is a larger and dryer passage. The trail passes Thorp’s Pit which drops away to the right. Thorp’s Pit demonstrates that vertical shafts have distinct tops and bottoms. They do not punctuate the entire thickness of the limestone. The water that has created Thorp’s Pit enters through a small canyon clearly visible directly across from the trail.

Thorp’s Pit also illustrates another mechanism of cavern enlargement. The pit has cut through a pile of breakdown that had accumulated in the much older horizontal passage. As breakdown in the pit is dissolved and removed, the remaining pile is undercut and slumps into the pit where it is also dissolved and removed.

Along the trail near Thorp’s Pit are masses of dried flowstone, seemingly formed by water emerging from the side canyons. It is somewhat of a mystery that there was large scale travertine deposition at some time in the past and no indication of further deposition during present-day conditions.

**Off Trail – The Route to Cathedral Dome.** A few hundred feet beyond Thorp’s Pit, there is a major fork in the trail. The upper canyon carries the tourist trail off to the right as Rose’s Pass. Boone Avenue forks to the left and continues into an unlit part of the cave. We follow Boone Avenue around a corner. Just before it is lost in breakdown, we double back into the lower canyon to a set of wooden steps which must be descended with some care. The steps bring us into a lower passage, here called Martel Avenue. If we were to continue straight ahead from the bottom of the steps we would cross the side of Thorp’s Pit close to the bottom and be stopped by a pile of rubble. At that point we would be under the stairs in Boone Avenue that took the tourist trail from the lower tube to the upper tube. Martel Avenue is the upstream continuation of the lower tube of Boone Avenue. This is an illustration of the difficulty of stringing together the paleohydrology of the system from the present-day accessible fragments of cave passage.

From the bottom of the wooden steps we double back again and continue in the upstream direction in Martel Avenue. A small canyon emerges from the right wall, and disappears into left wall. A short distance beyond the canyon emerges again to graze the left wall and then continues. This is Pinson’s Pass and is our route to still lower levels. Pinson’s Pass brings us out at ceiling level of the lower passages with another grazing connection. Pinson’s Pass continues and can be seen again farther along Martel Avenue. We, however, descend a short rubble slope into the lower passage.

The passage is in the lower strata of the Ste. Genevieve Limestone as indicated by the prominent chert beds protruding from the walls. Many of these are coated with black oxides of manganese. The passage is near the top of the flood-water zone and occasionally contains standing water.

The relationship of the sequence of tubes and canyons is sketched in Figure 24. These passages are drains from Houchins Valley and from parts of the dissected plateau to the east. The canyons represent periods of rapid shifting from one base level to another.
Edna's Dome. A short climb up a slope to the right of the trail brings us to Edna’s Dome, a large and very active shaft. Vertical streams of water have planned off the beds so that the walls are completely vertical except for a complex set of vertical grooves. Edna’s Dome has been the site of measurements of the rate of wall retreat and the pins for placing a micrometer can be seen.

Hawkins Pass. Bransford Avenue continues and was the key to important discoveries in the east end of Mammoth Cave Ridge. Our route is a narrow canyon called Hawkins Way that turns off to the left. Like many irregular canyons, Hawkins Way is high and narrow with very irregular walls containing many small scallops. Part way through is an alcove on the right side where a small stream of water pours out of a narrow fracture and disappears below. This is a window into the typical movement of vadose water in karstic aquifers. At the end of Hawkins Way, the trails skirts a pit with a pipe handrail and climbs a short slope to the floor level of a large chamber. Hawkins Way continues around a corner and, now called Becky’s Alley, it connects with other passages extending into the eastern portion of the cave.

Cathedral Dome. Cathedral Dome is a retreating shaft canyon on the north side of Mammoth Cave Ridge. We can follow the clay floor of the canyon for several hundred feet to where it ends at the cutting edge of the canyon where an active shaft has considerable water spraying
down. A pool at the base of the shaft drains as a tiny stream that flows under the bedrock wall and disappears.

Fig. 25. Distribution of vertical shafts around the margins of Mammoth Cave Ridge and Flint Ridge. Note that shafts are found slightly back from the edge of the caprock but most occur right at the edge. From Brucker et al. (1972).

Cathedral Dome and hundreds of other shafts track the edge of the retreating caprock. They tend to be concentrated in re-entrants into the ridges where there is maximum runoff from the plateau (Fig. 25). Thus we have a three-stage process in the geomorphic evolution of the Mammoth Cave Plateau and many other karst areas with a similar geologic setting: (1) there is the development of cave systems and internal drainage beneath the plateau from source areas beyond the plateau and from internal drainage due to breaches in the caprock, (2) there is intense internal weathering in the vadose zone, primarily the development of vertical
shafts as the caprock retreats and (3) denudation of the exposed limestone by intense weathering at the soil/bedrock contact after the caprock is gone.

There is much to observe in Cathedral Dome. Note the various forms sculptured on the wall by vertically streaming water. Note how these vary between bedding planes. High up on the walls of the dome is a cave passage, Bishop’s Way. It can be reached by climbing through a sequence of tubes and canyons further east. The walking-height passage ends abruptly where Cathedral Dome has cut through it. One can stand on the edge of the shaft and see the continuation of the passage on the other side.

We need to backtrack to Boone Avenue and follow the light string and tourist trail into Rose’s Pass.

**Rose’s Pass and Jeanne’s Avenue.** Rose’s Pass is a high canyon that veers off from the sequence of overlapping passages that we have been following. It climbs gradually to its merging into a wider and more nearly horizontal passage. Names change and this portion of the passage is called Jeanne’s Avenue. The continuation of Jeanne’s Avenue to the left is blocked by sediment producing a short blind passage called Ella’s Grotto. Continuing to the right (actually almost straight ahead) brings us to the Forks of the Cave. Overall from Boone Avenue to the Forks of the Cave is about half a mile.

Palmer (1981) has called attention to an interesting aspect of the paleohydrology. In Rose’s Pass, there are small scallops indicating flow toward Boone Avenue at velocities on the order of a foot per second. In Jeanne’s Avenue there are large scallops indicating slow flow toward the Forks of the Cave. Small scallops pointing toward Boone Avenue are superimposed on the larger ones showing a reversal of flow direction in the course of the evolution of this part of the cave.

**The Forks of the Cave.**

Jeanne’s Avenue widens, becomes more spacious and opens at the same floor and ceiling level with an even larger master trunk. To the right, the large passage ends immediately in a sediment and breakdown choke. To the left, it continues as a major passage.

We have gradually gained elevation and are now in the B Tier of cave passages and indeed in an upstream continuation of the Main Cave. The Main Cave, Croghan Hall, and Kentucky Avenue together add up to about 4.5 miles of master trunk, extending along the full length of Mammoth Cave Ridge. Between the Forks of the Cave and the end of Croghan Hall at the Maelstrom about 4000 feet of the trunk is missing. If the passage veered south, is has been destroyed by the enlargement of Doyel Valley. But if veered north, the passage may still exist, tucked under the edge of Mammoth Cave Ridge.

Cosmogenic isotope dates for the sediments in Ella’s Grotto and the Forks of the Cave are 1.67 and 1.78 million years, respectively (Fig. 16), comparable to other sediment dates from the Main Cave.
Kentucky (or Grand) Avenue.

We continue eastward in Kentucky Avenue (Grand Avenue on the Kämper map and now called the Grand Avenue tour by the Park Service). Unlike the Main Cave, Kentucky Avenue has suffered relatively little breakdown so there are smooth, solutionally-sculptured walls. Masses of dry flowstone occur at intervals. The rock is the J2 unit of the Joppa Member of the Ste. Genevieve Limestone. In about half a mile, we reach the base of a massive breakdown pile. There is a nice display of gypsum flower on the left wall, protected by a bit of chain-link fence.

Mount McKinley. The trail switchbacks up the breakdown pile, known as Mt. McKinley, and takes us to what seems to be a higher level of the cave. Looking back as we approach ceiling level there is the hint of a high level passage greatly modified by breakdown. There is also a massive flowstone deposit.

Fig. 26. Profiles of major trunk passages in Mammoth Cave. The plotted points are taken from the 1936 Walker instrument survey of Mammoth Cave. These data show clearly that the dip of the trunk passages (about 5 feet/mile) is less than the dip of the bedding (about 50 feet/mile).

The relationship of this eastern fragment of the Main Cave master trunk to the western fragment, the Main Cave itself, is somewhat problematic. In the Main Cave, between the Rotunda and the Methodist Church, the passage seems to consist of two distinct components
which separate at the Methodist Church, the upper components curving around and crossing the lower component to become Gothic Avenue. One hypothesis is that here, in the eastern section, Kentucky Avenue represents the lower component and this high level fragment represents the upper component. However, the separation between levels is greater – about 75 feet. Further, a cosmogenic isotope date of 3.2 million years makes the sediment from this high level fragment the oldest date found in the historic Mammoth part of the system. There is a 3.36 million year date from sediments is Dismal Valley in the Great Salts Cave portion of the system. Thus, one can advance the alternative hypothesis that the high level fragment at the top of Mount McKinley is a segment of the A Tier of passages.

In December, 1935, H.D. Walker of the U.S. Geological Survey, undertook an accurate instrument survey of Mammoth Cave (Mason, 1950). The U.S.G.S. established permanent benchmarks in the cave. From the survey data and from field observation to determine which benchmarks were actually in cave passages (as distinguished from breakdown piles or other sites not representative of the passage itself) it was possible to construct a profile through Mammoth Cave Ridge (Fig. 26). The profile puts the high level at an elevation of about 675 feet and seems to be well above the B-Tier passages below.

**Ups and Downs.** For the next half mile, the upper and lower passages are superimposed and in several places have collapse into each other. As a result, the trail descends into deep “canyons” and then climbs up the other side. There is a narrow meandering canyon between the passages which may have contributed to the instability and collapse.

The massive breakdown makes the passage extremely difficult to decipher. Beyond Mount McKinley at the edge of a “canyon”, there is the remnant of an old tourist trail on a ledge perched high above the “canyon”. It leads to Woodbury’s Pass, a fragment of high level trunk that is not collapsed into the passages below. It joins the main passage again at Aerobridge Canyon where a woven iron cable is stretched across.

**Grand Central Station.** There is a meeting of the ways known as Grand Central Station, a modest sized room along the passage in the lower level. Ahead, the trail climbs a breakdown pile and goes another half mile to the Frozen Niagara Entrance. An opening on the left part way up the hill connects with a complex series of passages which to the west ultimately connect to Cathedral Dome. An opening in the right wall of Grand Central Station takes us to the connecting passage to the New Entrance shafts.

Those on the Grand Avenue tour will continue ahead to Frozen Niagara. Those on the class field trip will climb the New Entrance shafts.

**The New Entrance Shafts.** We have been viewing shafts mostly from a single vantage point. At the New Entrance, we climb through the entire sequence of shafts for almost 200 feet. The access passage enters the side of Roosevelt Dome which is crossed on a bridge. Then the route follows stainless steel stairs that twist their way from shaft to shaft. Note Silo Pit, almost a perfect cylinder, which can be seen from bottom to top. We exit from the New Entrance on the east end of Mammoth Cave Ridge.
REFERENCES


Mid-Conference Fieldtrip Guide

Option 2: Mammoth Cave Trip

Led and Guide By:
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A Guide to the Historic Section of Mammoth Cave and Upper Levels of Crystal Cave

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Introduction

Mammoth Cave is located in one of America's largest karst regions. Because of its long and varied history and its extraordinary length, with 610 km (375 mi) of mapped passages, it is perhaps the best known cave in the world. The cave is also important for its well-documented geologic history, archeology, and diverse biota.

The recorded history of the cave began at the end of the 18th century, but abundant archeological finds show extensive use by prehistoric people as much as 4000 years ago. Evidence includes traces of mining of evaporite minerals from the walls, exploration with torches up to several kilometers from the nearest entrances, and even mummified bodies in Mammoth and nearby caves.

The cave was used for salt-petre mining in the early 1800s, but its greater value as a tourist attraction soon became evident. Under private management, tours were given throughout most of the 19th and early 20th centuries. Mammoth Cave National Park was authorized by Congress in 1936 and was officially dedicated in 1941. Exploration has taken place throughout this history and continues today.

Geologic Setting

Mammoth Cave is located in west-central Kentucky at the southeastern edge of the broad Illinois structural basin, in limestone of Mississippian age (early Carboniferous). See Figures 1–3. The great length of Mammoth Cave results from several coincident factors. Its drainage basin is large, nearly 300 km². Even though the limestones are relatively thin, their gentle dip causes them to be exposed over a large area. Prominent bedding, with many lithologic contrasts, allows diversion of vadose water along many progressively lower partings. The resistant caprock has protected many of the uppermost passages from erosional destruction. Finally, many small but discrete adjustments in base level have fostered the development of numerous independent cave levels.

Figure 1: Physiographic setting of the Mammoth Cave region.

The cavernous limestones are underlain by impure poorly karsted limestones, also of Mississippian age, and are overlain by sandstone and shale alternating with thin limestones, of Mississippian and Pennsylvanian (late Carboniferous) age. The insoluble rocks form hilly dissected plateaus in the center of the Illinois Basin, but around the edges of the basin the insoluble rocks have been removed by erosion, exposing the limestone at the surface. The limestone forms a broad, low-relief karst plain, typified by dolines and sinking streams, called the Pennyroyal Plateau, which lies 40–60 m (130–200 ft) below the highest ridges of insoluble rocks. The deeply dissected perimeter of the hilly region consists of limestone ridges capped by insoluble rocks and separated from one another by steep-walled valleys (Figure 2). Many of these are perched karst valleys at the general level of the Pennyroyal Plateau. This borderland, called the Chester Upland, is where Mammoth Cave is located. The Chester Upland and Pennyroyal Plateau form a crescent-shaped band of karst that extends around the southern and eastern edge of the Illinois Basin, from southern Illinois, through western Kentucky, into southern Indiana (Figure 1). Northward the karst diminishes in width and intensity of development because of decreasing limestone thickness and an overburden of glacial deposits.

Mammoth Cave extends under at least three different ridges of the Chester Upland and beneath the karst valleys that separate them (Figures 4–5). The ridges rise to altitudes of 250–275 m (~800–900 ft), and the karst valleys and local Pennyroyal level are at 180–200 m (~590–650 ft). The major entrenched river in the area, and the base level for cave development, is the Green River, which flows westward across the Pennyroyal Plateau and Chester Upland at a local altitude of 130 m (425 ft). Mammoth Cave has been formed by drainage from not only the upland, but also from adjacent areas of the Pennyroyal Plateau. This water emerges at several large springs along the Green River.

The largest springs are fed by passages 10–15 m (~30–50 ft) below present river level, which discharge through openings in thick alluvial sediment. Mammoth Cave lies more than 80 km (50 mi) south of the farthest limit of Pleistocene continental glaciers, so it was spared the direct effects of glaciation. But the Green River is a tributary of the Ohio River, whose base level was greatly affected by glaciation, and the 15-m thick alluvial deposits at Mammoth are the direct result of aggradation of the Ohio River during the latest (Wisconsinan) glacial advance.
Figure 3: Rock formations exposed at the surface in the Mammoth Cave region (Palmer, 1981).
Figure 4: Map of the Mammoth Cave System, Kentucky (based on surveys by the Cave Research Foundation and Central Kentucky Karst Coalition). Names are shown for caves explored separately but connected by later discoveries. E = entrances to tour routes in the main part of Mammoth Cave. ER = Echo River Spring; SS = River Styx Spring.

Figure 5: Geologic cross section through the Mammoth Cave region. A = caprock composed mainly of sandstone and shale, with minor limestone units (late Mississippian-mid-Carboniferous age); B = large upper-level canyons and tubes of late Tertiary age; C = tubular passage levels of Pleistocene age; D = vadose infeeder of various ages; E = passages flooded by late Pleistocene rise in base level; F = springs partly blocked by alluvium; G = truncation of upper-level passages by karst valleys; H = impure limestones that support surface drainage.
Figure 6: Detailed stratigraphic column for Mammoth Cave National Park. In the Historic section of the cave, most units above the Kamak are locally only about half as thick as shown here, and those below are up to twice as thick.
impure beds thicken into major sandstone and shale formations that partition the limestone. Thin limestone formations between the insoluble rocks in the Mammoth Cave area contain perched karst drainage. Springs in these limestones provide the main water supply to Mammoth Cave National Park.

