

THE SINKHOLE CONFERENCE

Multidisciplinary Conference on Sinkholes and the
Engineering and Environmental Impacts of Karst



Appalachian Karst
Symposium

Program with Abstracts 15th Sinkhole Conference 3rd Appalachian Karst Symposium

April 2-6, 2018

Shepherdstown, West Virginia

National Conservation Training Center

"Integrating Science and Engineering to Solve Karst Problems"





Multidisciplinary Conference on Sinkholes and the
Engineering and Environmental Impacts of Karst



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Credits: Program with Abstracts prepared by Brian A. Smith, Brian B. Hunt and Justin P. Camp, Barton Springs/Edwards Aquifer Conservation District, Austin, Texas. **Cover photograph:** Molers Cave, Jefferson County West Virginia. Photo by Ira Sasowsky taken November 2005. **Back images (from top, clockwise):** Geologic map from WVGES; Boyles Cave; and Sinkhole near Front Royal, Virginia (Photo by Dan Doctor).

Release: By attending the events herein, you hereby release any photographs that may be incidentally taken of you during these events by Sinkhole Conference 2018 to be used for any purpose. **Waiver:** By attending the events herein, you agree and acknowledge that you are participating in the 15th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst (Sinkhole Conference 2018) and its activities intentionally and of your own free will, and you are fully aware that possible physical injury might occur to you as a result of your participation. You give this acknowledgement freely and knowingly that you are, as a result, able to participate in Sinkhole Conference 2018, and you hereby assume responsibility for your own well-being. **Recording of Presentations:** The recording of any oral or poster presentation is prohibited without the prior approval of the author.



Appalachian Karst Symposium

1 March 2018

Welcome Karst Engineers, Managers, and Scientists!

We are delighted to be your hosts for the 15th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. For the past 34 years, this series of meetings has been among the most important in developing a better understanding of karst processes that result in environmental problems, and in creating effective measures that identify those problems before they occur, remediate them when they occur, and prevent them from occurring in the first place.

This year's conference is jointly organized with the Karst Waters Institute and includes the 3rd Appalachian Karst Symposium. We hope these partnerships will increase the exchange of knowledge between attendees and result in collaborations that will benefit you and karst research and management for many years to come. We are also delighted to host a record six Barry Beck Sinkhole Conference Student Scholars this year, and thank the generous sponsors who made that possible.

We are offering four outstanding short courses, an excellent series of papers, thought-provoking keynote addresses, two fascinating and fun field trips, a lively banquet presentation, and ample time for you to meet new and old friends to discuss and network on karst engineering and environmental research projects. Don't forget to visit the booths of our generous exhibitors and sponsors and support them for supporting the Sinkhole Conference! If you have any questions or concerns about the meeting, please tell us directly or leave a message at the registration desk and we will address them as soon as possible. We look forward to visiting with you soon.

Sincerely,

George Veni
Conference Co-chairman
Executive Director
National Cave & Karst Research Institute

Daniel H. Doctor
Conference Co-chairman
Associate Vice President for Communications
Karst Waters Institute

James W. LaMoreaux
Conference Co-chairman
Chairman
P.E. LaMoreaux & Associates, Inc.

David Weary
Conference Co-chairman
KARST Project
U.S. Geological Survey



Welcome to the karst of the Appalachians!

On behalf of the Karst Waters Institute, I welcome you to the conference and to West Virginia. This is the second time that the Karst Waters Institute has partnered with the National Cave and Karst Research Institute, and this conference is the satisfying result. The outstanding presentations, short courses, field trips, and social events are a testament to the energetic dedication of many people working together to bring this conference together.

The mission of the Karst Waters Institute is to improve the fundamental understanding of cave and karst systems for professionals and the public. One of our goals – to engage professionals in conferences and workshops to advance karst science – is well met by KWT's involvement in this conference. We are confident in our belief that the kind of communication and dissemination of knowledge that will take place at this conference will do much to advance the sustainable use of karst lands and waters.

I encourage you to enjoy yourselves, share your expertise across disciplines, and learn something new. And have fun!

Sincerely,

A handwritten signature in blue ink that reads 'Janet S. Herman'.

Janet S. Herman, Ph.D.
President, Karst Waters Institute

Organizing Committee

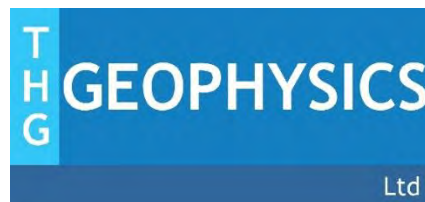
Task	Coordinator(s)
Chairmen*	George Veni, Dan Doctor, Dave Weary, Jim LaMoreaux
Banquet and food	George Veni, Dan Doctor, Dave Weary, Courtney Gasow
Beck Scholarship & Auction	E. Calvin Alexander, Jr., Dorothy Vesper
Circulars	Dan Doctor
Educational accreditation	Dianne Joop
Exhibitors and sponsors	Courtney Gasow
Field trip: Tuesday	Dan Doctor, Dave Weary
Field trip: Friday	Robert Denton, Joshua Valentino
Hotel/conference facilities*	George Veni, Dan Doctor, Dave Weary, Courtney Gasow
Invited speakers	Yongli Gao
Public Relations	Courtney Gasow
Proceedings Managing Editor*	Ira D. Sasowsky
Proceedings Assistant Editors	Mike Byle, Lewis Land
Proceedings Associate Editors	Douglas Aden, John Barry, Dan Doctor, Joe Fischer, Clint Kromhout, James Lolcama, Eric Peterson, Mustafa Saribudak, David Weary, Ming Ye
Proceedings Layout	Rebel Cummings-Saul, Julie Fielding
Program*	Jack Hess
Program w/ Abstracts Editors	Brian Hunt and Brian Smith
Registration*	Loren Darby and Courtney Gasow
Short courses	Robert Denton and Joe Fischer
Symbolic sale items	Sam Panno
Treasurer*	Loren Darby
Website	Gheorghe Ponta (main website) Dianne Joop (registration page)
Professional organization liaisons	Wanfang Zhou
16 th Sinkhole Conference liaison	Ingrid Padilla
Members at Large	Bashir Memon, Boo Hyun Nam, Brad Stephenson, Drew Thomas

* = Executive Committee



Sinkhole Plain, Rockbridge County, VA. Photo by GeoConcepts Engineering Inc.

Sponsors



Virginia Cave Board



Karren in limestone in the Shenandoah Valley, Va. Photo by Dan Doctor.

History of Conference



The roots of the Sinkhole Conference can probably be traced back to when Barry Beck became intrigued by caves as a teenager while living in Rochester, New York. His interest in caves and karst studies eventually led him to Texas, Mexico, Puerto Rico, Georgia, and Florida for extended periods, plus visits to many other karst areas around the world. Barry organized the First Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, which was held in Orlando, Florida, October 15-17, 1984. Subsequently, second and third conferences were held under the sponsorship of the Florida Sinkhole Research Institute, a division of the University of Central Florida in Orlando, in 1987 and 1989, which he directed. These conferences were established to meet a critical need for applied research information on the very complex hydrogeological environment of karst areas of the world.