Description of the Cave System
The presently known areas of Mammoth Cave extend beneath four of the major ridges of the Chester Upland south of the Green River. Mammoth Cave Ridge, Flint Ridge to the northeast, Joppa Ridge to the south, and Jockey Ridge to the east each contains major caves that have been linked together into a single system. The basic pattern of passages in the cave is dendritic, but there are so many superimposed levels and diversions to progressively lower levels that the dendritic pattern is almost completely obscured (Figure 4).

The three most common passage types are canyons, low-gradient tubular passages, and vertical shafts up to 60 m (200 ft) deep (Figures 7-9). Bedding is very prominent in the host limestones, and most fractures are small. As a result, the passages in Mammoth Cave are highly concordant with the beds (Palmer, 1989b). Tubular passages have wide lenticular or elliptical cross-sections that are elongate within the bedding (Figure 8). Even the numerous vertical shafts in the cave are strongly influenced by the prominent bedding, because inflowing water is generally perched along bedding-plane partings or on relatively resistant beds. Growth of a typical shaft takes place downward in stages through time, with the bottom deepening from one major bed to the next, and with successive drains in each bed.

Most passages that form in the vadose zone (canyons and perched tubes) have an almost perfectly consistent down-dip orientation, whereas those of platytic origin usually tend to parallel the local strike or at least have little relation to the dip. Passage sinuosity is strongly controlled by local variations in dip and strike of the controlling bed or bedding plane. The heterogeneous trends of the passages are controlled to a great extent by local variations in structure from bed to bed.

Recharge areas for the cave system are the Pennyroyal Plateau, the dissected karst valleys incised into the plateau, and the sandstone-capped plateau itself. The passages thus serve as regional drains, valley drains and shaft drains. Solutional scallops in the regional-drain passages indicate discharges up to tens of m³/sec, and runoff characteristics suggest catchment areas of several hundred km². Only a few regional drains can account for the runoff from the entire sinkhole plain portion of the Pennyroyal. Many fragments of abandoned regional drains still survive high in the cave system, while the lowest levels are active stream passages. The largest active cave streams drain to a few large springs along the Green River.

Valley drains more frequently drain internally into the regional drains. Drainage from the plateau top enters the subsurface through shafts. From the bottoms of the shafts low-gradient drains extend for long distances until they either intersect other passages or emerge at the surface.

Geomorphic History
The evolutionary history of the presently known Mammoth Cave System can be traced back as far as the late Tertiary (Mioke and Palmer, 1972; Palmer, 1989b; Granger et al., 2001). The sequence of passage development is fairly clear, and its relation to regional events seems to be understood, at least in general terms.
Figure 8: Typical tubular passage formed along the bedding at or near the water table (Cleaveland Avenue, Half Day Tour).

Passages in Mammoth Cave are scattered over a vertical range of ~120 m (~400 ft), as shown in Figure 5. Vadose canyons can form anywhere above base level, and roughly half of them are still active today. Tubular passages cluster at only a few elevations, which indicate significant pauses in base-level lowering. Vertical sinuosity in the tubes indicates that while forming, they extended as much as 23 m below the water table. Former base levels, which controlled the vertical positions of the tubes, can be determined by the elevations of points where there is a change in the original downdip direction from downdip vadose canyons to tubes with irregular, low gradients and no systematic relation to the dip. Many tubes are oriented almost along the strike of the beds, following shallow routes along the same beds that guide the incoming vadose canyons. These vadose-pelagic transition points cluster at elevations of 210, 183–189, 168, and 152 m (690, 600–620, 550, and 500 ft). These four levels were roughly dated from geomorphic evidence (Moore and Palmer, 1972; Palmer, 1989b) and by paleomagnetic analysis of sediment (Schmidt, 1982). Since then, more precise dates have been obtained from $^{26}$Al/$^{10}$Be ratios in quartz sediments (Granger et al., 2001). While the sediment is exposed at or near the surface, these two isotopes are produced in tiny quantities by cosmic radiation. When the sediment is carried underground, the isotopes decay at different rates, and their ratio indicates the duration of burial.

The two upper levels (above 168 m) are wide canyons and tubes, filled to various depths with stream-borne quartz silt, sand, and gravel. Some are completely filled, but in others, most of the sediment has been removed by stream erosion. The greatest sediment thickness is about 20 m (~65 ft). Passages at these levels have sediment dates of 2.3–3.5 million years and, of course, the passage origins predate the sediment. These passages represent slow fluvial entrenched during the late Tertiary, which was interrupted by periodic aggradation, perhaps in response to climate changes. The rather flat Pennyroyal Plateau surface formed at this time. At 2.7 million years ago there was widespread aggradation to as much as 30 m (100 ft), which filled all upper-level passages, some partially and others completely. Aggradation also took place on the Pennyroyal surface. This event coincides roughly with the first major North American glaciation, although the relationship is not clear.

The two lower levels consist of smaller passages, partly because groundwater recharge had been fragmented into many sub-basins by that time, and also because pauses in base level
were shorter. They represent fairly rapid Pleistocene entrenchment of the Green River. Prior to that time, karst was probably sparse on the Pennyroyal because of limited entrenchment. The rapid drop in base level during the Pleistocene caused nearly all surface drainage on the Pennyroyal to be diverted underground, and the extensive doline-dimpled surface of today began to form. Cave levels at 168 and 152 m (550 and 500 ft) are well-developed tubes with little sediment fill. Sediments at these levels, respectively, about 1.5 and 1.2 million years old. Passages at other elevations are mainly shafts, small canyons, and crawlways, mostly of vadose origin. Some large passage have formed below the 152 m (500 ft) level, but their elevations are not consistent. They include local tube segments fed by many vadose infeeders, as well as passages perched on relatively insoluble beds. Some are also remnants of phreatic loops that extended below the water table and emerged at springs that lay at higher elevations.

The sudden abandonment of the upper-layer passages, and development of many small passages at lower levels, apparently resulted from major changes in the patterns of surface drainage (see Mote and Palmer, 1972; Granger et al., 2001). Until the early Pleistocene the Ohio River was rather small, not significantly larger than the Green River. Most of the drainage from the east followed more northerly routes, first via the St. Lawrence River to the Atlantic, then through the so-called Teays River through northern states into the Mississippi River. The first major glacial advance into the region blocked the northerly route, and then the Teays, diverting the flow into the Ohio. Suddenly the Ohio became the largest river in the eastern United States. It began to entrench its valley rapidly and the Green River, as a tributary of the Ohio, did the same. Minor adjustments in drainage pattern may account for the periodic pauses in valley incision that resulted in the tubular passage levels.

At any time during the evolution of the cave, the pattern of active passages has been crudely dendritic. On cave maps, this pattern is obscured in several ways. For example, there are many superimposed levels of old, abandoned passages overlying more recent active ones. Even many active vadose passages can cross over active or abandoned passages at lower levels. Post-glacial alluvial fill in the valley has flooded roughly the lowest 15 m (50 ft) of the cave and reactivated many formerly abandoned passages.

**Present Water Chemistry**

The nature of the present water flow through Mammoth Cave seems representative of nearly the entire history of cave development. There is one exception: the earliest cave passages appear to have been fed by large sinking streams supplied by surface runoff from what is now the Pennyroyal Plateau, and from valleys in the Chester Upland tributary to the Green River. These streams entered the limestone ridges of the Chester Upland at only a few discrete points. No present-day examples remain, although their chemistry can be inferred from measurements of similar streams in other regions. There is no reason to suspect that the water chemistry and dissolution rates in other sources of recharge to the cave differ greatly from those of the past.

In the following paragraphs the saturation index of calcite (SI) is defined as $\log (\text{IAP} / K_s)$, where IAP is ion activity product and $K_s$ is the solubility product of calcite. Negative values represent undersaturation and positive values indicate supersaturation. The saturation index for dolomite (SI_d) is defined as $0.5 \log (\text{IAP} / K_{sd})$, where the coefficient 0.5 adjusts for the fact that dolomite releases twice as many ions as calcite, so the SI values will be compatible with those for calcite.

Present water sources include the following (Palmer, 2000):

- **Sinking streams on the Pennyroyal Plateau contribute water to many of the large base-level stream passages of the cave. They have a highly variable discharge, moderately high $P_{CO_2}$ (typically 0.001 to 0.01 atm), and widely fluctuating saturation levels that range from highly unsaturated during peak discharge to supersaturated during low flow. Typical SI values range from about −1.0 to +0.4, with SI values slightly lower. Most dissolution in the cave takes place during high flow events (Mein and Groves, 1997). On the basis of measurements of large sinking streams in other karst areas, those that feed the large upper levels of the cave in the past probably had similar characteristics to those of the smaller sinking streams described here. During pre-agricultural times, before deforestation, the discharge probably fluctuated much less that it does today. The general lack of floodwater features in the large upper-level passages of the cave suggests this idea.

- **Sinkholes on the Pennyroyal Plateau and in karst valleys in the Chester Upland supply the majority of the water to base-level cave streams, in addition to forming numerous minor vadose infeeders. This water acquires a moderately high $P_{CO_2}$ from the soil (typically 0.001 to 0.01 atm), but much of its solutinal potential is lost near the surface, so that it is only mildly aggressive by the time it reaches the caves. Typical SI values range from −0.5 to −0.1, and SI values from −1.1 to −0.7. Recharge from sinkholes and sinking streams accounts for most of the allochthonous detrital sediment carried into the cave. This consists mainly of quartz sand and gravel derived from weathering of the insoluble caprock, combined with clay, silt, and chert fragments derived from the carbonate rocks.**

- **Perched karst springs in the Chester Upland drain from the Haney Limestone, a thin carbonate unit sandwiched between sandstone formations within the caprock. Most of the recharge infiltrates through thin sandstone beds of the overlying Hardinsburg Formation. This water emerges from the Haney springs with surprisingly low SI (−2.0 to −0.5) and SI values (−2.0 to −1.0), and rather low $P_{CO_2}$ (0.002–0.008 atm). Evidently much of the limestone dissolution in the Haney takes place under conditions essentially closed to CO₂ because of the sandstone barrier between the essential and the limestone. Most of the spring water then flows on the surface over the Big Clifty Formation and enters the main cavernous aquifer through sinkholes in karst valleys. At this point the water is still very aggressive and forms vadose passages in the cave. These passages exhibit some of the most active dissolution in the cave.**

- **Dissolved inftation enters the main limestone directly through the sandstone caprock of the Chester Upland, especially where the sandstone is thin along the eroded ridge edges. Initial dissolution of the carbonate is under essentially closed conditions. As a result, as the water approaches saturation with dissolved carbonates, the equilibrium $P_{CO_2}$ drops to very low values (less than 10⁻⁴ atm) and the pH rises to as much as 9 or 10. These pH values cannot be measured in situ but are inferred from theoretical considerations, coupled with the following observations. When this seepage reaches creased caves, it rapidly absorbs CO₂ from the cave air and the pH drops, causing substantial corrosion of the cave walls. In places tiny seeps have etched the cave walls with irregular rills as deep as several centimeters. This is surprising, when one considers that the cave air has a very low**
CO₂ content (averaging about 0.00075 atm) compared to much higher values in most caves in other geomorphic settings. Small discrete streams that enter the cave through the sandstone share some of these characteristics. This water feeds many shafts and canyons. It is aggressive but lowers just below saturation during low flow. During high flow the SIₖ can drop as low as −1.0 and SIₕ to about −1.5.

- Seepage directly into the limestone through overlying soil has a high PₐCO₂ and enters the cave near calcite saturation, with a PₐCO₂ of about 0.003−0.01 atm. Dolomite is usually undersaturated, although in places it is slightly supersaturated (SIₖ up to +0.5), probably as the result of Mg enrichment during prior calcite precipitation. Loss of CO₂ to the cave air causes deposition of calcite speleothems. In the Mammoth Cave System this process if limited to relatively few areas where the sandstone cap is absent.

- Where the sandstone caprock is thick or contains interbedded shale, diffuse seepage into the underlying carbonate is very limited. This water tends to evaporate when it reaches the caves, precipitating gypsum and other evaporite minerals. The major source of sulfate for the gypsum is oxidation of pyrite. This is shown by the presence of residual limonite in the centers of many gypsum growths. Other supporting evidence comes from sulfur isotopes. S³⁵S in the cave gypsum ranges from −5 to −8 %, which contrasts with values that range from +14 to +19 % for primary sulfates in the bedrock (Francis Furman, Rolla, MO, 1998, personal communication).

- Backflooding from the Green River forces water into the caves through springs whenever the outside river level rises above the base-level streams in the cave. This is determined by the distribution of rainfall or snowmelt, and by artificial control of the river level by dams both upstream and downstream from Mammoth Cave. During large regional floods the cave water usually rises more rapidly than the Green River, so backflooding from the river typically occurs when water levels in the cave are declining. Rainfall and snowfall reduce base-level streams. The chemistry of the Green River water varies with season and discharge. During low flow it is usually supersaturated with calcite and during high flow (especially in winter) it is undersaturated. SIₖ varies from about −0.8 to +0.4, SIₕ from about −0.9 to +0.3, and PₐCO₂ from about 0.001 to 0.004 atm (calculated from chemical measurements by Miotke, 1975). Backflooding can account for a small amount of cave enlargement, enhanced by mixing of waters of contrasting CO₂ content. A considerable amount of fine-grained sediment is also deposited by backflooding (see Davies and Chao, 1959).

- Cave streams that are perched on shaly beds retain their aggressiveness for long distances, with SIₖ and SIₕ commonly as low as −1.0 and −2.0 respectively. Base-level streams and springs have a higher PₐCO₂, perhaps owing to oxidation of organic material, and they are closer to saturation, with SIₖ values that range from about −0.5 to +0.2, SIₕ about −1.0 to +0.2, and PₐCO₂ about 0.002 to 0.004 atm.

As the sandstone caprock retreats by erosion, water entering the cave at any given point tends to change its character in the following sequence:

- Diffuse seepage that evaporates when it reaches the cave walls, precipitating gypsum and other evaporite minerals.
- Aggressive seeps that etch the cave walls.
- Aggressive flows through thin sandstone beds.
- Water that passes directly through the soil into the limestone and deposits travertine in the cave (Figure 10).

This progression is shown in many places by gypsum crusts that are peeling from moist walls, and vadose shafts that were originally fed by aggressive water, but which are now lined with calcite speleothems.

For more details on the general setting, geology, and hydrology of the Mammoth Cave System, see White and White (1989).

Figure 16: Calcite speleothems are concentrated below areas where limestone is not overlain by sandstone. This flowstone, next to the Ruins of Karnak, is one of the few notable speleothems on the Historic Route.
Guide to the Historic Section of Mammoth Cave

The following pages describe the major features of interest seen in and around the Historic Route of Mammoth Cave. This section of the cave has been known the longest and was the site of aboriginal Woodland habitation and later saltpeter mining, tourism, and the earliest exploration. In addition, it clearly shows the various passage types and levels of the cave. There are other areas of the cave that are larger and more scenic, but this route shows the greatest variety of speleogenetic and historic features.

The Historic Section lies at the extreme downstream end of the underground flow system that formed Mammoth Cave, so most of the passages have formed at or near the level of the Green River. Therefore, they are well adjusted to the local sequence of base-level changes and represent a broad range of levels, from Tertiary to late Quaternary. Since the passages in the Historic Section were formed, the major water flow has been diverted to routes farther southwest.

The Historic Section clearly shows the effect of the caprock in both limiting and concentrating recharge to the cave. Shafts occur in or near areas where the sandstone has been breached, but where the caprock is intact the passages are dry and gypsum coated. The Historic Entrance of Mammoth Cave (Figure 11) has been known for thousands of years. Native Americans lived in the Mammoth Cave National Park area for more than 10,000 years. They first explored Mammoth Cave around 4000 years ago. Later, 2000–3000 years ago, they used this entrance to mine gypsum and other sulfate minerals from the cave. During the 1790s European Americans re-discovered the cave, which they also valued for its minerals, particularly saltpeter. This entrance has been used for cave tours since 1816. The first tour guides were the overseers and family of the man who ran the saltpeter operation. Apparently these guides did little active cave exploring and Mammoth Cave remained only a local attraction.

When Franklin Gour purchased the cave in 1838, he brought in three slave guides, Stephen Bishop, Mat Bransford, and Nick Bransford. These three guides actively explored the cave and greatly expanded the length and scope of the cave tours. Stephen Bishop became internationally famous as a cave guide, and Mammoth Cave became a destination for tourists from around the world. All three remained at Mammoth Cave after they were freed. The Bransfords started a family guiding tradition that lasted until 1939. They were only one of many families that developed family cave-guiding traditions at Mammoth Cave. The national and international reputation that Mammoth Cave earned through the 19th and early 20th centuries led to it being designated a National Park in 1941. Later it was named a World Heritage Site (1981) and the core of an International Biosphere Reserve (1990).

Although Mammoth Cave is among the most biologically rich caves in the world (Culver and Sket, 2000, Poulson, 1992), the Historic Tour does provide a limited view of the biology. Bats, especially solitary roosting pipistrelles (Pipistrellus subflavus), may be seen occasionally on the tour, most often in the entrance area. Occasionally cave crickets can be observed in the Mammoth Dome area (see map, Figure 12). River Styx provides a good chance to see not only aquatic cave-adapted animals (cave crayfish and eyeless fish), but also some terrestrial cave-adapted animals (including cave crickets, several types of cave beetles, and sometimes other invertebrates).

Figure 11: Historic Entrance of Mammoth Cave. The recessed beds are thin shales in the Girkin Formation (limestone). The contact between the limestone and the overlying Big Clifty Formation (quartz sandstone) is located along the trail in the right background.

Points of interest are indicated by number on the cave map (Figure 12).

1. Historic Entrance and Nearby Surface Features

The Historic Entrance formed by a large collapse sinkhole. The entrance passage (Houchins’ Narrows) continues beyond the sink toward the Green River as a separate cave (Dixon Cave). During much of the year, one can feel significant wind at the Historic Entrance. The Mammoth Cave System is complex, with 25 known entrances (natural and artificial). The elevation range of nearly 245 m (800 ft) among the entrances allows temperature driven differences in air density to cause significant air movement; this effect is also known as the chimney effect (or convective airflow).

Because the air movement is controlled by the difference between the surface air temperature and the cave air temperature, it is highly seasonal in nature. During the winter, warm (cave temperature) air rises out of higher elevation entrances, because it is less dense than the cooler surface air. Cold surface air is then drawn into lower elevation entrances. In the summer, the opposite occurs. Cool dense (cave temperature) air flows out of the lower elevation entrances and warmer (surface) air is drawn into the upper entrances. The Historic Entrance is a relatively low-elevation entrance, ~192 m (630 ft) above mean sea level, so cooler surface air comes into this entrance during the winter, and cave temperature air flows out during the summer. Deep in the cave temperature is about 14°C (57°F). When the surface temperature is near that cave temperature, air flow is slow or stagnant. As the surface temperature deviates further from that temperature, the rate of air flow at the entrance increases.
Prior to the connection with the caves in Flint Ridge and Joppa Ridge, the Historic Entrance was the only natural entrance to Mammoth Cave. It is located at the point where a small surface valley intersects one of the upper-level passages. The entrance is located in the middle beds of the Giskin Formation. The contact between the limestone and the overlying Big Clifty Sandstone (the basal unit of the resistant caprock) lies 7 m (23 ft) above the head of the entrance stairs. Outcrops of sandstone project along the trail leading to the entrance. Near the foot of the valley, along the banks of the Green River, is River Styx Spring, which drains some of the water from Mammoth Cave during high flow. Most of the water in Mammoth Cave exits at the alluvialized Echo River Spring about one kilometer (~3300 ft) to the south (see Figure 4).

Other features of interest near the entrance include the Old Guides' Cemetery, where Stephen Bishop is buried, and Mammoth Dome Sink, a collapse sinkhole extending into the limestone through the insoluble caprock, located 500 m (~1600 ft) south of the Historic Entrance.

During the early 19th century, when the cave was mined for saltpeter, several large furnaces were located above the cave entrance for boiling down the nitrate solution. The hollowed-out tulip poplar logs, through which this solution was piped out of the cave, are still visible in the entrance passage. They were partly buried to avoid freezing during the winter. Water at the entrance was collected and piped into the cave for use in leaching the calcium nitrate from the cave sediment.

Figure 12: Map and profile of the Historic Section.
The entrance passage (Houchins’ Narrows) slopes gently downward into the cave. Its original gradient was in the opposite direction, toward the Green River, but ceiling collapse and cave fill have reversed the apparent gradient.

2. Rotunda

The passages seen here are deep canyons filled more than half way with sediment. They are typical of the large upper levels of late Tertiary age, at altitudes of 173–200 m (~575–650 ft). The full vertical extent of these canyons can be seen in only a few places in Mammoth Cave and nearby caves, where the sediment has subsided into underlying passages.

Broadway and Audubon Avenue form a single strike-oriented passage extending around the nose of a local anticline. The original low flow direction was into Audubon Avenue. The entrance passage (Houchins’ Narrows) is a later diversion passage oriented down the local dip of 19 m/km (about 1 degree). More than one stage of canyon deepening and filling may have occurred here. As the passages were enlarging, it is likely that much of the time they were floored by wide and fairly shallow meandering streams.

The prominent bedding of the limestone can be seen in the passage walls. Most of the walls consist of the Paoli Member of the Girkin Formation, which is 7 m (23 ft) thick here. The meter thick Bethel Member forms a recessed niche near the ceiling. This is one of the incompetent, shaly beds that separate the purer limestones of the Girkin Formation. The original solutional ceiling was located at the top of the Paoli, but breakdown of the ceiling and walls has obliterated nearly all traces of dissolution. Arched break-out domes in the ceiling, such as the Rotunda, are common in wide places in the main passages of the cave.

The remains of the 19th century saltpeter works are well preserved here, including several leaching vats and the ruins of a tower that once housed a hand pump to force the nitrate-bearing solution to the entrance. After leaching, the sediment in the vats was piled along the passage walls to become regrown with nitrate. Most of the nitrate probably came from bat guano. Bats were once common in the cave but have been almost entirely absent since the mining began.

3. Broadway

The tour follows Broadway in the former upstream direction. This is the major uplevel passage of the cave. Fractures of the elaborate pipe system, through which water was brought into the cave and the solution of leached nitrate was pumped out, are seen in this passage (Figure 13). Most of these were made from the trunks of tulip trees, which have a soft pithy heartwood that is easily hollowed out with a spoon drill.

4. Junction with Gothic Avenue

Broadway splits upstream into two branches on different levels. The upper level extends to the right, (southward) as Gothic Avenue, in the Paoli Member (Figure 14). This is the oldest major passage in Mammoth Cave Ridge, and was formed by water from Houchins Valley. The so-called Main Cave continues straight ahead on the lower level, in the Ste Genevic Limestone. This passage was formed when water was diverted to a lower level from Gothic Avenue and joined water from the Pennyril Plateau. The junction of these two passages is rather complex, because the Main Cave originally passed beneath Gothic Avenue and joined it further downstream at the Methodist Church. Breakdown and sediment fill have obscured their original relationship. Gothic Avenue ends in breakdown about one kilometer (~3000 ft) in the former upstream direction from this junction.

The downstream junction of Gothic Avenue and the Main Cave is called the Methodist Church because religious services were held there in the 19th century, making use of a natural pulpit of rock (on right in Figure 13) and a broad, flat-floored area for the congregation. On early tours it was customary for the guides to throw burning torches of kerosene-soaked cotton onto the high ledges in this room to illuminate it. Black smudges on the walls resulted from this practice. The walls and ceiling in this part of the cave are unusually dark because of the cumulative smoky coating from the early kerosene and oil lanterns, and from the flaming torches of the aboriginal explorers more than a thousand years before.

Other saltpeter vats are seen at the upstream junction of Gothic Avenue and the Main Cave. The hand rail around the vats is made from the remains of a second pumping tower that once occupied this site (Figure 15).

Figure 13: Looking in the former downstream direction (northwest) in Broadway at the “Methodist Church,” where the upper-level continuation of Gothic Avenue merges with the lower-level Main Cave to form a single passage. Note the wooden pipes that were used to convey water and nitrate solutions in the early 1800s.
5. Giant’s Coffin and Wooden Bowl Room

The gypsum coating on the walls of the Main Cave in this area shows the impact of Native American mining. Battering of the gypsum to remove loose pieces is evident as round white marks in the dark gypsum coating. The battering extends above normal human reach because climbing poles were used by prehistoric people to extend their reach. Several of these poles have been found in the cave. In addition, many other artifacts of these early caves have been found. These include cane and plant stems used for torches, charcoal debris from torches, stoke marks on the walls from knocking ash off torches, digging sticks, woven plant slippers, gourds, mussel shells, and occasional stone artifacts. These people explored at least 19 km of the Mammoth Cave System beginning around 4000 years ago, but concentrated mainly between 3000 and 2000 years ago. Among the most interesting remains that these people left behind in the cave are paleofaces. These have provided information about the diet, parasite load, and gender of the people who visited the cave at that time (Watson, 1997; Sobolik et al., 1996).

Main Cave continues in the former upstream direction for many kilometers. Over most of that length the passage was formed by water that closely followed the local dip of the beds. The elongate northwest trend of Mammoth Cave shown in Figure 4 is a result of this flow pattern, which was concentrated by a broad, gentle syncline with a northwesterly axis.

Figure 15: Saltpotar vat at the junction of Main Cave with Gothic Avenue.

Figure 16: The “Giant’s Coffin” is a breakdown block that nearly seals the diversion route from Main Cave into the Wooden Bowl Room. Behind a large breakdown block (“Giant’s Coffin,” Figure 16) the tour leaves the Main Cave and descends through a small passage to the Wooden Bowl Room at next lower level. This route is one of many that resulted from the diversion of late-stage streams from the Main Cave. The Wooden Bowl Room is located at the junction of several passages, one of which (Garter Avenue) contains most of the in situ aboriginal artifacts in Mammoth Cave. The room is named for one of these artifacts. The ceiling is formed by the base of the thick-bedded Kamik Member of the St. Genevieve, and the thin-bedded Spar Mountain and Fredonia Members are exposed in the walls. Passages at this level are much smaller than those in the upper level and are predominantly tubular. They are of early Pleistocene age, when the Green River began its entrenchment below the level of the Pennyroyal Plateau.

6. Black Snake Avenue and Bottomless Pit

The tour route descends to a tubular passage at an altitude of 165 m (540 ft), named Black Snake Avenue (Figure 17). This
pit by bridging the gap with a wooden ladder. Bottomless Pit was the limit of exploration in the lower levels of Mammoth Cave.

Black Snake Avenue consists of several braided passages (Figure 17). Rills, anastomoses, and dead-end fissures give evidence for periodic flooding during the last stages of its evolution. These passages lie at and just below one of the major levels in the cave, ~168 m (550 ft) above sea level. None of them reaches large size, however, because they were formed by rather local recharge.

7. Fat Man’s Misery and Great Relief Hall

Black Snake Avenue continues another half kilometer as Pensacola Avenue, but the tour route enters a side passage and descends through breakdown to a still lower level, at 152 m (500 ft), of mid-Pleistocene age. Sediment from this level shows dates of at least 1 million years (Granger et al., 2001). The tour follows a low, wide passage floored with sand and gravel named Buchanan’s Way. It is shortly blocked by sediment fill, but a narrow, sinuous canyon with a keyhole-shaped cross section branches off as a diversion route to a parallel passage at the same level. The narrow canyon is named Fat Man’s Misery (Figure 18), and the large tubular passage beyond is called Great Relief Hall (Figure 19). All of these passages have developed along a prominent bedding-plane parting near the bottom of the Fredonia Member of the Ste. Genevieve Limestone. The underlying dolomite bed contains many small solution pockets and has a conspicuously porous appearance. Joint-controlled

Figure 18: Fat Man’s Misery is a small drain leading to Great Relief Hall.

passage is located in a thick-bedded unit of the Fredonia Member and is floored by a local yellow dolomitic limestone. The passage extends beneath the Main Cave, in the former downstream direction, and skirts the northeastern edge of Mammoth Cave Ridge. Vadose water entering along the eroded edge of the caprock has formed several vertical shafts that intersect the tubular passage and drain into lower-level canyons. The deepest shaft is Bottomless Pit, which reaches 32 m (105 ft) below the trail almost to the level of the Green River. Prior to 1838, when Stephen Bishop crossed the

Figure 19: Great Relief Hall is located at the 500 ft level (152 m).

Note the chart dikes in the ceiling, which includes some of the lowest beds in the Ste. Genevieve Formation. Note the pitting of the dolomite bed near the floor.

Figure 20: River Hall is about 10 m below Great Relief Hall but is part of the same “500 ft” level. This is part of a phreatic loop that extended below base level while the passage was still actively forming. Note the ceiling scallops indicating convergent flow with that of Great Relief. The walls are in the upper St. Louis Limestone.
fissures in the limestone ceiling of Great Relief Hall extend almost perpendicular to the passage trend. This is a typical situation and shows the negligible influence of fractures on passage patterns in these prominently bedded strata. Nodules and dike-shaped bodies of chert project from the ceiling. These are common shapes for chert bodies in the Ste. Genevieve Limestone, in comparison with the beds and thin lenses of chert in the underlying St. Louis Limestone.

8. River Hall

Black Snake Avenue, Buchanan’s Way, and Great Relief Hall were all fed by water from Houchans Valley to the east. At River Hall the tubular passage of Great Relief Hall slopes downward across the beds to the Ste. Genevieve - St. Louis contact, where it joins a passage that once carried drainage from major sources located farther southeast, perhaps as far away as the Pennyroyal Plateau. This combined passage ends in breakdown at the northern end of River Hall. The top of the St. Louis Limestone forms a projecting ledge about 2 m (6 ft) below the ceiling. Although River Hall is located 12–15 m (40–50 ft) above the level of the Green River, it occasionally fills completely with water during periods when the river floods. During a flood in 1962, the water level in the cave rose 19 m (62 ft).

9. River Styx and Echo River

Following the left-hand (southern) tributary at River Hall, the tour route proceeds in the former upstream direction, as is shown

Figure 22: A boat ride on Echo River was once offered by the Park Service, but maintenance after frequent floods became a problem.

by prominent scallops in the walls and ceilings (Figure 20) and by the layout of the passages. This passage branches into a lower river passage partly filled with sediment and containing slow-moving water at essentially the same level as the Green River. This is River Styx. The sound of a small waterfall (Charon’s Cascade, Figure 21) can be heard plunging from the ceiling into a pool. Perched on sediment, River Styx flows southward, in the opposite direction from the flow that originally formed the passage.

The two passages cross each other several times and eventually merge into a single tube containing deep water. Here the cave stream is known as Echo River (Figures 22 & 23). This passage was originally fed by major sources of water to the southeast, but now receives recharge only from local sources. Drainage from Echo River follows a flooded passage to Echo River Spring (Figure 4).

The Echo river passage has had a long, intricate history. It originated as a phreatic tube that looped downward below base level at least 20 m (65 ft). Traced upstream for 2 km (1.2 mi), it changes to a vadose canyon at an altitude of 152 m, which corresponds to that of its tributary, Great Relief Hall. This is one of the major levels in the cave. Further entrenchment of the Green River allowed the

Figure 23: The upstream part of Echo River is part of the “500 ft” level in the cave, even though its true elevation is 425 ft. This part of the passage was a phreatic loop that converged with passages at 500 ft. The nearly submerged connection route between Mammoth Cave and the Flint Ridge System is hidden in the shadows in the background.
continue at a higher level. The tour route then drops slightly into Sparks Avenue, a wide tubular passage at the Ste. Genevieve - St. Louis contact. Although Sparks Avenue is at essentially the same level as uppermost Echo River, its small size and thick sand and gravel fill indicate that it is probably a late-stage diversion route for one of the upstream passages such as Buchanan’s Way. Prominent blind joint-controlled fissures in the ceiling show evidence for periodic flooding. Along one of these joints the passage jogs upward several meters and continues within the lower beds of the Ste. Genevieve (Figure 24). Cross beds in the sediment, and wall scallops, indicate that the original flow was in the direction followed by the tour.