In 1992, following the closing of the Florida Sinkhole Research Institute, Barry joined the staff of P.E. LaMoreaux & Associates, Inc. (PELA) and opened the company's Oak Ridge, Tennessee office. Beginning with the Fourth Multidisciplinary Conference in 1993, PELA sponsored the continuation of this important series of conferences along with many other distinguished organizations. The Geo-Institute of the American Society of Civil Engineers took the lead in sponsoring the conference in 2003, 2005, and 2008 after which PELA took over the sponsorship again for the 2011 conference. Since the 2011 conference, this

conference series has come under the management of the National Cave and Karst Research Institute (NCKRI). As a government-established non-profit organization, NCKRI is focused on karst phenomena, and organized in part to conduct and support such conferences. PE LaMoreaux & Associates, Inc., as cosponsor, and the Organizing Committee remain an integral part of the conference. This year's Sinkhole Conference is co-organized with the Karst Waters Institute.

The proceedings of these conferences have been valuable additions to karst libraries around the world. Below is a list of the proceedings from the beginning conference to 2015.

Previous Conferences

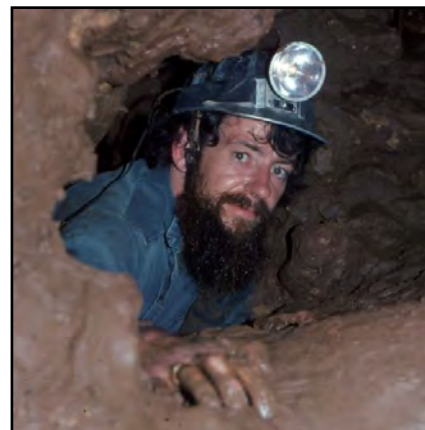
No.	Proceedings	Year	Location
1st	Sinkholes: Their Geology, Engineering and Environmental Impact	1984	Orlando, FL
2nd	Karst Hydrogeology: Engineering and Environmental Applications	1987	Orlando, FL
3rd	Engineering and Environmental Impacts of Sinkholes and Karst	1989	St. Petersburg Beach, FL
4th	Applied Karst Geology	1993	Panama City, FL
5th	Karst GeoHazards: Engineering and Environmental Problems in Karst Terranes	1995	Gatlinburg, TN
6th	The Engineering Geology and Hydrogeology of Karst Terranes	1997	Springfield, MO
7th	Hydrogeology and Engineering Geology of Sinkholes and Karst	1999	Harrisburg/Hershey, PA
8th	Geotechnical and Environmental Applications of Karst Geology and Hydrology	2001	Louisville, KY
9th	ASCE Geotechnical Special Publication No. 122	2003	Huntsville, AL
10th	ASCE Geotechnical Special Publication No. 144	2005	San Antonio, TX
11th	ASCE Geotechnical Special Publication No. 183	2008	Tallahassee, FL
12th	Carbonates and Evaporites volume 27, nos. 2-3	2011	St. Louis, MO
13th	NCKRI Symposium 2: 13th Multidisciplinary Conference on Sinkholes and Karst	2013	Carlsbad, NM
14th	NCKRI Symposium 5: 14th Multidisciplinary Conference on Sinkholes and Karst	2015	Rochester, MN

Barry F. Beck Sinkhole Conference Student Scholarship

The Barry F. Beck Sinkhole Conference Student Scholarship (Beck Scholarship) is a competitive grant that is awarded to one or more students who are presenting the results of their research at the Sinkhole Conference. The award was established in 2013 in memory of the late Dr. Barry Beck, a pioneer in the scientific study of sinkholes who founded the Sinkhole Conferences, and who died in 2011.

At least one Beck Scholarship will be awarded for each conference. Additional scholarships may be awarded if funded from donors for the conference. Please consider donating to the scholarship fund at the time of registration.

For more information about the Beck Scholarship and to fund future scholars, watch for future Sinkhole Conference websites or visit the National Cave and Karst Research Institute website at <https://support.nckri.org/barry-beck-scholarship> and contact info@nckri.org or by calling 575-887-5518.



*Photograph of a the Five-hundred meter Aperture Spherical radio Telescope (FAST) in southwest China.
Photo taken by Yongli Gao.*

Barry F. Beck 2018 Sinkhole Conference Student Scholarship Recipients

Joshua Benton

GIS student, Northern Virginia Community College

Sinkhole Conference paper: Investigating Vadose Zone Hydrology in a Karst Terrain Through Hydrograph and Chemical Time Series of Cave Drips at Grand Caverns, Virginia

Joshua Benton is a student of hydrology and hydrogeology, specifically critical zone hydrology and karst hydrogeology. He is a recent graduate of James Madison University, obtaining a Bachelor's of Science in geology and is currently taking classes at a local community college while continuing to work as an intern for the US Geological Survey, where he spent 3 years learning how to characterize vadose zone groundwater flow in a cavern system. He has applied to graduate schools to pursue a Master's Degree in geology beginning in the fall of 2018. His goal is to answer scientific questions involving the physical and chemical behavior of natural waters, with the long-term career goal to provide scientific data needed for policy makers to make the most informed decisions regarding the management of water resources. Mr. Benton has also conducted research in Michigan Paleozoic limestone, presented his research at local and regional conferences, and taught field geology to a local high school earth science class.



the earthquake in Mineral, Virginia. While an undergraduate, she also worked at an environmental consulting firm where she collected soil, vapor, and water data, worked with oil-water separation and the extraction of underground storage tanks. Now as a Master's student she is focused on karst geochemistry, hydrology, and increasing community involvement in those topics. She has been funded by a West Virginia University grant and crowd-sourcing donations. Her current research involves evaluating the quality and quantity in the Peter's Mountain region of West Virginia. She has presented her research at regional and national Geological Society of America meetings.