11. Mammoth Dome

Sparks Avenue is intersected by Mammoth Dome, one of the largest vertical shafts in the Mammoth Cave System (Figure 9). There appears to be no genetic relationship between the shaft and the passage. Water enters Mammoth Dome through a narrow canyon visible in the ceiling, falls 58 m (190 ft) and exits through a boulder-choked drain. The source may be Mammoth Dome Sink, which is located 100 m (300 ft) to the south, but dye tracing between them has been unsuccessful. Intersecting canyons have created a complex pattern of fluted walls and pillars, including the feature known as the Raun of Karnak. Dripping water has also formed draperies of flowstone, which is rare in this part of the cave (Figure 10).

The variety of limestone types in the Ste. Genevieve and St. Louis formations is clearly seen here. The Ste. Genevieve - St. Louis contact is located about 2 m below the lowest landing in Mammoth Dome, where the dark brown, shaly St. Louis contrasts with the lighter gray of the Ste. Genevieve. Vertical flutes are well developed in the lower beds of the Ste. Genevieve but are only poorly developed in the thinner beds. The bed that forms the pillars of the Rauns of Karnak is abnormally thick here, forming a single unit of more than 6 m (20 ft). The pitted dolomite that forms the lower walls of the Great Relief Hall (Figure 19) is seen again beside the lower stairs leading out of Mammoth Dome.

The tour ascends Mammoth Dome on a spectacular staircase, bypassing all the intermediate passage levels and returning to the highest level of the cave.

12. Little Bat Avenue

This small tube was barely intersected by Mammoth Dome and has no genetic relationship to the shaft. It appears to have been a drain for Audubon Avenue after the latter passage was partly filled with sediment. Little Bat Avenue is located mainly at the Aux Vases - Joppa contact.

13. Audubon Avenue

Little Bat Avenue emerges into Audubon Avenue, which is the downstream continuation of the Main Cave and Broadway (Figure 25). This passage ends in breakdown at the edge of the Green River Valley several hundred meters to the west. The passage spans the entire thickness of the Paoli Member, and the sharply recessed niche at the Girkin - Ste. Genevieve contact is clearly visible.

The tour returns to the Rotunda and exits through the Historic Entrance.

Springs along the Green River

The low-level stream passages seen on the tour discharge to two springs along the Green River (Figure 4). From the Historic
Figure 25: Audubon Avenue at a point where the passage diverges at two different levels near the Green River.

A short walk downhill toward the river leads to River Styx Spring (Figure 26), which delivers overflow from the cave passages around Echo River. The exact underground route is not known.

Echo River Spring is located near the Green River Ferry. Take the road southeast from the Visitor Center to the first right turn, and follow it downhill to the Green River. At the ferry landing, park on the right side and follow a short trail near the entrance to the parking lot to a broad pool in which water rises from a passage below. This water drains directly from Echo River in the cave through a water-filled passage about a mile long (~1500 m) and about 10 ft (~3 m) below the water table. It has been mapped by divers. Both springs feed short streams that discharge into the Green River. When flood pulses move down the river, the water often backs up temporarily into the cave.

Figure 26: River Styx Spring, below the Historic Entrance, drains overflow from the base-level passages in the cave. The vertical rod is a staff gauge for measuring water-level variations.
Upper Levels of Crystal Cave

Flint Ridge, Mammoth Cave National Park

Introduction

Crystal Cave is at the northeastern edge of Flint Ridge, which is separated from Mammoth Cave Ridge by a fairly deep dry valley (Houchins Valley). Its location is shown on Figure 4. The cave is very historic for several reasons. It was discovered in 1917 by Floyd Collins, a son of the landowner, and the cave was opened to tours soon afterward. The location was far from highways, however, and the tourist trade was slow, so Floyd tried to find other entrances closer to the highway. He normally explored alone. On one occasion he dug in a small cave about 5 km (3 mi) south of Crystal Cave and was trapped when a rock fell on his ankle. A massive, widely publicized rescue was mounted, but a ceiling collapse made it impossible to free him before he died. For many years his coffin lay in the first room of Crystal Cave, and because of his widespread fame (though posthumous), he drew many visitors to Crystal Cave.

In 1954 the National Speleological Society organized a weeklong 60-person expedition to push the cave’s seemingly endless passages (Lawrence and Brucker, 1955). The effort achieved little, but it energized a small group of the explorers, mainly from Otsego and Kentucky, who continued to push the cave. In 1954–1955 a great breakthrough was made to new passages in the heart of Flint Ridge, and only a few years later connections had been found with most of the other large caves in the ridge.

The group established the Cave Research Foundation in 1957 with the goal of continuing the explorations and initiating scientific research. Crystal Cave was sold to Mammoth Cave National Park in 1961, under the condition that the CRF could continue exploring and mapping from the entrances on the Crystal Cave property. Eventually CRF obtained permission to map caves throughout the Park. In 1972 a connection was found between the Flint Ridge System and Mammoth Cave via low-lying passages that extend beneath the intervening valley (Brucker and Watson, 1970). In 1983 the combined cave was connected to Roppel Cave to form the system shown in Figure 4 (Borden and Brucker, 2000). Crystal Cave thus served as the starting point for this entire post-1950s history.

Houchins Valley

The tops of Mammoth Cave Ridge and Flint Ridge lie at elevations of about 240–250 m (~780–820 ft.), and the valley extends down to an elevation of about 182 m (600 ft). This is about 50 m (170 ft) above the level of the Green River, which provides space for passages to extend beneath the valley to connect the caves in the neighboring ridges. Most of these passages are located in the upper Fredonia Member of the Ste. Genevieve, shown in Figure 6.

Crystal Cave Entrance

The entrance is located just below the contact between the Girkin Formation (limestone) and the overlying Big Clifty Formation (sandstone). The contact is seen only a few meters above the entrance. The Green River valley lies only a few hundred meters to the north. Be careful when descending the stone stairs, because they are slippery and uneven.

Figure 27: The Grand Canyon in Crystal Cave is a wide section of Collins Avenue where the lower-level Dyer Avenue intersects it. The ceiling is formed by the base of the Beech Creek Member, and most of the walls are in the Elsberry. An impure bed in the Elsberry forms the prominent recess in the walls. Note the large scallops, which indicate slow flow toward the entrance.

Collins Avenue

The entrance stairs lead directly to Collins Avenue (Figures 27 & 28). This is genetically the uppermost passage in the Mammoth Cave System, with a ceiling at about 210 m (680 ft) elevation. Its ceiling is irregular, with rises and falls in the former direction of flow, showing that it was initially phreatic. A later drop in base level caused at least 22 m (72 ft) of enchainment below the ceiling tube, forming a wide canyon best seen in the first room, the Grand Canyon. The passage cuts through the entire thickness of the Elsberry, Elsberry, and Beaver Bend Members of the Girkin Formation. For most of its length it is roughly parallel to the strike of the beds, which further supports an initial phreatic origin.

A later rise in base level filled the passage nearly to the ceiling. Although the passage is apparently much older than others in the Mammoth Cave System, the age of the sediment is about 2.7
Mn, essentially the same age as in all the other major passages, such as Broadway on the Historic Route, which is at least 30 m (100 ft) lower in elevation. This evidence suggests a major and widespread rise in base level at that time as a result of changing climates or sea level. Remnants of this sediment are found in other caves throughout the region, as well as on the surface, and can be traced throughout much of the east-central USA.

In the former upstream direction, Collins Avenue extends as a low, narrow passage floored by thick sand and clay. Most of the traversable space has been excavated by hand. There are some small speleothems of little note (largely vandalized). The passage terminates against the wall of a narrow valley to the east.

**Dyer Avenue**

The Grand Canyon was formed by the intersection between Collins Avenue and the lower-level Dyer Avenue. Dyer Avenue (Figure 29) lies at the same level as Broadway and Audubon Avenue on the Historic Route of Mammoth Cave. It is located in slightly higher beds—mainly the Beaver Bend Member of the Girkin Formation. The Paoli Member, seen in the Rotunda of Mammoth Cave, is exposed only in the deepest parts of Dyer Avenue.

Dyer Avenue is an extension of the upper half of Salts Cave, whose main passage is larger than Broadway in Mammoth Cave and at roughly the same elevation. The main passage of Salts extends down the dip toward the northwest, but then makes a turn to the northeast, more or less along the strike of the beds, to form Dyer Avenue. Dyer Avenue continues downstream, where it merges with the Salts. Dyer Avenue contains an extensive cave pool near the end of this hinge line.

**Figure 29:** Dyer Avenue, a former downstream segment of the upper level of Salts Cave (see Figure 4). The ceiling and upper walls are in the lower Reelsville Member, and the recessed beds are the Samplie (above) and Bethel (below). The main walls are in the Beaver Bend Member and the lower walls in the Paoli. Note the remnants of handrails from when the cave was open to the public.
As in Collins Avenue, the eastern end of Thomas Avenue is nearly filled with sediment. Elsewhere in the passage most of the sediment has been removed by stream erosion.

Scotchman’s Trap, a small hole in the floor about 2/3 of the way through Thomas Avenue, leads to the extensive lower levels of the cave (Figure 28). Through this hole and the complex passages beyond, the connection with the rest of the Mammoth Cave System can be made.

References


Abstracts

PEOPLE, POLITICS, AND A PARK: THE UNVARNISHED STORY OF THE CREATION OF MAMMOTH CAVE NATIONAL PARK

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Seventy years after Mammoth Cave National Park's formal dedication, the protected area with its many caves overlain by expanses of woodland is a fait accompli, and it is easy to lose sight of the fact that establishing the park was a contentious and uncertain endeavor. Unlike the earliest national parks in the U.S., which were carved out of the public domain and established the model of a national park as uninhabited wilderness, land in the Mammoth Cave area had been privately owned since the late 1700s, was thoroughly settled, and held a mix of small farms, rural communities, and businesses. In other words, it was anything but uninhabited wilderness. Mammoth Cave, itself, had been a privately owned and operated show cave since the early 1800s, and tourism was an important part of the local economy.

Using the official record of U.S. Congress published in the Congressional Record and the archives of the Mammoth Cave National Park Association, this paper explores processes by which Mammoth Cave National Park became a reality. The park was a project of a small group of Kentucky's political and business elite who faced challenges in three key areas: legislative, financial, and public relations. Rhetoric deployed in forwarding various parts of this agenda tended to frame issues in terms of core American values. Park leaders encountered resistance to their plans where their expressed values were countered by other core American values: stewardship versus entrepreneurship; regional economic development versus private property rights. Thus, although Mammoth Cave National Park is a story of American values writ large, it is also a story of the triumph of some American values over others. Park promoters were more successful in navigating the legislative process than in raising money or convincing ordinary Kentuckians to help, but, in the end, politics was enough.

SULFIDE OXIDATION AND EVAPORATIVE CONCENTRATION: COMPETING MECHANISMS IN THE SEMI-ARID KARST OF NORTHEASTERN BRAZIL

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A regional scale hydrochemical survey of wells, springs and vadose cave water in the semi-arid dolomitic Una Group karst of northeastern Brazil shows high sulphate levels that display variable correlation with increased levels of chloride and other ions. Underground karst morphology shows hypogene features that are not associated with surface (epigene) sources of acidity. High salinity values in the Una Group karst may be due to: (i) concentration due to evaporation of precipitation and/or aquifer water or (ii) increased contact time with the bedrock and leaching of minerals. Hydrochemistry coupled with sulfur isotope analysis has demonstrated that both mechanisms are operative in the area. Groundwater in the more arid northern sector of the area displays higher salinity values. Moreover, groundwater from quartzite, a much less chemically reactive bedrock, also displays high salinity values, demonstrating the contribution of evaporative processes. Statistical correlation between SO$_4^{2-}$ and Ca + Mg levels, however, demonstrates that sulfide is being produced by reactions within the bedrock. The absence of sulfate intercalations in the dolomite and the frequent occurrence of sulfide beds suggest
that sulfide oxidation may be a major process in the area, contributing sulfate anions to groundwater and increasing the potential for carbonate dissolution and speleogenesis.

GEOLOGICAL STRUCTURE AND UNDERGROUND DRAINAGE OF A HIGH-ALPINE KARST AQUIFER SYSTEM, WETTERSTEIN MOUNTAINS, GERMAN ALPS

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Water resources in mountainous karst regions are vital for regional water budgets and freshwater supply. While several previous studies focused on plateau-like karst massifs, little is known about the underground drainage of steep, high-alpine mountain chains. Therefore, hydrogeological investigations have been started in the Wetterstein Mountains, which peak at Zugspitze, Germany’s highest summit (2,962 m). The area belongs to the Northern Calcareous Alps and is mainly formed by up to about 1 km thick Triassic limestone. Karst landforms include karren, vertical shafts and several caves. The underlying marly limestone and major thrust faults act as regional aquiclude. The strata are folded and form two regional synclines and a large anticline. Previous tracer tests in two different zones of the Wetterstein Mountains have revealed significant differences in underground karst drainage: High velocities (ca. 100 m/h) and convergent flow towards one major karst spring was found in the Zugspitz Cirque, while lower velocities (ca. 10 m/h) and divergent drainage towards numerous karst springs have been identified in the adjacent Alpsspitze area. The goal of the current study is to characterize the geological structure, karst development, recharge processes and underground drainage pattern of the entire mountain range, so as to obtain general insights into the hydrogeology of high-alpine karst systems. This paper presents first results of the field work and outlines a large-scale multi-tracer test (6 injections) planned in July 2011.

A REPORT ON THE POSITIVE EFFECT OF GEODIVERSITY ON BIODIVERSITY IN FLORIDA

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This research presents the findings of a basic investigation to confirm previous findings that the geodiversity of a landscape promotes greater biodiversity. Based upon prima facie evidence, the concept that geodiversity promotes biodiversity would be valid in the State of Florida, USA. Geodiversity is a term used to describe the vast variations of morphological, lithological, and hydrological features possible in various landscapes. Biodiversity, the diversity of life, is driven by adaptive radiation, which is caused when species are forced to adapt to geographical separations, climate variations, niche availability, and different hydrological regimes. Florida has many instances of diverse terrains. Therefore, it is logical to assume that a geodiverse terrain in Florida would promote a greater diversity of life than a homogenous landscape. Sinkholes, circular subsidences in the landscape caused by the movement of groundwater removing subsurface materials, are common features in the autogenic karst that is present in much of Florida. This study examines how the presence of sinkholes in various ecosystems relates to the diversity of plants in Florida. The study was conducted in west-
central Florida, in Pinellas and Hillsborough counties, along the Gulf of Mexico coast. Plant diversity was measured by transect-line survey within the confines of the sinkholes' influence, and then in the area outside the geomorphic influence of the sinks. Data was collected and analyzed using standard statistical methods. There followed an analysis of the effects of local hydraulic conductivity, urban environmental factors, and geodiverse-feature clustering on the study's results. The final results of the investigation indicate that there is an overall positive effect of 5% on the biodiversity of terrains in Florida in or near sinkholes. This is in agreement with other studies, and supports the hypothesis that geodiversity promotes biodiversity. The results of this study can validly be added and applied to ecological population-location models to optimize the selection of sites intended for biodiversity preserves. Locally, this supports the need for 'Geosite' preserves in Florida, which will act not only to preserve geologically unique and important landscape features, but which also serve as unique niches and habitats for the endangered life of Florida.