Yong Je Kim

Ph.D. Student, Civil Engineering University of Central Florida

Sinkhole Conference paper: A Comparative Study of Karst Sinkhole Hazard Mapping Using Frequency Ratio and Artificial Neural Network for East Central Florida--Predicting Sinkhole Susceptibility to Enhance Public Safety



Yong Je Kim is originally from Jeju Island, a basaltic island of South Korea. He earned his Bachelor's and Master's degrees in Civil Engineering at the University of Illinois at Urbana-Champaign. Always curious and fascinated about geology, when sinkholes recently became a serious hazard in South Korea, he decided to pursue his Ph.D. in geotechnical engineering, especially in sinkhole hazard assessment to fill the gap between geoscience and geoengineering. As a member of the Florida Sinkhole Research Institute at the University of Central Florida (UCF), he has been involved in probabilistic/statistical sinkhole hazard modeling and mapping. He has gained expert research skills in frequency ratios, logistic regressions, decision trees, and artificial neural networks. Mr. Kim is also involved in a joint international project between the South Korean government and UCF looking at environmental emergency and disaster management systems. He aspires to continue his research and teaching upon graduation, including the study of sinkhole hazards from deteriorating sewer pipes. Mr. Kim has presented his research at several American Society of Civil Engineering conferences and has published a peer-reviewed

Emily Bausher

Master's student, Geology West Virginia University

Sinkhole Conference paper: Geochemical Comparison of Karst and Clastic Springs in the Appalachian Valley and Ridge Province, Southeastern WV and Central PA

Emily Bausher began her geology career with undergraduate research at Lehigh University interpreting well data, creating soil profiles, and working with GIS data on



journal article in *Environmental Earth Sciences*, with several manuscripts in progress.

Ryan Shamet

*Ph.D. student, Civil Engineering
University of Central Florida*

*Sinkhole Conference paper:
Development of Sinkhole
Raveling Chart Based on Cone
Penetration Test (CPT) Data*

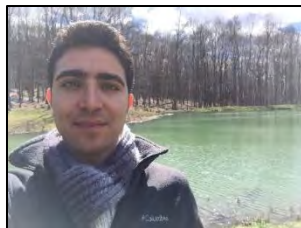


Ryan Shamet's study of civil engineering was an unexpected passion. Growing up in Central Florida, he noticed the variations of "dirt," and spent a lot of time visiting and exploring the region's famous freshwater springs. These hidden oases instilled in him awe and curiosity at these relentless fresh, crystal-clear water sources. During his third semester at the University of Central Florida (UCF), his childhood interests were reignited when he began studying and researching soil variations and geologic formations, and how engineers can effectively design foundations, roadways, and earth-structures to minimize the risk of soil-failure in the most economical ways. Currently, Mr. Shamet is researching sinkhole mechanisms and engineering in karst geology. He recognizes the imperative need for effective engineering in karst geology in Florida. He loves working with team members from various disciplines and cultures. After graduation, he hopes to continue learning as a researcher in a national or international setting. The broad expanse of geotechnical engineering problems and opportunities to continue learning on a global scale bring out the wonder and curiosity he had as a kid, and he can't wait to get started.

Mohammad Shokri

*Ph.D. Student, Civil Engineering,
Water Resources University of
Central Florida*

*Sinkhole Conference paper: Bulk
Chemistry of Karst Sediment
Deposits*



Mohammad Shokri was born and raised in Sanandaj, Kurdistan, Iran. He attended the School of Geology at the University of Tehran for an undergraduate program in geology in 2005. He became interested in hydrogeology and decided to pursue a Master's in that field at Shahrood University of Technology. During that time he developed his interest in karst hydrogeology while working on the assessment of a karst

aquifer in northeast Iran for his Master's thesis. His interests led him to the United States, where he joined the Department of Geology and Geography at West Virginia University (WVU). He worked on the geochemistry of cave and karst spring sediment deposits for the assessment of the impact on electrokinetic remediation of karst groundwater. Graduating from WVU in 2017, Mr. Shokri is now pursuing a Ph.D. in the Civil Engineering Department at the University of Central Florida. His background in geology, hydrogeology, and karst attracts him to think more about aquifer responses to geologic, lithologic, stratigraphic, and tectonic conditions to interpret groundwater flow conditions, and the fate and transport of pollutants as well as groundwater exchange between conduit and matrix porosities. He would also like to apply geophysical methods to better characterize vadose zone of karst aquifers.

Moataz Hesham Ali Soliman

*Ph.D. Student, Civil Engineering
University of Central Florida*

*Sinkhole Conference paper:
Experimental and Numerical
Analysis on the Mechanical
Behavior of Cover-Collapse
Sinkholes in Central Florida*



Moataz Soliman has long believed that Civil Engineering has a significant role in the life of every human being. He received his Bachelor of Civil Engineering at Cairo University in his home country of Egypt. His high GPA qualified him for the honor of joining the teaching and research assistants' staff at Cairo University. After receiving his Master's degree in Civil Engineering from that same university, he joined the Ph.D. program of Civil Engineering at University of Central Florida (UCF) and received a fellowship upon admission in 2016. He considers himself lucky to be a part of the sinkhole research group at UCF where he can satisfy his curiosity of learning and exploring one of the most complicated geotechnical engineering problems. Mr. Soliman also considers studying sinkhole problems is one way by which a researcher can serve humanity, by finding solutions to this geohazard, predicting sinkhole occurrence, and finding proper precautions to avoid any human or property damage. He is eager to attend the Sinkhole Conference as an opportunity and place where different researchers and experts will share their knowledge and experience and have a great influence on research in this field and also on young researchers.

Conference Location

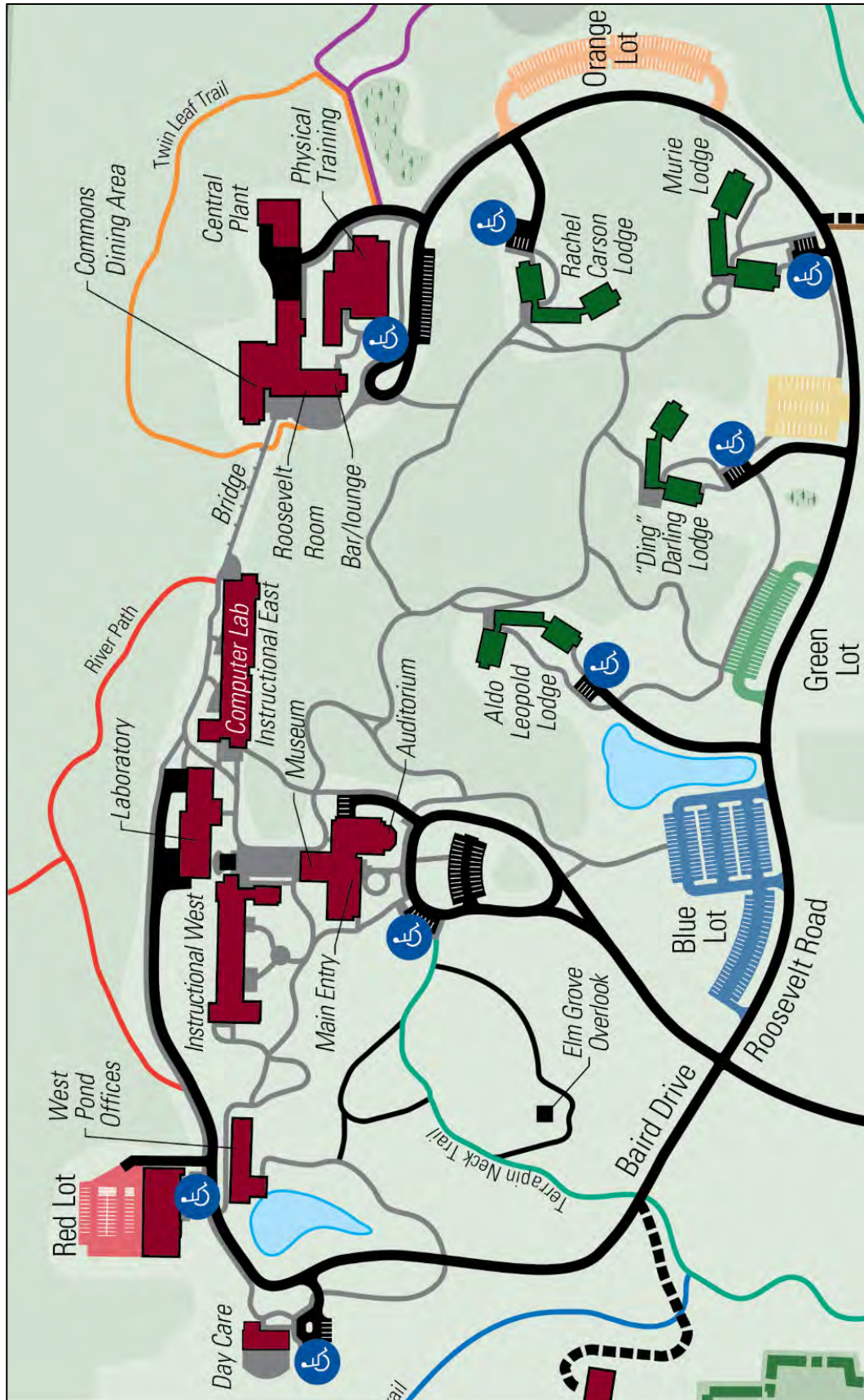
The 15th Sinkhole Conference will be held jointly with the 3rd Appalachian Karst Symposium in the heart of the Appalachian Great Valley karst at beautiful and historic Shepherdstown, West Virginia. The host facilities are the National Conservation Training Center (NCTC).



Source: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, Increment P Corp.



NCTC Campus Map



Field Trips (Optional)

Karst of the Appalachian Great Valley

Tuesday, April 3, 2018

8:00 am-6:00 pm

Trip Co-leaders: Daniel Doctor and David Weary

The Appalachian Great Valley hosts one of the outstanding karst landscapes in North America. During this field trip, participants will visit several sites to observe karst development in folded and faulted carbonate rocks. Discussions will focus around the links between karst landscape evolution, hydrologic dynamics, water resource sustainability, and sinkhole hazards. Stops will include a large karst window, sinkholes exposed in a limestone quarry, discussion of hydrogeologic investigations at the USGS Leetown Science Center, and the remarkable bluffs of carbonate rocks along the Potomac River within the C&O Canal National Historic Park. Participants will be transported by bus between sites, but some walking will be required to access the sites. Sturdy shoes are necessary as some of the walking will be through uneven, wooded terrain.



Karst window. Photo by Dan Doctor

Karst of the Urban Environment

Friday, April 6, 2018

Noon-6:00 pm (Half day)

Trip leader: Robert Denton

This field trip will focus on karst issues in the Eastern Panhandle of West Virginia, where the presence of large karst springs and fertile soils associated with carbonate rocks encouraged European settlement over 250 years ago. Participants will have the chance to visit sites throughout Berkeley County, illustrating both historical and modern ways of dealing with karst issues in the region. Buses will transport the participants to sites, but some walking on gravel paths and up and down moderate slopes will be required.



Priest Spring along Opequon Creek, Virginia. Photo by Dan Doctor.



Sinkhole and retention pond collapse, Frederick MD. Photo by Dan Doctor.

Short Courses (Monday, April 2)

Four courses are offered to expand your knowledge of practical applications of karst science. Space is limited and registrations are processed on a first-come, first-served basis. Onsite registrations can only be accepted on a space-available basis.

Short Course 1: Geologic Site Characterization in a Karst Setting

Instructors:

Lynn Yuhr, P.G.,
President of Technos, Inc.,
Miami, Florida (retired)

Richard C. Benson, P.G., C.P.G.,
Founder and Sr. Engineering Geologist
of Technos, Inc.,
Miami, Florida (retired)

Instructional East, Room 105

Course length – 4 hours

Geologic site characterization is the technical foundation for all geotechnical and environmental projects. The objective of a geologic site characterization is to gain an accurate and complete understanding of subsurface conditions that will impact the engineering or environmental decisions made at a site. If the site characterization is done right, these decisions will be made with a high degree of confidence and be supported by reliable technical data. This effort can be fairly straightforward in a uniform geologic setting; however, karst often provides some of the most variable and diverse geologic settings to deal with. This 4-hour course is based upon an integrated approach to site characterization. Therefore, we will cover a wide range of topics ranging from a discussion of the problem, a strategy using an integrated systems approach of appropriate methods, and adequate levels of site coverage that consider the impact of scale. Case histories will be presented to illustrate the process.

This topic is covered in detail in the new book out called *Site Characterization in Karst and Pseudokarst Terrains* authored by Richard C. Benson and Lynn B. Yuhr (2016). It is based upon their combined and diverse experience specializing in site characterization with an emphasis on karst.

Short Course 2: Grouting in Karst

Instructors:

Joseph A. Fischer, P.E.,
Geoscience Services

Michael J. Miluski, P.E.,
Compaction Grouting Services

Instructional East, Room 103

Course length – 4 hours

There will be an overview of the differing karst environments and how they influence both the site investigation and the possible differing needs for effective grouting procedures in these karst environments. Geotechnical investigation concepts, types of grout, procedures, equipment descriptions and examples will be discussed. Preparing a grouting program concentrating on grout refusal criteria, secondary injection points and grout hole spacing will be discussed. We will provide tools to help you determine what pricing scheme will satisfy the client. Important aspects of field inspection including calibrating pump strokes, determining injection rates and tracking quantities will also be discussed. Handouts of the course content will be provided. Instructors Joseph A. Fischer, P.E. of Geoscience Services and Michael J. Miluski, P.E. of Compaction Grouting Services, Inc. have extensive experience in grouting in karst environments from both the geotechnical engineer's and contractor's viewpoints.



Grout truck. Photo provided by Joe Fischer.

Short Course 3: Stormwater Management in Karst– A Regional Perspective

Instructor:

Robert K. Denton Jr., CPG, LPSS
(GeoConcepts Engineering Inc.)