CARBONATE ROCK DISSOLUTION RATES IN DIFFERENT LANDUSES AND THEIR CARBON SINK EFFECT

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Research on karst processes is important for the determination of their carbon sink potential, as is research into terrestrial ecosystems in karst areas. Solutional denudation rates of soils from three karst spring watersheds supporting different land uses were studied. Solution rates showed a distinct pattern based on land use, with a generally higher rate being recorded in forest use soil. The mean values for tablet dissolution from the cultivated land, shrublands, secondary forest, grassland and primary forest were 4.02, 7.0, 40.0, 20.0, 63.5 t/km²a, respectively. Changes in vegetation patterns could improve the size of karst carbon sinks; for example, in this study the carbon sink was 3 times higher in primary forest than in secondary forest soil and 9 times higher than under shrubland, equating to an increase from 5.71-7.02 t/km²a to 24.86-26.17 t/km²a from cultivated land or shrub to secondary forest and to primary forest, respectively. Data from monitoring and experimental sites showed that karst processes, as a low-temperature geochemical open system, are very sensitive to environmental change and are a special geological process that is involved in the short-term carbon cycle. Carbon sinks of terrestrial ecosystems increase with vegetation development or reforestation, here it was shown that similar processes caused by karst dissolutional denudation can occur underground as well.

CHARACTERIZATION OF FLUIDS AND EVALUATION OF THEIR EFFECTS ON KARST DEVELOPMENT AT THE DISCHARGE ZONE OF THE BUDA THERMAL KARST, HUNGARY

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Europe's largest naturally flowing thermal water system can be found in Budapest, Hungary. The springs and wells that supply the famous baths originate from a regional Triassic carbonate
THE INFLUENCE OF ALLOGENIC WATER ON KARST PROCESS—A CASE STUDY IN THE MAOCUN SUBTERRANEAN RIVER IN GUILIN, CHINA

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Allogenic water comes from non-karst region to karst region, with low pH value and carbonate saturation index, and high erosion to carbonate rock so as to speed up the dissolution of atmospheric CO\textsubscript{2} in water. This study focused on the Maocun Subterranean River in Guilin and observed its main outlet for one year. The results showed that 1) the HCO\textsubscript{3}\textsuperscript{-} concentration of the allogenic water ranges from 0.1~0.4 mmol/l; 2) its Ca\textsuperscript{2+} concentration 2~12 mg/l; 3) its conductivity 14.2~26 \mu S/cm; 4) with the water and rock interaction after allogenic water enters into karst region, the content of dissolved inorganic carbon (DIC) gradually increases, the same as the carbonate saturation index, which goes from unsaturation to saturation; 5) after one hour’s water and rock interaction, the HCO\textsubscript{3}\textsuperscript{-} concentration rapidly increases to 0.9~2.64 mmol/l, and eventually reaches to 3.4~4 mmol/l after a long time interaction. The results of tracing tests showed that 1) the allogenic water flow contributes 34.5\% to the karst groundwater’s; 2) from September 7, 2010 to March 22, 2011, the carbon sink resulted from allogenic water is 3.04×10\textsuperscript{5} gC; 3) after one hour’s water and rock interaction, it goes up to 3.04×10\textsuperscript{5} gC, which realizes an increase of an order of magnitude. Thus it could be concluded that allogenic water promotes karst processes and has a great impact on karst carbon sink.
INTERCONNECTION OF THE EDWARDS AND TRINITY AQUIFERS, CENTRAL TEXAS, USA

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The Edwards and Trinity Aquifers are critical water resources, supplying high-quality potable water to over two million people in the greater Austin-San Antonio region of central Texas, USA. These Cretaceous carbonate aquifers are hydrogeologically juxtaposed by extensive Miocene tectonic deformation associated with the Balcones Fault Zone, where the younger Edwards Group limestone has been downthrown relative to the older Trinity Group. The karstic aquifers are managed separately by regional water regulatory entities, and they have been historically treated as independent systems, both scientifically and from a water policy standpoint. Recent awareness of a significant interconnection between the Edwards and Trinity Aquifers has resulted in a number of hydrogeologic investigations documenting how they may actually operate as a single system. Studies related to upland recharge variability (spatial and temporal), stream loss, phreatic dye tracing, multi-port well monitoring, geochemistry, biologic habitat analysis, geophysics, and groundwater modeling indicate that the two are much less separated that previously observed. Summaries of these investigations conclude that changes in management strategies may be required to properly protect the quantity and quality of water in the Edwards and Trinity Aquifers.

THE GROUNDWATER TO THE GULF COLLABORATION

Robin Gary
Barton Springs/Edwards Aquifer Conservation District, TX, USA

Groundwater to the Gulf (G2G) is a free 3-day, field-trip based workshop for Central Texas teachers that emphasizes techniques for teaching water-based curricula to students in grades 4 through 8. Participants follow the path of water in Central Texas from its origins to its final destination in the Gulf of Mexico. Topics include: hydrology, groundwater, riparian and wetland habitats, urban watersheds, water use by humans and wildlife, water quantity and quality, rain water harvesting, green gardening and composting, water quality protection, and conservation. Educators investigate local resources available to their classrooms to increase teachers’ confidence in covering water topics through hands-on activities. Teachers who attend the workshop return to their classrooms prepared to guide students in environmental investigation. The workshop promotes the cultivation of environmental stewardship. Studies show that the less contact with nature one has, the less likely one is to be a good steward of one’s environment. By using the tools and techniques for monitoring the environment, educators acquire the skills and understanding to teach their students about the potential effects of various pollutants, the acceptable standards or limits of various pollutants, and the impact on stream quality and watershed due to land use patterns. G2G leverages the diverse expertise of the collaborating staff from 12 local and state agencies to discuss, explore, and demystify the oftentimes complex scientific issues faced in our own community. Each year approximately fifty educators attend the workshop and in turn reach over 5,000 students annually. Over the course of the five years the workshop has been offered, approximately 250 educators have been trained, reaching over 25,000 students annually.
LONG-TERM TRENDS OF PRECIPITATION, STREAMFLOW, AND BARTON SPRINGS DISCHARGE, CENTRAL TEXAS

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Effective management of karst aquifers depends on an accurate understanding of the available water budget. Recent studies have shown an increase in discharge at Barton Springs since the 1960s, attributable, in part, to urbanization increasing recharge. However, similar patterns of increasing streamflow from rivers in the area suggest a potential climatic shift since the 1960s and just after the areas drought-of-record. This poster presents an evaluation of long-term precipitation and streamflow data from stations up to 75 miles from Barton Springs and the potential influence of regional climatic changes on the water budget and springflow. Source data include monthly precipitation totals from nine National Oceanic and Atmospheric Administration weather stations and monthly average streamflow records for ten U.S. Geological Survey gaging stations. In addition, selected temperature and evaporation records were also evaluated. Long-term precipitation trends from Austin (since 1856) and San Antonio (since 1871) show conflicting trends with Austin showing no trend, while San Antonio shows a trend of increasing precipitation. Streamflow records of most perennial rivers with data from the early 1900's to present show a trend of increasing discharge, with a visible increase since the 1960's. Preliminary assessment of the data gathered suggests that increased streamflow may have contributed to increased recharge and therefore increases in discharge at Barton Springs. Further evaluation of the precipitation data are needed to understand the potential influence on increasing streamflow trends, and thus climatic influences on the overall water budget of the aquifer.

HYDROGEOLOGY AND GEOMORPHOLOGY OF CARBONATIC CONGLOMERATES IN THE FOLDED MOLASSE ZONE OF THE NORTHERN ALPS

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Clastic sedimentary rocks are often considered non-karstifiable and therefore less vulnerable to microbial and chemical contamination than karst aquifers. However, dissolution phenomena have been observed in clastic carbonatic conglomerates of the Folded Molasse zone of the Northern Alps, indicating karstification and high vulnerability. Therefore, a comprehensive research program was carried out at the Hochgrat site (Austria/Germany) in order to study the geomorphological and hydrogeological characteristics of this little-known type of aquifer. The study included mapping and characterization of karst phenomena, comparative multi-tracer tests with fluorescent dyes and bacteria-sized fluorescent microspheres, as well as analyses of fecal indicator bacteria (FIB) in spring waters during different seasons. Both fracture-controlled and hydrodynamically-controlled karren were observed on conglomerate outcrops. Dolines are widespread and typically circular, funnel-shaped, often 2-9 m in diameter and 1-6 m deep, and they frequently act as swallow holes. Poljes are very small (ca. 1 ha), occur in either glacial cirques or syncline depressions, are flat floored and lined with sediment and soil, and drain underground via swallow holes. Short conglomerate caves, springs with marked discharge variations and estavelles are evidence for underground karst development. The results of the tracer tests and spring monitoring demonstrate that (i) flow velocities in carbonatic
conglomerates are similar as in typical karst aquifers, often exceeding 100 m/h; (ii) microbial contaminants are rapidly transported towards springs; and (iii) the magnitude and seasonal pattern of FIB variability depends on the land use in the spring catchment and its altitude. Different groundwater protection strategies than currently applied are consequently required in regions formed by karstified carbonatic clastic rocks, taking into account their high degree of heterogeneity and vulnerability.

**KARST ISSUES IN JAMAICA**

Angella Graham

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Approximately 50% of Jamaica is comprised of highly dissected limestone plateaus which vary in height from 305 m- 914m ft above mean sea level. These areas are predominantly developed within the White Limestone Formation which is Upper Eocene- Lower Miocene in age. The most important types of landscape found in tropical karstland are cone or cockpit karst, and tower karst. In areas where the rainfall is low, doline karst develops. Poljes (interior valleys) are associated with marly limestones. The main features of the hydrology of north central Jamaica are major caves, sinks and "blue-holes."

Groundwater accounts for about 84% of all available water resources. The White Limestone formation is the principal aquifer in Jamaica. Due to its karstic nature and the fact that the overlying soil is thin, it is highly vulnerable to contamination. Seawater Intrusion, Deforestation, Bauxite Mining and Processing, Sugar Production and Tourism have all impacted negatively on the quality of the water resources in these areas. This presentation highlights the challenges of managing the water resources in the karst areas of Jamaica.

**OVERVIEW OF QUANTITATIVE CHARACTERIZATION METHODS TO ESTIMATE WATER FLUXES IN KARST HYDROGEOLOGIC INVESTIGATIONS**

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United States Geological Survey

The collection of quantitative data required for characterization of karst aquifers is often more intensive and difficult than that required for aquifers in non-karst settings. Over the last several decades, a variety of techniques have been developed, tested, and employed to better characterize inputs, throughputs, and outputs of karst flow systems, determine conduit hydraulic properties, and estimate water fluxes. For the fullest understanding of a karst system, the use of multiple complementary study methods is often required. Karst investigators should anticipate the need for designing a study approach that treats groundwater and surface water regimes as a single, dynamic flow system and must be prepared to select and apply a variety of relatively specialized techniques such as water-tracer tests, hydrograph analysis, and statistical or numerical modeling. We present an overview of methods that are particularly useful in the investigation of karst aquifers and in the study of water fluxes in karst terranes, as described in a recent U.S. Geological Survey Techniques and Methods paper published by the authors http://pubs.usgs.gov/tm/04d02/pdf/TM4-D2-chap3.pdf. The intent of the publication and this presentation is to provide information to aid the karst researcher in choosing those study approaches that will best characterize and describe the processes they are investigating, and to highlight the benefits of applying a multidisciplinary approach.
DIGGING DEEPER INTO A BOWLING GREEN, KENTUCKY, KARST LEGEND: THE UNCLE HENRY STORY

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In 1921, Popular Mechanics magazine published a story about Bowling Green, Kentucky, a town blessed with a “sewer system more than a million years old.” The author described Bowling Green’s practice of sending municipal wastewater into sinkholes under the misguided assumption that the limestone beneath the city would act as a natural sewage filtration system, and, eventually, clean drinking water would emerge down slope and flow harmlessly into surface streams. The only individual featured in the article was an elderly African American man named “Uncle Henry Jameson.” Uncle Henry used a “witch stick” to locate sinkholes and thus show property owners where to directly pipe untreated waste into the subsurface. This Popular Mechanics piece has been referenced in numerous academic articles and karst textbooks. Yet, “Uncle Henry” was portrayed as little more than a highly racialized, almost comical character, and his role in Bowling Green’s karst history has not been critically assessed. This research examines the life of Henry Jamison (his name misspelled in the article), and how he became the most famous “sink digger” in Kentucky. The “Uncle Henry” story is a reflection of public perceptions of karst environments and racial history in Bowling Green. His familiarity with karst likely came from experiences as a slave, farm laborer, his army service, and folk knowledge. Henry Clay Jamison was born into slavery in Kentucky in 1843. He joined the Union Army in 1864 as a “substitute” for a white draftee. After the Civil War, as a free man, he worked on a farm in Bristow, Kentucky, located on a karst plain east of Bowling Green. By 1900, Henry was in Bowling Green working as a “sink digger.” Jamison continued his work as a sink digger along with other occupations until his death in 1930.

METHODOLOGY FOR EVALUATING FLOW AND HYDROCHEMISTRY OF AUTOGENIC RECHARGE IN KENTUCKY’S MISSISSIPPIAN PLATEAU

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Autogenic recharge of soil-mantled karst aquifers travels through the epikarstic zone before entering the main part of the aquifer, often at discrete drains. On Kentucky’s Mississippian Plateau agricultural land use commonly introduces bacterial and agrichemical contaminants to autogenic recharge, which may reside in epikarstic storage for weeks or longer before moving downward to rapidly move through conduits in the main part of the aquifer to springs. Understanding the storage and movement of water through the epikarstic zone is thus critical for evaluating fate and transport of these contaminants. Work is underway to understand the movement and biogeochemistry of autogenic storage water flowing to a single epikarst drain in Crump’s Cave.

We have developed a monitoring strategy and equipment design that allows for quantitative characterization of flow and hydrochemical behavior below the drain using electronic data logging, weekly site visits for data collection, instrument maintenance, and calibration, and storm monitoring. A station above the cave collects atmospheric data with ten-minute resolution, and rainfall is collected weekly for pH and stable isotopes. Soil lysimeters are installed at three depths, and soil and
atmospheric CO₂ gas concentrations are measured weekly. Epikarstic drainage in the cave 25m below the surface is measured (ten minute resolution) with a barrel-weir for discharge, and then duplicate spC and temperature and triplicate pH for instrument redundancy and calculation of a standard deviation in the case of pH. In future monitoring we will undertake quintuplicate pH and triplicate spC and temperature. Weekly water samples are analyzed in the laboratory allowing regressions relating spC to calcium, bicarbonate, and magnesium concentrations, respectively, in turn to allowing calculation of CO₂ pressures, saturation indices, and calcite dissolution rates to evaluate water/rock interactions. Duplicate automatic water samplers with staggered timing collect samples at desired intervals for tracing experiments and storm pulse analysis.

MODELING TRACER TEST RESULT IN KARST CONDUIT, A CASE STUDY AT GUANCUN SUBTERRANEAN RIVER

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Several tracer tests were done in the same karst conduit at Guancun subterranean river under different discharges. NaCl with the mass of 50kg was injected in impulse manner. Specific electrical conductivity was recorded for concentrations, and discharge was measured with a current meter. We used QTRACER2 to get parameters from breakthrough curves about conduit, conduit flow and dispersion. The section value of conduit varies little among the tests, which shows that the conduit is filled by water even in the lowest discharge. Reynolds numbers in all tests are bigger than 20,000, which are above the threshold value of turbulence flow. Dispersion coefficient is linear with the mean tracer velocity. The classic one dimension advection dispersion equation was used to model the breakthrough curves. But the modeling curves have bigger mean tracer transit time than actual one. This can’t be explained by changing conduit shape. In the model mean velocity in the conduit section is used which slower tracer transport. To dismiss this error, a transit storage model OTIS is used for getting parameters and modeling results. The section of conduit is divided into main channel and storage zone in OTIS model. The advection and dispersion actually happens in the main channel, and the transit storage mechanism in the storage zone leads to tailing of the breakthrough curves. The OTIS model is successful for modeling these tests.