Instructional East, Room 103
Course length – 4 hours

The short course will detail general principles of karst characterization utilized for the siting and design of stormwater best management practices (BMPs) in karst. Topics to be covered will include:

1. Utilization of terrain, hydrogeological, and subsurface investigation analyses (borings, electrical resistivity, etc.) to properly characterize and design stormwater BMPs in karst, with special emphasis on the karst terrain of the Appalachian regions of Virginia, West Virginia and Maryland;
2. Environmental issues including the mitigation of the transport and migration of soil-adsorbed contaminants into the karst aquifer
3. Design of stormwater BMPs for internally drained sites (onsite absorption, dry ponds, Class V injection wells, etc.);
4. The impact of limestone saprolite on pond design and failure;
5. Understanding and utilization of the Karst Reduction Factor;
6. A review of regional guidelines and regulations governing karst stormwater BMPs.



Short Course 4: Identifying Closed Depressions from Lidar-Derived Digital Elevation Models

Instructors:

Daniel H. Doctor, Ph.D.,
Research Geologist, U.S. Geological Survey

John Wall, Ph.D. Candidate
North Carolina State University

Instructional East, Room G30 (GIS Lab)
Course length – 4 hours

*Shepherds
Cove lidar.*



This short course will introduce users to a number of tools and techniques for identifying sinkholes and other closed depressions from lidar-derived elevation data within ESRI ArcGIS software. Topics to be covered will include:

1. Semi-automated methods for extracting closed depression features from lidar elevation using filling and contour-tree algorithms;
2. Hydrologic conditioning of lidar-derived DEMs for removal of false closed depressions along “digital dams,” such as roads and railways;
3. Implementation of flow-routing algorithms for generation of vector stream networks and modeling of sinkhole flooding from lidar elevation models;
4. Optimized visualization of lidar-derived elevation for identification of karst landscape features;
5. Derivation of geomorphic parameters of closed depression datasets.

Short course participants will be provided with a computer workstation with ArcGIS v.10.3 software, and access to customized toolboxes for processing the lidar to extract closed depressions. Participants may also bring their own lidar data and laptop computer; however, ArcGIS 10.2 or higher must be pre-loaded on a personal computer. Additional skills to be learned will include:

- Enhanced visualization of lidar elevation datasets for geologic mapping;
- Access to publicly-available lidar data;
- Using GIS software to extract closed depression polygon and contour vector data from lidar elevation models;
- Export and visualization of lidar data to Google Earth.

Program At-A-Glance

	Monday 2 April	Tuesday 3 April	Wednesday 4 April	Thursday 5 April	Friday 6 April	
6:30	Breakfast (6:30 - 8:30)	Breakfast (6:30 - 7:30)	Breakfast (6:30 - 8:00)	Breakfast (6:30 - 8:00)	Breakfast (6:30 - 8:00)	
7:00	Commons Dining Rm	Registration Begins (7:00)				
7:30	Registration Begins (7:30)	Field Trip: Karst of the Appalachian Valley <i>(Board bus outside of the Commons)</i>	Registration Begins (7:30)	Registration Begins (7:30)	Registration Begins (7:30)	
8:00			Introductions & Keynote (8:00-9:15) Auditorium	Announcements (8:00-8:10)	Announcements (8:00-8:10)	
8:30	Short Course 1: Geologic Site Char. in a Karst Setting (8:00-12:00)		Karst Hydrogeology Session I (9:20-10:00)	Appalachian Karst (8:10-10:00)	Karst Geophysics Session II (8:10-8:50)	
9:00	Instructional East, Room 105					
9:30					Geotechnical & Modeling Investigations in Karst	
10:00			Break & Exhibits	Break & Exhibits	Break & Exhibits	
10:30	Short Course 2: Grouting in Karst (8:00-12:00)		Panel Discussion: Sinkhole Litigation & Liability (10:30-12:00)	Appalachian Karst (10:30-11:50)	Geotechnical & Modeling Investigations in Karst Session (8:55 - 11:50)	
11:00	Instructional East, Room 103					
11:30						
12:00	Lunch (12:00-1:00)		<i>(Board bus outside of the Commons)</i>	Lunch (12:00-1:00)	Lunch (12:00-1:00)	Lunch (12:00-1:00)
12:30	Commons Dining Rm					
1:00	Short Course 3: Stormwater Management in Karst (1:00-5:00)	Planning Session for 16th Conference (1:00-2:00)		Formation of Karst and Sinkholes Session (1:00-3:00)	Field Trip: Karst of the Urban Environment <i>(Board bus outside of the Commons)</i>	
1:30						
2:00		Karst Hydrogeology Session II (2:00-3:00)				
2:30						
3:00		Break & Exhibits		Break & Exhibits		
3:30	Short Course 4: Identifying closed depressions from lidar (1:00-5:00)	GIS-Mapping- Management of Karst (3:30-4:50)		Formation of Karst and Sinkholes Session (3:30-3:50)		
4:00				Karst Geophysics Session I (3:50-5:35)		
4:30		Instructional East, Room G30 (GIS Lab)				
5:00						
5:30		Dinner (5:30-6:30)	Dinner (5:30-6:30)			
6:00	Dinner (5:30-7:30)					
6:30	Commons Dining Rm	Welcome Reception (6:30-9:00) Roosevelt Rm	Karst Hydrology and Geochemistry (Posters) (6:30 -9:00) Roosevelt Rm	Banquet (6:30-9:30) Commons Dining Rm Speaker: E. Scott Bair Introduction to next conference		
7:00						
7:30						

Detailed Program

Monday 2 April 2018

6:30 AM	8:00 AM	Breakfast (Commons Dining Room)	
7:30 AM		Registration Opens	
8:00 AM	12:00 PM	Short Course 1: (Instructional East Building; Room 105) Geologic Site Characterization in a Karst Setting (4 hrs); Instructors: Lynn Yuhr, P.G., President of Technos, Inc., Miami, Florida (retired); Richard C. Benson, P.G., C.P.G., Founder and Sr. Engineering Geologist of Technos, Inc., Miami, Florida (retired)	Short Course 2: (Instructional East Building; Room 103) Grouting in Karst (4 hrs); Instructors: Joseph A. Fischer, P.E., Geoscience Services; Michael J. Miluski, P.E., Compaction Grouting Services
12:00 PM	1:00 PM	Lunch (Commons Dining Room)	
1:00 PM	5:00 PM	Short Course 3: (Room 103) Stormwater Management in Karst – A Regional Perspective (4 hrs); Instructor: Robert K. Denton Jr., CPG, LPSS (GeoConcepts Engineering Inc.)	Short Course 4: (Room G30-GIS Lab) Identifying Closed Depressions from Lidar-Derived Digital Elevation Models (4 hrs); Instructors: Daniel H. Doctor, Ph.D., Research Geologist, U.S. Geological Survey; John Wall, Ph.D. Candidate, North Carolina State University
5:30 PM	7:30 PM	Dinner (Commons Dining Room)	

Tuesday 3 April 2018

6:30 AM	7:30 AM	Breakfast (Commons Dining Room)	
7:00 AM		Registration Opens	
7:30 AM	5:30 PM	Karst of the Appalachian Valley Field Trip Buses for field trip will leave from the parking lot/turnaround loop outside of the Commons Dining area	
5:30 PM	6:30 PM	Dinner (Commons Dining Room)	
6:30 PM	9:00 PM	Welcome Reception (Roosevelt Room)	

Wednesday 4 April 2018

6:30 AM	8:00 AM	Exhibitor Setup (Hallway outside of Auditorium)	
6:30 AM	8:00 AM	Poster Setup (Commons Dining Room)	
6:30 AM	8:00 AM	Breakfast (Commons Dining Room)	
7:00 AM		Registration Opens	
8:00 AM	9:15 AM	Opening Session (Auditorium)	
8:00 AM	8:10 AM	Introductory Remarks from George Veni (NCKRI) and Dan Doctor (KWI)	
8:10 AM	8:20 AM	Remarks from Mitch Blake - West Virginia Geological and Economic Survey	
8:20 AM	8:30 AM	Remarks from Stephen Sites - Division of Highways, West Virginia Department of Transportation	
8:30 AM	9:15 AM	Keynote Speaker- Chester F. (Skip) Watts , Radford University & Virginia Tech	An Appalachian Mystery: The Hydrogeology of Mountain Lake in Giles County, Virginia--Leaky Landslide or Covered Karst?
9:20 AM	10:00 AM	Karst Hydrogeology Session I - James Lolcoma (Auditorium)	
9:20 AM	9:40 AM	John Barry	Coupling dye tracing, water chemistry, and passive geophysics to characterize conduit flow in a siliciclastic pseudokarst aquifer, Southeast Minnesota, U.S.A.
9:40 AM	10:00 AM	Brian Smith	Groundwater flow systems in multiple karst aquifers of central Texas
10:00 AM	10:30 AM	Break & Exhibits (Hallway outside of Auditorium)	

Wednesday 4 April 2018

10:30 AM	12:00 PM	Sinkhole Litigation and Liability Panel Discussion - Michael Byle (Auditorium)	
		Jesse Richardson	Karst, scientific uncertainty, and the law
		Steven Miano	When sinkholes become legal problems
		Larry Madrid	Litigation and the complexities of sinkhole insurance claims in Florida
		Michael Byle	Engineering assessment of karst sinkhole causation and prediction in litigation
12:00 PM	1:00 PM	Lunch (Commons Dining Room)	
1:00 PM	2:00 PM	Planning Session for the Next Sinkhole Conference (Auditorium)	
2:00 PM	3:00 PM	Karst Hydrogeology Session II - James Lolcama (Auditorium)	
2:00 PM	2:20 PM	James Berglund	Using stable isotopes to identify sinkhole and diffuse storm infiltration
2:20 PM	2:40 PM	Lui Hong	The hydro-chemical characteristics of Karst faulted Basin: case study of Baiyi Basin, Kunming, China
2:40 PM	3:00 PM	Amael Poulain	Surface to cave dye tracing: lessons learned from the Belgian karst
3:05 PM	3:30 PM	Break & Exhibits (Hallway outside of Auditorium)	
3:30 PM	4:50 PM	GIS-Mapping-Management of Karst Session- Clint Kromhout & John Barry (Auditorium)	
3:30 PM	3:50 PM	Michael Alfieri	Photolinears, fractures, and fallacies: A case study of a "ground-truthed" photolineament assessment study, Hillsborough County, Florida
3:50 PM	4:10 PM	Clint Kromhout	Assessment of historical aerial photography as initial screening tool to identify areas at possible risk to sinkhole development
4:10 PM	4:30 PM	Lasha Asanidze	Mapping of potential show caves in the Racha Limestone Massif (Country of Georgia)
4:30 PM	4:50 PM	Yongje Kim	A comparative study of karst sinkhole hazard mapping using frequency ratio (FR) and artificial neural network (ANN) for east Central Florida
5:30 PM	6:30 PM	Dinner (Commons Dining Room)	
6:30 PM	8:00 PM	Karst Hydrology and Geochemistry Posters - Jack Hess (Roosevelt Room)	
		Mohammad Shokri	Bulk chemistry of karst sediment deposits
		Emily Bausher	Geochemical comparison of karst and clastic springs in the Appalachian Valley & Ridge Province, southeastern WV and central PA
		William Jones	An Unusual Spring in the Jackson River, Bath County, Virginia
		Liu Hong	Study on early recognition methods of cover-collapse sinkholes in China
		Amael Poulain	Advances in ultra-portable field fluorometry for dye tracing in remote karst
		Kimberly Hetrick	The role of suspended sediments on the electrochemical remediation of karst groundwater
		Binggui Cai	The water chemical characteristics of Qinglongdong karst spring, Kunming China
		Zong Yuan Pan	Review of monitoring and early warning technologies for cover-collapse sinkholes
		Jeffery A. Green	Electronic Access to Minnesota Springs, Karst Features and Dye Traces Information