LOCALIZED HYDROLOGY OF AUTOGENIC RECHARGE IN KENTUCKY’S MISSISSIPPIAN PLATEAU

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Autogenic recharge of soil-mantled karst aquifers, often with contaminants, travels through the shallow epikarstic zone around the soil-bedrock interface before entering the main part of the aquifer, often at discrete drains. Work is underway to understand the movement and biogeochemistry of autogenic storage water flowing to a single epikarst drain in Crump's Cave on Kentucky's Mississippian Plateau. One aspect involves measuring the drain’s surface recharge area to facilitate mass balance experiments, and we use several approaches. In this study, rainfall rates above the cave and discharge of the water flowing from the drain below were measured every ten minutes in winter and spring 2010-11. After baseflow separation of eleven discrete storms, stormflow was integrated to measure individual storm volumes, and a nominal recharge area parameter ζ was determined for each by setting
the storm surface recharge and drainage volumes equal and then dividing the resulting recharge volume by the measured rainfall depth, assumed to be uniform over the small recharge area.

Values of $\zeta$ range from 843 m² to 11,200 m², with lower values presumably resulting from water entering epikarst storage that does not reach the drain during that storm response. Values of $\zeta$ may thus provide way to quantify varying epikarst storage input. Data so far also suggest that the actual recharge area is on the order of 100x100 m, though temporal variations may occur.

Using between-storm baseflow discharges and individual values of $\zeta$, we calculated unit-baseflow (UBF)--baseflow discharge per unit recharge area, or in this case $\zeta$, and a trend is that values for the epikarst drain are 2-3 orders of magnitude higher than published UBF values for regional springs in the same geological setting. This gives quantitative evidence that storage is more concentrated in the epikarst than in the regional aquifers as a whole.

KARST DEVELOPMENT AND HYDROGEOLOGY OF WONOSARI BASIN

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Previous studies suggest that Wonosari Basin is not considered as a karst area. The basin is a part of Wonosari Formation in which Gunung Sewu karst develops well. Basin morphology is the reason for the limited karstification in the area. However, karst morphology and karst drainage system are encountered in some localities. This research accordingly comes up with some detail investigation on karst morphology and hydrogeology of the area. This paper is based on field survey and bore data analyses. Field survey included water level measurement; spring, sinkhole, blind valley, resurgence, cave, and karst hills investigation. Analyses were also incorporated by reconstructing 164 bore data logs to understand the karst aquifer and karst drainage system of the area. The result shows that though only in small percentage, Basin Wonosari experiences karstification. Limited karst morphology and karst drainage system has develop in the north-east part of the basin. The karst morphology is characterized by sinking stream, resurgence, cave, and scattered conical karst hills. Early development of underground rivers is also encountered in the area.

KARST IMPACTS ON DAM SAFETY RISK ASSESSMENT IN THE US ARMY CORPS OF ENGINEERS

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The US Army Corps of Engineers (USACE) has several structures constructed within carbonate karstic environments throughout the United States. An exhaustive undertaking of assessing possible risks associated with those structures on karst has shed light on the uncertainty associated with the interaction of natural karstic environments and engineered structural performance. Particular aspects of karst related to Dam Safety include: 1) Karst genesis and types of karst, in both non-glaciated and glaciated environments; 2) How dam construction methods (1950-1975) truly contend with potential adverse karstic effects within a structures foundation; 3) How reservoir impoundment affects karstic characteristics over time; 4) How instrumentation and subsurface investigations monitor karstic behavior over time and what are the limitations and pitfalls of each. This presentation is intended to discuss the issues faced with understanding and communicating potential risk of karstic environments within USACE and how the
organization may learn from other fields of karstic study to better define risk assessment of dams on karst.

ESTIMATION OF SOIL EROSION RISK IN CHAHE TOWN, GUIZHOU PROVINCE USING GIS AND REMOTE SENSING

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Rocky desertification, soil erosion and land degradation are major threats to sustainable agriculture and regional development in karst landscapes, especially in developing countries, and soil erosion mapping is indispensable for monitoring such environmental changes. In Chahe town, Guizhou, southwest China, the karst has suffered severe soil erosion in past decades. In order to understand the erosion situation and conduct risk evaluation, erosion factors such as rainfall, vegetation cover, slope, land cover and soil type were investigated by combining multi-temporal and multi-sensor spatial data and using GIS and remote sensing (RS) to evaluate and map erosion risks. The soil erosion hazard map indicates that 46% of the region is under moderate, high and severe soil erosion risk, and most of the erosion has resulted from frequent land cover changes.

NUTRIENT SUPPLY AND CHEMOLITHOAUTOTROPHY AS A POSSIBLE DRIVER OF STYGOBIONT DIVERSITY AND AQUIFER EVOLUTION: THE EDWARDS AQUIFER OF SOUTH-Central TEXAS

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Most subsurface ecosystems are dependent on allochthonous, photosynthetically-derived organic matter. On a global scale, high species richness in some subsurface habitats has been linked to long-term high levels of surface productivity. However, temporally and spatially more abundant and consistent inorganic nutrient resources may be more important than surface productivity for the maintenance of subsurface species richness in chemolithoautotrophic systems. We have been assessing, from geochemistry, microbiology, and food web investigations, the differences in allochthonous and autochthonous nutrient and organic matter for the fresh water and saline water portions of the Edwards Aquifer of South-Central Texas. A steep gradient between fresh water and saline water is characterized by an increase in temperature, sulfate, sulfide, and ammonium concentrations, and a decrease in dissolved oxygen. Although the Edwards Aquifer is geographically extensive, species-rich groundwater sites only occur near the freshwater-saline water interface. This is likely due to the redox gradient at the transition zone that supports chemolithoautotrophic primary production. Molecular characterization of microbial diversity reveals putative chemolithoautotrophs, including Nitrospira, Thiothrix spp. (Gammaproteobacteria), and Epsilonproteobacteria along the fresh water-saline water interface. Animals from the transition zone, which are hydrologically distant from recharge features, have isotopic ratios ($\delta^{13}$C = -27 to -37‰; $\delta^{15}$N = 2 to 16‰), suggesting carbon sources that are, at least in part, of chemolithoautotrophic origin (terrestrial sources, $\delta^{13}$C ≈ -20‰). Nitrogen isotopes reveal more trophic levels than are typically found in subterranean aquifer foodwebs, and/or potentially complex nitrogen cycling. Springs and cave sites proximal to the freshwater-saline water interface may also be subsidized by terrestrial resources. Spring morphology, aquifer porosity, and geochemical gradients driving microbial processes such as sulfide oxidation all suggest a hypogene contribution to the formation and evolution of the Edwards Aquifer.
OCCURRENCE OF HYPOGENIC CAVES IN COASTAL RE-ENTRANTS AND GULLIES PROBABLY NEED A BETTER TITLE

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The walls of coastal re-entrants and dry gullies that are associated with modern and paleo carbonate island coastlines commonly contain segments of caves that are oriented perpendicular to the trend of the re-entrent or gully wall. Massive speleothems that have formed along both walls of these features suggest an origin from epigenic stream cave dissolution and subsequent collapse. However, these features are usually too wide to have been a single cave passage, but the presence of speleothems argues for a cave origin. Our explanation is that during glacioeustatic sea-level highstands seawater invaded the coastal re-entrants and gullies, and fresh-water lens discharge from the feature walls developed flank margin caves. Caves formed in coastal re-entrants are protected from mechanical wave action during sea-level highstands, and are eroded open by surface weathering processes during lowstands. In gullies, changes in sea level due to glacioeustasy or by uplift, formed small flank margin caves at different elevations that reflect sea-level highstands. Uplift and/or glacioeustatic fall in sea level allowed surface streams to re-establish subaerial erosion to breach and erode the caves, revealing the cave segments and speleothems. The general lack of dendritic cave systems within the gullies does not support the early model of epigenic cave formation and subsequent conduit collapse. However, there are a few exceptions where recharge from surface gullies has formed epigenic cave systems in the highland reaches of the gullies. In the downstream segments of the gullies, the morphology of the features appears to be the result of flank margin cave speleogenesis.

REGIONAL FEATURES OF HYPOGENE SPELEOGENESIS IN THE PRICHERNOMORSKY ARTESIAN BASIN (NORTH BLACK SEA REGION)

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The paper presents a summary of speleogenetic studies of two areas in different sides of the Prichernomorsky artesian basin in the north Black Sea region (south of Ukraine), the Odessa area in the continental part and the Inner Range of the fore-mountain Crimea in the south, where the basin borders with the fold-trust Alpine mountain region. Caves in the first area occur in Early Pliocene and Miocene (Sarmatian) limestones of the Neogene system, whereas in the second area they occur in limestones of Eocene and Paleocene age. The results strongly suggest hypogenic origin of solution conduits and cavities. This interpretation is based on the analysis of cave morphology and occurrence relative to lithostratigraphy and structural features, cave sediments, isotopic and mineralogical data, and paleohydrogeological analysis. Characteristics of caves scattered in between these areas and hydrogeological and geochemical features of the regional aquifer system throughout the basin are concordant with the basin-wide dominant role of hypogene speleogenesis in the development of solution porosity and permeability. Despite of differences in the host rock age and pre-speleogenetic matrix porosity, caves demonstrate remarkable common features in morphology and the geological/hydrostratigraphic occurrence, imposed by the common origin. Known thermal and chemical anomalies of groundwaters in the multi-story aquifer systems of the Plain Crimea part of the basin are related to the presence of transverse high permeability zones, one of the prime results of
hypogene speleogenesis. Another result is the high degree of hydraulic connection between individual aquifers in the multi-story aquifer system, a characteristic feature of regional hydrogeology. Hypogene speleogenesis is also likely to play a role in the formation of carbonate-hosted reservoirs, in the migration and accumulation of hydrocarbons in the Prichernomorsky basin.

KARSTIFICATION IN BRECCIA AND FLYSCH (MOUNT NANOS, SLOVENIA)

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Characteristic, but for Slovenia relatively rare karst phenomena, were discovered for this type of karst in breccia that lie on a sloping foundation of impermeable flysch. We distinguished characteristic types of caves and initial stages in the development of dolines. The largest and most frequent are caves that developed in breccia above the contact with flysch, smaller and most often filled with fine-grained sediment are caves that occur in the middle of breccia, and of special origin are fissure caves across the slopes. The geological, geomorphological, speleological, and hydrological diversity of Slovenia’s karst has been demonstrated also by the study of the karstification of breccia that formed beneath the western slopes of Mount Nanos. Water, in most cases percolating diffusely through the permeable surface of scree material or breccia to the more or less impermeable flysch bedrock, creates young karst phenomena. Earthworks have revealed the early stages in the formation of unique dolines.

Characteristic types of caves developed in the young and very porous breccia, which is consolidated only in places, lying on the more or less slanting flysch, an impermeable bedrock. The true karst caves are formed in a locally and periodically flooded zone and they are often paragenetically enlarged. The largest caves formed above the contact with the impermeable flysch bedrock where the largest streams join. To a very small extent, karstification also takes place inside the flysch where the marlstone or sandstone contains at least calcite cement. Although the described karst is relatively young, discovered in its early development stages, it still reveals all the characteristics of the karstification of breccia. Learning about it expands our knowledge of Slovenia’s diverse natural karst heritage and forms the basis for future planning of interventions in the environment.

IMPACT OF LAND USE AND CLIMATE CHANGES ON LONG-TERM DISCHARGE OF SPRINGS

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Detailed analysis of land-use and climate changes and their impacts on spring discharge was performed for drainage areas of three large springs in the continental United States and one in China. Flows of all four springs, which are located thousands of miles from each other, have been monitored for decades and provide a good foundation for long-term analysis of their discharge characteristics and the impacts of varying climate on continental scales. Crater Lake Spring in Idaho, northwestern United States, drains a highly prolific basaltic plateau aquifer and shows a very predictable delayed response to precipitation and snowmelt over uniform decadal oscillations, without any obvious trends. Big Spring in central United States, one of the first magnitude springs draining large karst areas of Missouri, shows a very similar behavior for over 80 years now, whereas a first-magnitude karstic Rainbow
Spring in Florida has notably different characteristics and has a clear decreasing discharge trend. A very similar decreasing trend has been observed at Niangziguan spring in China. These differences are explained through analyses of land-use changes, climate and aquifer characteristics, and various climate cycles such as El Niño-El Niña extended family, North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO), and Pacific Decadal Oscillation (PDO). Time series of discharge, precipitation and climate cycles and their interconnections are examined using frequency-domain analysis and various time-series models, are compared for the four springs. The results of the analyses are discussed as they relate to water management practices, protection of aquifer recharge areas, and predictions of expected future variations in spring discharge.

ASSESSMENT OF INTERNATIONALLY SHARED KARST AQUIFERS: EXAMPLE OF DINARIC KARST AQUIFER SYSTEM

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Systematic assessment of international surface watercourses has been exercised already for more than a half of century. Transboundary aquifers (TBAs), however, have started to gain more attention only during the last decade. Firstly, UNECE (United Nations Economic Commission for Europe) conducted an inventory of TBAs in Europe (1999), followed with two assessments in Europe and Central Asia (in 2007 and 2011. In 2001, UNESCO has launched so-called ISARM umbrella programme (www.isarm.net), (co)organising various TBA activities all over the world. Development of a global TBA map, TBA methodology, TBA course and legal guidelines are just some of activities associated with this programme. In the last several years, Global Environment Facility (GEF) initiated and funded several large TBA projects (Guarani, Nubian, Limpopo, etc.) and encouraged inclusion of groundwater component in various surface water-related projects. A DIKTAS (Protection and Sustainable Use of the Dinaric Karst Transboundary Aquifer System) project is the first regional GEF TBA project in a karst region.

The DIKTAS project aims to improve understanding of transboundary groundwater resources of the Dinaric region and to facilitate their equitable and sustainable utilisation, including the protection of unique karst groundwater dependent ecosystems. The project is implemented by UNDP (www.undp.org) and executed by UNESCO-IHP (www.unesco.org/water/ihp). The core project partners are Albania, Bosnia and Herzegovina, Croatia and Montenegro. Several other countries (in the Dinaric region and beyond) and international organizations (including IAH) have also joined this challenging project. Full-size project execution has started in November 2010 and it will last for 4 years. More information and the contact data are available at the DIKTAS project site: http://dinaric.iwlearn.org.

GEOPHYSICAL INVESTIGATIONS OF ANTHROPOGENIC KARST PHENOMENA IN SOUTHEASTERN NEW MEXICO

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A significant minority of sinkholes and other karst phenomena in the lower Pecos region of southeastern New Mexico are of human origin. Anthropogenic sinkholes are often associated with improperly cased abandoned oil wells, or with solution mining of salt beds in the shallow subsurface. In 2008 two brine wells in a sparsely populated area of northern Eddy County, New Mexico abruptly collapsed as a result of solution mining operations. The well operators had been injecting fresh water into underlying salt beds and pumping out brine for use as oil field drilling fluid. A third brine well within the city limits of Carlsbad, NM has been shut down to forestall possible sinkhole development in this more densely populated area. An electrical resistivity survey conducted adjacent to one of the Eddy County sinkholes shows a large, brine-filled cavity ~80 m below ground level beneath the existing sink. Additional surveys conducted over the brine well site in Carlsbad have produced useful subsurface information in spite of the presence of anthropogenic sources of interference such as buried pipelines, and the logistical challenges of conducting geophysical surveys in an urban environment.

CARBON DIOXIDE DEGASSING FLUX FROM TWO GEOTHERMAL FIELDS IN TIBET, CHINA

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Over geological time scales, Earth degassing has a significant impact on atmospheric carbon dioxide (CO₂) concentrations, which are an important component of global carbon cycle models. In Tibet, structural conditions and associated widespread geothermal systems lead to carbon dioxide degassing during geothermal water migration. We characterized the hydrochemical conditions of two geothermal fields on the Tibetan Plateau. The chemical composition of geothermal waters was controlled by K-feldspar and albite. Geothermal waters in the Langjiu geothermal field were sodium chloride type and those of the Dagejia geothermal field were sodium bicarbonate type. Simulations of CO₂ partial pressure within the two hydrogeothermal systems showed that CO₂ degassing occurs during hot water migration from the aquifer to the surface. Carbon dioxide degassing flux from the Langjiu geothermal field was estimated to be ~3.6×10⁶ kg km⁻²a⁻¹, and that from Dagejia was ~3.3×10⁶ kg km⁻²a⁻¹.