Thursday 5 April 2018

6:30 AM	8:00 AM	Breakfast (Commons Dining Room)	
7:30 AM		Registration Begins	
8:00 AM	8:10 AM	Announcements (Auditorium)	
8:10 AM		Appalachian Karst - Dave Weary & Dan Doctor (Auditorium)	
8:10 AM	8:30 AM	Ernst Kastning	Studies of the Appalachian Karst: 1770 – Present
8:30 AM	8:50 AM	David Brezinski	Factors affecting karst spring turbidity in eastern Washington County, Maryland
8:50 AM	9:10 AM	Wil Orndorff	Patterns of heterogeneity within phreatic karst aquifers of the Great Valley, VA and WV: results of time series monitoring and stygobite site occupancy
9:10 AM	9:30 AM	J. Steven Kite	Cold-air trap temperature records support simple high-density air-flow mechanisms at an Appalachian limestone cave entrance sinkhole
9:30 AM	10:00 AM	Joshua Benton	Investigating vadose zone hydrology in a karst terrain through hydrograph and chemical times-series analysis of cave drips at Grand Caverns, VA
10:00 AM	10:30 AM	Break & Exhibits (Hallway outside of Auditorium)	
10:30 AM	10:50 AM	Gheorghe Ponta	Geologic framework of karst aquifer systems in Alabama
10:50 AM	11:10 AM	Joel Maynard	Packer testing and borehole geophysical characterization of observations wells in a vertically integrated karst aquifer in Augusta County, Virginia.
11:10 AM	11:30 AM	Brent Waters	Using geophysics to map bedrock faults, dikes, and surficial geology in relation to karst features in the Briery Branch Quadrangle, Rockingham County, Virginia
11:30 AM	11:50 AM	Jacob Gochenour	Investigating Subsurface Void Spaces and Groundwater in Cave Hill Karst Using Resistivity
12:00 PM	1:00 PM	Lunch (Commons Dining Room)	
1:00 PM	3:50 PM	Formation of Karst and Sinkholes Session - Eric Peterson & Douglas Aden (Auditorium)	
1:00 PM	1:20 PM	Gildas Noury	Role of floods in the sinkholes outbreak in covered karst contexts. Case study of the Orléans area (France) during the 2016 meteorological event and perspectives in other karst environments.
1:20 PM	1:40 PM	Douglas Aden	Quantitative comparison of sinkhole geomorphology of four karst regions in Ohio
1:40 PM	2:00 PM	Valeria Ramirez	Assessment of the karstification degree in the Copacabana Group for a tailings dam foundation, south Andes, Peru
2:00 PM	2:20 PM	Andrew Francis (Eric Peterson presenting)	Lithology as an erosional control on a fluviokarst system
2:20 PM	3:00 PM	Shuning Dong	Comprehensive investigation and remediation of concealed karst collapse columns in Renlou Coal Mine, China
3:00 PM	3:30 PM	Break & Exhibits (Hallway outside of Auditorium)	
3:30 PM	3:50 PM	Ros Fatimah Muhammed	The extreme karst class of Kinta Valley, Perak, west Malaysia
3:50 PM	5:35 PM	Karst Geophysics I - Charlotte Krawczyk & Lewis Land (Auditorium)	
3:50 PM	4:15 PM	Sonja Wadas	Sinkhole imaging and identification of fractures with SH-wave reflection seismic
4:15 PM	4:35 PM	Charlotte Krawczyk	Joint project SIMULTAN - Sinkhole characterization and monitoring with supplementing geophysical methods
4:35 PM	4:55 PM	James Lolcoma	Remedial investigation of large scale karst flow conduits with enhanced resistivity imaging and colloidal borescope methods
4:55 PM	5:15 PM	Saskia Tschache	The combination of 2D shear wave reflection seismics and near-surface active seismic tomography for the investigation of a sinkhole area
5:15 PM	5:35 PM	David Harro	Imaging of deep sinkholes using the Multi-Electrode Resistivity Implant Technique (MERIT) case studies in Florida
6:30 PM	9:30 PM	Banquet (Commons Dining Room)	
		Speaker: E. Scott Bair	The Science Beneath the Ohio State Geothermal Field Fiasco: A Cool Story About a Hot Topic
		Ingrid Padilla/Brian Smith	Introduction to the Next Sinkhole Conference

Friday 6 April 2018

6:30 AM	8:00 AM	Breakfast (Commons Dining Room)	
7:30 AM		Registration Begins	
8:00 AM	8:10 AM	Announcements (Auditorium)	
8:10 AM	8:50 AM	Karst Geophysics II - Charlotte Krawczyk & Lewis Land (Auditorium)	
8:10 AM	8:30 AM	Peter Hutchinson	Avoiding caverns in the Arbuckle Mountains using electrical imaging methods
8:30 AM	8:50 AM	Lewis Land	Sinkholes as transportation and infrastructure geohazards in mixed evaporite-siliciclastic bedrock, lower Pecos Region, southeastern New Mexico
8:55 AM	11:50 AM	Geotechnical and Modeling Investigations in Karst - Joe Fischer & Pierre-Yves Jeannin (Auditorium)	
8:55 AM	9:15 AM	Joseph Fischer	Remediation of the Centenary College President's House
9:15 AM	9:35 AM	Walter Kutschke	Case histories: Karst successes and failures in the eastern United States
9:35 AM	9:55 AM	Randall Orndorff	Linking geology and geotechnical engineering in karst: The Qatar Geologic Mapping Project
10:00 AM	10:30 AM	Break & Exhibits (Hallway outside of Auditorium)	
10:30 AM	10:50 AM	Boqin Zhu (Yongli Gao presenting)	Site characterization of the world's largest five-hundred-meter aperture spherical radio telescope within the Dawodang Karst Depression
10:50 AM	11:10 AM	Ryan Shamet	Development of a sinkhole raveling chart based on cone penetration test (CPT) data
11:10 AM	11:30 AM	Moataz Soliman	Physical and numerical analysis on the mechanical behavior of cover-collapse sinkholes in central Florida
11:30 AM	11:50 AM	Pierre-Yves Jeannin	A way to predict natural hazards in karst
12:00 PM	1:00 PM	Lunch (Commons Dining Room)	
1:00 PM	6:00 PM	Karst of the Urban Environment Field Trip Buses for field trip will leave from the parking lot/turnaround loop outside of the Commons dining area	



Hollow Mogote (karst hill) in Vega Baja, Puerto Rico. Photo by Brian A. Smith.

Keynote Speaker: Chester F. (Skip) Watts



An Appalachian Mystery: The Hydrogeology of Mountain Lake in Giles County, Virginia

Leaky Landslide or Covered Karst?

Mountain Lake, in Giles County, Virginia was the principal filming location for the 1987 movie *Dirty Dancing*, at a time when the lake was full. Starting in about 2002, water levels decreased significantly during the fall months and recovered only partially during the summer months. In 2008, the lake went completely dry and then nearly so again in 2011.

Mountain Lake is one of only two naturally formed lakes in Virginia. At an elevation of 3,875 feet above sea level, it is a truly unique feature in the Valley and Ridge Province within the unglaciated southern Appalachians. A karst collapse origin for the lake has often been suggested. Recent geophysical studies suggest that the lake owes its existence, at least in part, to colluvial damming of an ancient water gap in the breached limb of a dissected plunging anticline approximately 6,000 years ago.

Major conduits are believed to form periodically within the colluvial dam allowing water and lake sediment to pipe through the debris until such time as the conduits become sufficiently clogged to again hold back nearly 100 feet of water depth. The colluvial deposits are likely never completely free of leaks, however it does appear that leakage varied in severity somewhat over the thousands of years. In 2013, the owners undertook a massive earthmoving project intended to restore the lake by filling depressions at the base of the dam, caused by the piping of lake sediment, with naturally available materials from the site. The effort was successful and water levels rose rapidly until encountering additional side conduits at higher elevations that now appear to control lake levels.

Radford University researchers have utilized dye studies, electrical resistivity, seismic refraction, side scan sonar, SCUBA, submersible ROV, unmanned aerial systems, and more to investigate the lake. Observations indicate that the leaks overall are greatly reduced and that precipitation is nearly normal for this region, raising the question of whether changes within the watershed may also play a role by decreasing the inflow side of the water budget equation. In 2002, a part of the drainage basin was modified by the development of new cottages, parking lots, and storm water retention basins. Runoff modeling using the rational method reveals that annual surface flow to the lake has decreased from that area. Groundwater modeling reveals that infiltration beneath these stormwater retention basins lies outside of the groundwater divide for the system that provides base flow recharge to the lake, hence surface water captured by the retention basins appears permanently lost to the lake.