CHARACTERISING GROUNDWATER FLOWS IN SMALL-SCALE KARSTIC VOIDS USING SINGLE BOREHOLE TRACER DILUTION TESTS

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Understanding the distribution of localised flows in karst and fractured aquifers is difficult because of their high spatial heterogeneity. In highly karstic aquifers cave mapping enables flow patterns to be directly investigated, but smaller voids can only be investigated via boreholes or outcrops. Single Borehole Dilution Tests (SBDTs) carried out under natural head conditions provide a simple and cheap method of tracing vertical flow within boreholes and determining the location of inflowing, out-flowing and cross-flowing fractures. In this study simple forward modelling was carried out to aid interpretation of SBDTs and develop the technique as a tool for identifying flows. The technique was applied to 24 boreholes in an area of ~ 400 km² in the English Chalk, a carbonate aquifer with small-scale karstification. 120 flowing features were identified with average vertical spacing of 8.8 m but with frequency that decreased with depth. Results were compared to data on stratigraphy, karst geomorphology, topography and borehole imaging. Flowing features are generally bedding-parallel fractures enlarged by dissolution to form small conduits or planar fissures. There appears to be a lithological control suggesting that certain lithologies may act as inception horizons similar to those described in highly karstic aquifers. Our conceptual model of karstic development in the Chalk is that many fractures are solutionally enlarged on a small-scale. These occur throughout the aquifer but are more common at shallower depths, in river valleys, and in areas where surface stream sinks and dolines are present. Although large scale tracer testing has demonstrated rapid flow over many kilometres in a few networks of larger conduits and fissures, most of the flowing features revealed by SBDTs are probably far less extensive, and the overall lateral distances covered by typical clusters of linked features remain unknown. Nevertheless, flow in other carbonate aquifers with small-scale karstification may have similar characteristics.

WATER CHEMISTRY VARIATIONS & SOURCE MIXING OF A DISTRIBUTARY SPRING SYSTEM: THE CARROLL CAVE – TORONTO SPRINGS SYSTEM

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Located along Wet Glaize Creek in the central Missouri Ozarks, Toronto Spring is a distributary spring system where surface stream flow mixes with flow from the Carroll Cave system. Following recharge area delineations for Thunder River and Confusion Creek in Carroll Cave, flow from these rivers was found to discharge from ten of the 13 springs at Toronto. Seepage runs along Wet Glaize Creek, upstream of the springs, identified two major losing reaches of streamway, which appear to be controlled by proximity to the Montreal Fault Block. Dye tracing confirmed the hydrologic connection between these losing reaches and ten of the spring outlets. Base flow water chemistry data gathered through the use of dataloggers and ion sample collection was used to characterize the differences among individual springs. Statistical analysis of the water chemistry data indicated that springs hydrologically connected to Carroll Cave were typically similar in ion concentrations. Using ion data gathered over the duration of the project, a two end member mixing model was developed for the spring system, using Wet Glaize Creek and Carroll Cave as the primary end members. The mixing models showed that groups of springs had very similar chemistry, varying by less than five percent in each model. The similarities of these groups have allowed for delineating possible conduit patterns, which contribute water to the various springs at Toronto Springs. Depending on the hydrologic conditions, flow discharging from springs at Toronto Springs was either dominated by Carroll Cave, under baseflow, or by Wet Glaize Creek during high flow.
INFLUENCED OF LAND USE PATTERNS ON DISSOLVED INORGANIC CARBON AND $\delta^{13}$C$_{\text{DIC}}$ FOR EPIKARST SPRINGS

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The hydrochemistry, dissolved inorganic carbon (DIC) and the carbon isotopic composition of it ($\delta^{13}$C$_{\text{DIC}}$) were studied in three epikarst springs under different land use (shrubbery, agriculture and shrubbery, rocky desertification land), which are located in southern of Chongqing City, Southwest China. The DIC concentrations and the $\delta^{13}$C$_{\text{DIC}}$ values showed seasonal variations, with lower DIC concentrations and $\delta^{13}$C$_{\text{DIC}}$ values in wet season. However, due to the different land use of the spring catchments, the DIC concentrations and $\delta^{13}$C$_{\text{DIC}}$ values in springs were different. The Boshuwan spring with shrubbery land use had the highest DIC concentrations (5.27 mmol/L) and the lowest $\delta^{13}$C$_{\text{DIC}}$ values (-12.52‰), while the Hougou spring with serious rocky desertification land use had the lowest DIC concentration (3.37 mmol/L) and the highest $\delta^{13}$C$_{\text{DIC}}$ values (-8.26‰). The relationships between DIC and $\delta^{13}$C$_{\text{DIC}}$ values showed positive in Boshuwan and Lanhuagou springs, while showed negative in Hougou springs. It indicated that the relationship between them could not be interpreted in the terms of dilution effects and soil CO$_2$ effects. The relationship between major ions as well as the relationship between $\delta^{13}$C$_{\text{DIC}}$ values and equivalent ratios of (Ca$^{2+}$ + Mg$^{2+}$)/HCO$_3$ showed that other processes or mechanisms instead of carbonate dissolution by carbonic acid may be responsible. The positive relationships between $\delta^{13}$C$_{\text{DIC}}$ values and equivalent ratio of SO$_4^{2-}$/HCO$_3$ as well as NO$_3^{-}$/HCO$_3$ confirm it. It indicated that although carbonate dissolution by carbonic acid is the main origin, sulfuric acids and nitrate acids also took part in the dissolution of carbonate. However, because of the different land use of the spring catchments, the DIC and $\delta^{13}$C$_{\text{DIC}}$ values were influenced by different factors, respectively. The Boshuwan spring was also influenced by oxidation of organic matter, and Lanhuagou spring was influenced by oxidation of pyrite and fertilizers, while Hougou spring was influenced by sulfuric acid derived from oxidation of pyrite, nitric acid, dissolution of sedimentary gypsum and fertilizers.

DAM AND RESERVOIR CONSTRUCTION ON COASTAL PLAIN CARBONATES: SITE STUDY FROM SMITH COUNTY, MISSISSIPPI

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In 1999, Smith County community leaders proposed establishing a 1000+ hectare recreational lake in the Oakhay Creek basin of the Bienville National Forest. Geological and hydrological assessment of the site began in 2006. The footprint of the proposed dam and reservoir lie across outcrops of the carbonate Glendon and Marianna Formations of the Vicksburg Group of Oligocene age, dipping 6.6 m/km to the SSW, indicating that a karst assessment was necessary. The carbonates are sandwiched between clastic units. Outcrops are rare, which required the use of drilling and geophysical traverses to determine the karstic nature of the lake site. Well logs from previous work (water wells, seismic shot holes, lignite assessment, etc.) and wells specifically drilled for this study encountered numerous bit drops (up to 2 m) and many loss of circulation events when drilling within the Glendon-Marianna footprint. Field reconnaissance revealed few karst features, but recent cover-
collapse sinkholes were located. Water budget analysis revealed little water loss and/or return to the carbonate units. Field work suggested that the Oakohay Creek has incised down through most of the carbonate section, and active karst flow many only be occurring in the headwater regions. Geophysics (primarily GPR) has located voids within the Glendon and Marianna Formations, and targeted drilling has also encountered voids. While the Oakohay Creek is today physically separated from significant hydrological exchange with the karstic Glendon and Marianna Formations, pool stage of the proposed lake would allow invasion of older, abandoned conduit systems with the potential to pass flow around the dam. Unlike dam construction in areas of dense, telogenetic carbonates, as in the TVA watershed to the northeast, the Smith County setting involves eogenetic carbonates that did not create a distinctive karst landscape, requiring different approaches to karst assessment.

INVESTIGATING THE ROLE OF GUIDED SHOW CAVE EXPERIENCES IN KARST UNDERSTANDING

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Anthropogenic karst disturbances partially occur because of the poor dissemination of scientific information to the general populace and policymakers, and budgetary and time constraints of municipalities. Yet, despite the abundance of karst and the important role it plays in supplying worldwide freshwater drinking supplies, no single, comprehensive study investigates the role of informal environmental education through guided cave tours to fill these regulatory and public knowledge shortcomings. The purpose of this study was to: 1) reveal if any differences in the nature of tour material exist with ownership (i.e. private vs. governmental) at karst attractions, and 2) evaluate the effects and simplicity of increasing the quality and quantity of educational karst material presented to cave visitors. To achieve these goals, four show caves in the US were selected and outcomes assessments distributed at each location before and after undertaking guide retraining. The results of this study revealed that although differences exist in the nature of the educational material presented to visitors during tours, the educational quality and quantity of material at both privately- and publically-owned is often significantly lacking and over 90\% of visitors to the participating show caves are largely uneducated about karst attractions. Additionally, although the physical features of a facility directly impacted the material that could be learned by visitors, with slight changes to tour content each show cave could successfully increase visitor karst knowledge while simultaneously maintaining their entertainment value.

PROMOTING OUTREACH AND COMMUNITY EDUCATION ABOUT CAVE AND KARST RESEARCH PROJECTS THROUGH SOCIAL AND VISUAL MEDIA

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Effectively communicating the goals and results of cave and karst projects can be difficult since the general public is often minimally aware or uneducated about these topics. Collaborative support and funding for such projects also requires awareness and understanding that should be enhanced through branding and making your project accessible. Yet, these are some of the most important and
often overlooked areas in the funding and communication of cave and karst projects. Whether you are an established researcher or just starting your career, your project’s image needs to be branded to maximize its impact with students, faculty/collaborators, government agencies, and the general public. This occurs through the use of visual media, such as logos, posters, website development, mission statements, and project-specific business cards, which can be the simplest and easiest way to promote your project. Additionally, in these modern times, social networking is an essential part of communicating with the general public and providing access to your project or research group. Collectively, infographics, newsletters, and graphics-based visuals can provide an attractive and interesting method by which you can convey results or project goals to spark conversation about the project and positively impact cave and karst communities. If no one is talking about your cave and karst project, it’s up to you to start the conversation and engage the community and collaborators in disseminating the information using different avenues to maximize the impact.

ANALYTICAL MODELING OF KARST PROCESSES ON THE BASIS OF PETROGRAPHIC MAPPING

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The complexity of karst processes has become increasingly apparent in the past few decades, especially where deep-seated processes are involved. While instrumentation has improved greatly, basic microscopic techniques are often bypassed as unnecessary or too time-consuming. However, a powerful first step in the interpretive process is simple petrographic mapping from thin sections, ideally accompanied by X-ray diffraction to verify mineral phases. Once the minerals, sequences, and relationships have been recognized, it is easy to reconstruct the local geochemical history. Quantitative interpretation can then be guided by basic principles such as chemical equilibrium and kinetics. The mass balance can be applied to relationships among discharge, solute concentration, mineral density and volume, and time. Meanwhile it becomes easier to anticipate mineral associations and isotopic signatures. Advanced laboratory analyses can then be carried out more efficiently. Incompatible evidence is more easily recognized so that the study is less likely to lead to blind alleys.

An example is the recognition of past sulfuric acid events. Features and processes observed in active systems are usually detectable from subtle clues in inactive systems, even in paleokarst, or where sulfuric acid processes were not suspected. These features include replacement of carbonate rock by gypsum, with fringes of anhydrite along the reaction front; embayed contacts between bedrock and replacive material; products of pyrite oxidation and clay alteration; calcite that contains petrographic relics of former sulfates; and fossil filaments of sulfur-oxidizing or iron-oxidizing bacteria. These are more easily detected with petrographic mapping than with most advanced laboratory techniques. Unfortunately this approach is time-intensive, and the requisite skills are rapidly being lost.

PHYSICO-CHEMICAL FORMATION DURING STORM EVENTS IN AN UNDERGROUND RIVER OF A TYPICAL KARST WATERSHED, SW CHINA

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Qingmuguan groundwater system (QGS), mainly underlain by Triassic carbonate rock and developing a single master conduit, is located at western Chongqing, China. The Jiangjia Spring (JJS)
totally discharges the QGS as the sole supply of domestic water for as many as 2,000 locals. Hydrologic processes and selected physico-chemical parameters (i.e., turbidity, suspended particles matter (SPM), specific conductance (SC), total organic carbon (TOC) and major cations) at JJS during two storm events in late April 2008 were monitored with 2~3-hour resolution. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analyses on SPM and water quality assessment at JJS were also performed. The results indicated that the selected physico-chemical parameters responded rapidly to the precipitation. The elevations in turbidity and SPM concentration concurrent with hydrograph were caused by the input of the fluxes of surface soil erosion (allochthonous). Concentrations of the Al, Fe, Mn and TOC increased with SPM in groundwater; and those ions were the concomitants of SPM. So the storm rainfall could increase in the ions (Al, Fe and Mn), turbidity and SPM due to surface soil erosion, and decrease in carbonate-derived ions (Ca, Mg and Sr) due to dilution effect. The discharge flux of SPM > 0.45μm in diameter was ~9.7 tons in QGS during these events. The results of water quality assessment suggested that the spring water cannot be used for drink without purification during storm events. Thus, soil erosion and nutrient losing not only could spoil the fragile karst ecological environments and led to eutrophication of discharged basin, but also could seriously pose a great threat to the drinking water safety of locals.

**EVALUATING KARST DISTURBANCE IN PUERTO RICO: EXAMINING METHODOLOGIES AND FUTURE IMPLICATIONS**

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Karst landscapes contain fragile and unique environmental resources that are easily impacted by human activities due to the interconnected nature of the surface and subsurface. Due to the diverse nature of karst environments throughout the world, measuring human impact is difficult without having an adaptable methodology that is suitable to this diversity. The Karst Disturbance Index (KDI) is a holistic tool used to measure anthropogenic impacts on karst environments, and has been applied and refined in studies performed in Florida and Italy, yet still remains untested and susceptible to modification for other areas. Application of the KDI in Arecibo, Puerto Rico, which is a geographically isolated island setting, and highly vulnerable due to its sensitive karst resources, provides an opportunity to test the index in a different type of karst terrain. This research utilized both the original and recently modified methods of applying the KDI and resulted in two KDI scores for the study area. The scores from the original and modified methods reflect a significant to severe disturbance to the karst environment of Arecibo measuring 0.54 and 0.68, respectively. Issues regarding the KDI were found from the application and comparison of these methodologies and revealed the need for adding additional indicators, including mogote removal and coastal karst disturbance. Several new refinements and recommendations pertaining to scale, weighting, and incorporating the two methods together to create a single, more practical KDI tool. The disseminated results of the assessment of the area using the KDI will educate and help to foster stewardship of this vital resource in Puerto Rico. An additional recommendation and current research project stemming from this research is the development and practicality of creating and online KDI tool for broader dissemination and public availability.
PROTECTING KARST SYSTEMS AND GROUNDWATER IN RURAL CHINA THROUGH COMMUNITY OUTREACH AND SCIENCE EDUCATION

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Through a grant awarded by the US Agency for International Development to the Vermont Law School and the Woodrow Wilson International Center for Scholars, Chinese and American scientists from the International Research Center on Karst (IRCK) and the Hoffman Environmental Research Institute (HERI) at Western Kentucky University (WKU), respectively, held an environmental justice workshop related to public karst groundwater concerns in rural Wuming County, Nanning City, Guangxi Autonomous Region, China. This location was selected based on growing concerns about Ling Shui Spring, the sole water source for the over 100,000 residents currently residing there. Ling Shui Spring water quality and quantity have undergone deterioration in the past thirty years, with growing population concerns further threatening the water supply.

A training and educational workshop was held in Wuming County to an audience of over 200 people, including presentations by US and Chinese scientists on protecting karst systems and groundwater through science, education, and relevant laws. Outcomes include enhancements between US-China University relations, and a proposal on protection of Ling Shui water resources by Wuming County political consultative conference and IRCK to set up water resource protection areas, stricter control of groundwater use, and further outreach and education activities.

SIGNIFICANCE OF FREE-SURFACE FLOW REPRESENTATION FOR NUMERICAL MODELING OF KARST

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Conceptually, karst aquifers consist of highly conductive solution conduits embedded in a less permeable fissured and / or porous rock matrix (subsequently denoted as matrix) resulting in a strong heterogeneity with a distinctive anisotropy. Consequently, discharge in a karst aquifer is characterized by a dual flow behavior with slow and laminar matrix flow and rapid conduit flow. Depending on the state of karst development, conduit diameters range from centimeters to meters (Shuster and White 1971). In strongly enlarged conduits, free-surface flow can be observed, which is likely to affect the behavior of the karst system (Raeisi et al. 2007). Existing hybrid models for the simulation of the dual flow behavior of karst systems couple discrete conduit networks to a groundwater continuum model (Teutsch and Sauter 1991). However, the models omit free-surface flow characteristics and, therefore, potentially neglect effects like conduit storage and wave propagation in open channels. To overcome these limitations, an existing free-surface flow model intended to describe overland flow was adapted to simulate dynamic flow processes in variably filled karst conduits.

Model application to an idealized karst catchment demonstrates the importance of taking into account free-surface flow. In particular, important consequences are: (1) The occurrence of a reduced interaction between karst conduit and surrounding matrix in case of free-surface flow. This behavior will suddenly change if discharge exceeds the conduit flow capacity resulting in pressurized flow; (2) Signal transmission is characterized by a specific time lag, caused by the speed of the wave flowing through the conduit system.; (3) Conduit storage affects the spring discharge significantly, particularly during transition from pressurized to free surface flow.
HYDROGEOLOGICAL INVESTIGATIONS AND SINKHOLE RESEARCH ON FORESTED KARST LANDSCAPES OF COASTAL BRITISH COLUMBIA, CANADA

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Over the past number of years a variety of research projects associated with the forested karst lands of coastal British Columbia (BC) have been initiated at Vancouver Island University including: an examination of karst springs and their associated aquifers and source areas, as well an investigation into karst sinkhole (or doline) microclimate, geomorphology and hydrology. From the karst spring investigations it is readily apparent that alogenic sinking streams play an important role in controlling water quality and flow rates at the study site on Quadra Island. A program of winter and summer dye tracing on a series of karst insurgences and springs has indicated relatively linear flow paths with few cross-connections between subsurface streams, and a likely complex subsurface geology. Spring monitoring techniques have been able to link rainfall events with flow rate, water temperature and conductivity, suggesting relatively shallow karst aquifers strongly influenced by alogenic stream recharge.

The preliminary research on sinkhole microclimates has confirmed that larger (typically >20 m diameter) forested sinkholes have distinct microclimates (using air temperature as a surrogate for microclimatic conditions), and that the microclimates of large forested sinkholes are significantly different than those of recently logged sinkholes of similar size. The size and shape of forested sinkholes also appear to have a significant impact on the nature and type of the microclimate, as does the density of the tree canopy.

Recently two other karst research projects in Coastal BC have been initiated as part of doctoral studies by two of the authors. The first is an investigation into karst management systems on forested karst lands, and the second an investigation into the morphometry and ecological characteristics of forested sinkholes. All research initiatives are expected to contribute towards a better understanding of karst processes of Coastal BC, and will eventually lead to improved management of these forested karst lands.

ASSESSING RECHARGE ELEVATIONS FOR KARST SPRINGS OF THE KAWEAH RIVER, SEQUOIA AND KINGS CANYON NATIONAL PARKS, CALIFORNIA

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In allogenic karst systems, it is typically assumed that recharge is derived from surface streams sinking into the carbonate bedrock, flowing through conduit systems, and discharging at a spring. High flow velocities in conduits and relatively low storage capacity in primary bedrock porosity often result in short residence times in karst aquifers. Karst aquifers in the Kaweah River basin are developed in metamorphosed marbles with very low primary porosity. These aquifers do, however, contribute to river discharge year-round and appear to have significant long-term storage capacity, which is contrary to what is expected. To determine where water is recharged from and to begin quantifying storage components in the aquifers, we used liquid water stable isotopes (δD and δ18O) measured at springs to determine average source water elevations. The elevational gradient of δD and δ18O in precipitation
provides a framework for modeling average source elevation for spring waters within the basin. This provides insight into temporal and spatial differences in source and type of aquifer storage: allogenic sinking stream sources (with a high elevational signal), or autogenic recharge derived from local infiltration into soils and epikarst (with a lower elevational signal).

Liquid water stable isotope values were measured at rivers, springs, and in precipitation during both high and low flow conditions in 2010. Precipitation values show an isotopic lapse rate of -0.18 ‰ per 100 m elevation for oxygen, and -1.32 ‰ for deuterium. Spring data show similar isotopic lapse rates of -0.16 ‰ and -1.41 ‰ per 100 m. However, spring values were typically lighter in both isotopes, indicating average recharge elevations higher than the spring. Seasonal variations in isotopic values were seen primarily at higher elevation springs (>2000 m), indicating seasonal shifts in the dominant recharge source from higher elevation snowmelt runoff during high flow conditions to more locally derived recharge during baseflow.

A PROCESS MODEL OF CAVE DRIPWATER δ₁⁸O VALUES: A TEST OF RECONSTRUCTING DECADAL VARIABILITY IN SPELEOTHEM CLIMATE RECORDS

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The oxygen isotope composition of speleothem calcite (δ₁⁸Occ) in arid regions is typically interpreted as an indicator of the total amount of precipitation or its seasonal balance. Such paleoenvironmental studies rarely address the potential influence of groundwater mixing processes on the oxygen isotopic composition of dripwater (δ₁⁸Odw) and precipitated calcite, however. Here, we develop a simple dripwater model, which we compare to δ₁⁸Odw and δ₁⁸Occ measurements from monthly monitoring of Cave of the Bells, Arizona. The model consists of two layers: an upper “soil” layer that closely resembles traditional “leaky-bucket” soil models, and a lower “rock” layer that is a well-mixed, larger reservoir that feeds into the cave. In observations and the model, fed with modern climate data, δ₁⁸Odw is most comparable to the oxygen isotopic composition of rainfall (δ₁⁸Omw). We show that seasonality and duration of the regional summer monsoon affect how much summer precipitation reaches the cave. We employ a Monte Carlo method to specify statistically realistic ranges for input climate variables and produce time series and variance spectra of cave drips. These synthetic δ₁⁸Odw spectra exhibit a high degree of variance at decadal to multidecadal frequencies, despite being driven by synthetic climate data that includes only a seasonal cycle. This suggests that some background level of variance in speleothem oxygen isotope records could be due to non-climatic processes, such as subsurface water storage and mixing. Interpreting climatic vs. non-climatic signals in δ₁⁸Occ records could be achieved by replicating records from different caves and/or by monitoring the influence of local processes on the modern cave system.

STORM EVENT IMPACTS ON EPIKARST STORAGE AND TRANSPORT OF ORGANIC SOIL AMENDMENTS IN KENTUCKY

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The groundwater in agricultural karst areas is susceptible to contamination from organic soil amendments and pesticides. During major storm events of spring 2011, dye traces were initiated using sulphorhodamine-B and fluorescein in a known groundwater recharge area where manure was applied to the ground. Water samples and geochemical data were collected every four hours before, during, and after the storms to track the transport and residence time of the epikarst water and organic soil amendments during high flow conditions. These data included pH, specific conductivity, temperature, and discharge of water in a waterfall in the cave flowing from the known recharge area, and the total rainfall amount. Cave water samples were collected for the analysis of anions, cations, bacterial count, and the presence of dye. The dye traces show variability in the characteristics of epikarstic response and flowpaths. The changes in geochemistry indicate simultaneous storage and transport of meteoric water through epikarst pathways into the cave, with rapid transport of bacteria occurring through the conduits that bypass storage. The results indicate that significant precipitation events affect both the storage properties and rapidly impact the various pathways and timing of contaminant transport through the epikarst zone.

HYDROGEOLOGICAL - ENVIRONMENTAL ISSUES AND CAUSES OF KARST WATER SYSTEMS IN NORTHERN CHINA

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There are 108.8 x 108 m³/a of the karst groundwater resources stored in 68.5 x 104 km² carbonate aquifer, which is located in the east of the Helan-liupan Mountain, south of the Yin Mountain-Shenyang, north of the Huaihe River and west of the Yellow Sea-Tanlu fault zone of the North China Plain. Because of a great amount of water yield, stable hydrological dynamics and good quality, the karst groundwater in northern China is the main drinking water supply for more than 30 prefecture-level cities, 100 county-level cities and the majority of rural karst mountainous areas, it also is used for the cooling water sources of dozens of medium-sized power plants, over 70% of large-scale mines production and living water sources, and irrigation water sources of thousands of fields; meanwhile, with its rich histories and cultures, unique natural landscapes, many karst springs have become the most important tourism resources, presenting fine Eco-environment function on the lower reaches of the water systems. The karst water has equally importance and irreplaceable role especially for the energy bases in northern China.

In northern China, karst groundwater mainly circulates within relatively isolated water resource systems of spring basins respectively. The flow rates of more than 130 springs are greater than 100 L/s (100 L/s to 16000 L/s). On the basis of previous research results, the authors divided the karst groundwater into 119 systems. These systems are characterized by large dimensions (the average area of 119 systems is 1452.46 km²), numerous water resource components, complex conversion relations of the water resource components (precipitation, surface water, loose bed pore water, Clastic fissure waters and karst groundwater resources and other types of groundwater often exist in a system) and “water-coal coexistence” (82 of 119 systems contain coal-bearing formation). According to the superimposition relationship of geological structures and fluid fields, the authors grouped the 119 systems into 5 different framework models such as the monocline-seriate model, the monocline-inverse model, the strike model, the syncline-basin model and fault block model and others. Besides, different models have respective distinct characteristics about the geological structure, fluid field patterns, hydrodynamic field distribution, the main recharge source of karst groundwater and its accumulation, the inherent vulnerability of water quality and quantity as well as the main hydrogeological and environmental problems.
In recent 30 years, with the change of natural condition and the intensification of human activities, the karst water systems have been changed fundamentally in their input - structure - the component conversion –output. Consequently a lot of environmental problems related to karst water happened frequently, including flow attenuation and dry up of springs (nearly 1/3 springs dried up and 80% springs with recession discharge), the continuous decline of the regional karst water table, water pollution and deterioration of the water quality, frequently happened disasters of mine water inrush. This long-term imbalance of water resources recharge-drainage not only make water pump can not reach the water table, affect the normal water supply, loss of tourism value of the spring, reduce the ecological functions of the spring, but also bring mountain karst aquifers to dewatering, reduce aquifer recharge to plains, induce crack and ground subsidence, lower the storage of karst aquifer and trigger karst collapse, leading to coastal seawater intrusion, speed up resource capture among karst aquifer systems, exacerbate the negative effects of pollution to karst groundwater. It poses a severe challenge to people’s healthy drinking, industrial and agricultural production as well as social stability and security. Based on field surveys and the results of previous studies over the years, according to the setting of karst development, karst hydrogeology, karst water system models and the main hydrogeological –environmental problems, the authors divided the northern China into 13 karst hydrogeological-environmental areas. Furthermore, in line with the structural model of karst water system, water elements of composition and precipitation changes, forms and other aspects of human activities, the authors analyzed the occurrence and development of evolutionary mechanisms of main environmental problems in different karst hydro-environmental areas aiming at providing the basis for scientific management and protection to the north karst water resources.
Special Guest Biographies

Mr. Roger Brucker

Roger W. Brucker has been exploring and writing books about Mammoth Cave for more than 55 years. He is co-author of four nonfiction books: The Caves Beyond, The Longest Cave, Trapped! The Story of Floyd Collins, and Beyond Mammoth Cave: A Tale of Obsession in the World’s Longest Cave. His fifth book and first historical novel, Grand, Gloomy, and Peculiar: Stephen Bishop at Mammoth Cave, tells the story of Stephen Bishop, the slave who gained fame as an early guide and explorer at Mammoth Cave. Mr. Brucker is currently working on a novel based on the life of 19th century Mammoth Cave entrepreneur George Morrison. Through his writings, Mr. Brucker has inspired generations of new cave explorers and promoted an appreciation of caves to millions of readers around the world. Mr. Brucker has published many scientific papers on speleology, and has consulted for National Geographic Television. He is a co-founder and past president of the Cave Research Foundation, an Honorary Life Fellow of the National Speleological Society, and winner of the NSS 2004 Peter M. Hauer Spelean History Award. He is also a co-founder of Karst Environmental Education and Protection, which focuses on the protection of karst areas, and he helped organize Eight Rivers Safe Development, Inc., a cave preservation organization in West Virginia. Mr. Brucker and his wife, Lynn, reside in Beavercreek, Ohio, where they raise Standard Poodles and enjoy bicycling. More information is available at www.RogerBrucker.com.

Dr. Nicholas C. Crawford

Dr. Crawford is a professor in the Department of Geography and Geology and the former Director of the Center for Cave and Karst Studies at Western Kentucky University. He has written over 200 articles and technical reports dealing primarily with groundwater contamination of carbonate aquifers. The recipient of over 200 grants and contracts for hydrological research on environmental problems of karst regions, he was awarded Western’s highest award for Outstanding Achievement in Research in 1985 and Western’s Professional Public Service Award in 1996. He is a fellow and Honorary Life Member of the National Speleological Society. He received the Kentucky Outstanding Geologist Award in 1998 from the American Institute of Professional Geologists. As a consultant specializing in carbonate aquifers for the past twenty-six years, Dr. Crawford has performed over 2000 dye traces and has worked on numerous groundwater contamination and other karst problems for private firms and for federal, state, and local government agencies.
Dr. Art N. Palmer and Peg Palmer

Arthur N. Palmer has recently retired from the State University of New York (SUNY) at Oneonta, NY, where he was SUNY Distinguished Teaching Professor of hydrology and director of the Water Resources program at that school. He is author of about 100 papers and several books on caves and karst, including Cave Geology (2007), and A Geological Guide to Mammoth Cave National Park (1981), and teaches a summer karst field course for Western Kentucky University. He is a GSA fellow and Kirk Bryan Award recipient.

Margaret V. Palmer is a retired geologist who specializes in carbonate petrology. She is the author of several publications on karst geomorphology and paleokarst, and co-editor of several conference proceedings for the Karst Waters Institute. Her recent investigations concern mineral transformations in caves and mining districts, particularly those involving sulfuric acid processes.

Together they have studied the geology and origin of caves throughout much of the world. They are honorary members of the National Speleological Society and co-authors of the book Caves and Karst of the USA (2009). They have established two geoscience scholarships at SUNY. Current projects include the geology of Mammoth Cave and of caves in the Guadalupe Mountains (NM) and Black Hills (SD).

Drs. William B. and Elizabeth L. White

Dr. Will White is a professor emeritus of geochemistry at the Pennsylvania State University. He holds a B.S. degree in chemistry from Juniata College (PA) and a Ph.D. in geochemistry from Penn State (1962). Dr. White taught an undergraduate course on caves and karst at Penn State for many years. He has supervised 18 M.S. and Ph.D. theses on karst-related subjects and has written 150 papers on karst hydrology and geomorphology. He is the author of “Geomorphology and Hydrology of Karst Terrains” co-editor of “Karst Hydrology: Concepts from the Mammoth Cave Area”, and co-editor of “The Encyclopedia of Caves and Karst.” Much of his hydrologic work was in the Mammoth Cave area.

Dr. Elizabeth White is a civil engineer (Ph.D. from The Pennsylvania State University) who worked not only on stormwater management and geological hazards, but also on cement, the beneficial use of fly ash, and other topics. Trained as an engineer, she was working on graduate hydrology research in the statistical characterization of drainage catchments of the Appalachian Mountains of the eastern US when she became intrigued by the behaviour of karst, and has had a passion for the subject ever since. In particular, she has made important contributions to the understanding of surface-water dynamics within karst-drainage systems.
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