Dr. Skip Watts received his PhD from Purdue University in 1983. He teaches Geology Applied to Engineering and Hydrogeology at Radford University and Virginia Tech. Skip received several regional and national teaching awards, including the State Council for Higher Education's Outstanding Professor Award, Virginia's highest teaching honor, awarded by the Governor. He spent 18 months as a USGS Congressional Fellow serving Senator Joe Lieberman as a science adviser. He was named the 2003 Jahns Distinguished Lecturer speaking on the topics of Geology and Public Policy and Military Operations in Difficult Terrain. He appeared on The Weather Channel's documentary series Storm Stories in an episode entitled SLIDE! and as a guest on National Public Radio's Weekend Edition. Skip provides rock slope safety and stability consulting services for federal and state agencies as well as for private industry. He is presently serving as director of the Radford University GeoHazards Research Center, specializing in the use of unmanned aerial systems (UAS) for geologic mapping and investigating natural hazards of all types.

Banquet Speaker: E. Scott Bair



The Science Beneath the Ohio State Geothermal Field Fiasco: A Cool Story About a Hot Topic

The geothermal wellfield at Ohio State University was designed to heat and cool five, 11-story dormitories. The estimated cost of the HVAC conversion project, including construction of 480 geothermal wells to a depth of 550 feet, was \$4.5M. An east coast company received the drilling contract based on cost and use of multiple air-rotary drilling rigs to complete the wells with 100 feet of steel casing through 80-90 feet of unconsolidated glacial deposits, with the remaining depth completed as 'open hole' through limestones and dolostones. No problems occurred drilling the first well. However, while drilling the second well at a depth of 280 feet, the first well, located 30 feet away, began spouting water 10-15 feet in the air. Work on the second well was halted as drilling began at a third well about 200 feet away. The first and second wells spouted water as the drilled depth in the third well hit 400 feet. As well construction continued, as many as seven wells often could be seen simultaneously spouting water. Commonly, previously drilled wells that had spouted water did not spout water as new wells were drilled in close proximity. The drillers, who normally worked in crystalline rocks, had not seen anything similar to the number, erratic pattern, and irregular participation of spouting wells. Engineers maintained that the air-rotary rigs pressurized an existing 'fracture zone' at a depth of 250 to 400 feet creating the 'geysers'. Three test wells spaced across the geothermal field did not encounter the 'fracture zone,' nor did several of the geothermal wells. Drilling proceeded for several months despite the numerous spouting wells and associated runoff problems. The state and city cited the university with daily fines for violating ordinances limiting drainage to a nearby river and sediment loads to sewers. Shortly thereafter, the driller was fired, lawsuits threatened, a new bid document released, and another company hired, one that proposed a different drilling method and a completion technique that would solve the problems caused by a well-known paleokarst zone. At least it was well known to local hydrogeologists and several faculty in the Earth Sciences Department. Ignorance delayed completion of the geothermal wells by a year and added \$4M to the overall project cost.

E. Scott Bair took his B.A. in geology from the College of Wooster and his M.S. and Ph.D. from Penn State University. Following graduate school he worked six years at Stone & Webster Engineering Corporation. Tired of corporate politics and remembering academe to be devoid of it, Scott joined the faculty at Ohio State University in 1985. Over his career he taught courses in earth science, water resources, environmental geology, speleology, petroleum geology, hydrogeology, field methods in hydrogeology, and groundwater flow modeling. In 1991, he received the Ohio State award for teaching excellence; as penance he served six years as department chair. Scott advised 34 graduate students who worked on projects funded by Ohio DNR, Ohio EPA, NSF, USEPA, USDOE, USDA, USGS, and Ohio State. Scott likes to talk. He's given seminars at more than 90 colleges and universities in the U.S., Canada, and Japan, at several federal and state agencies, the Ohio Bar Association, Harvard Law School, and the National Research Council. From 1987 to 2015 he co-taught short courses for the National Ground Water Association (NGWA) including Principles of Groundwater Flow, Transport and Remediation; Aquifer Test Design and Analysis; Groundwater Control and Construction Dewatering; Artificial Recharge and Induced Infiltration; and Delineating Capture Zones of Wells for Contaminant Remediation and Wellhead Protection. He is co-author of the semi-successful textbook Applied Problems in Groundwater Hydrology. He is a Fellow of the Geological Society of America (GSA), recipient of its Birdsall-Dreiss Distinguished Lectureship, and former chair of its Hydrogeology Division. Scott was an associate editor of the journal Ground Water for 11 years, a member of the Ohio Hazardous Waste Facilities Board for three governors, a technical reviewer for the Centers for Disease Control investigation of male breast cancers at U.S. Marine Corps Base Lejeune, and a member of the USEPA Science Advisory Board on Hydraulic Fracturing. He received the George B. Maxey Award from GSA and the Keith E. Anderson Award from NGWA for his service to those organizations and his contributions to the greater groundwater community. Scott and his wife recently retired to the Outer Banks of North Carolina where they plan to lollygag in the sun and surf until rising sea level carries them away.

Presentation Abstracts

(in order of presentation)

Wednesday, April 4th

9:20 am - 10:00 am

Karst Hydrogeology Session I

(James Lolcoma)

Coupling dye tracing, water chemistry, and passive geophysics to characterize a siliciclastic pseudokarst aquifer, Southeast Minnesota, USA

John D. Barry, Minnesota Department of Natural Resources
Jeff A. Green, Minnesota Department of Natural Resources
Joseph W. Rutelonis, MN Department of Natural Resources
Julia R. Steenberg, Minnesota Geological Survey
E. Calvin Alexander Jr., University of Minnesota

A decade of dye tracing in southeastern Minnesota within shallow, buried Cambrian siliciclastic units has revealed groundwater flow characteristics more commonly associated with carbonate karst aquifers. To understand the hydrologic system, several characterization methods were used on a pair of dye traces in central Winona County in southeast Minnesota. South of the City of Stockton, Minnesota, a deeply incised north-south trending valley and its tributaries contain a number of large springs and several sinking streams. In the project area, streams sink into the lower part of the Cambrian siliciclastic Jordan Sandstone or the upper portion of the underlying Cambrian St. Lawrence Formation. The St. Lawrence Formation consists of interbedded well-cemented siltstone, very fine-grained sandstone, and very thin shale. Most of the large springs found in deeply incised valleys in southeastern Minnesota emanate from the basal St. Lawrence and upper Lone Rock Formations. The Lone Rock is a siliciclastic unit consisting of fine-grained sandstone and siltstone with minor beds of shale and dolostone. Passive charcoal detectors were used to calculate dye-breakthrough velocities that ranged between 58-203 meters/day at one location and 47-72 meters/day at another. These velocities are consistent with other trace velocities measured within siliciclastic units in southeastern Minnesota. Water samples collected at the sinking streams, springs, and a domestic well in the project area show elevated nitrate and chloride concentrations indicating the presence anthropogenic impacts likely related to application of

fertilizers and road salt. Passive geophysical data were collected at the sinking stream locations and at transects within two valleys to characterize depth to bedrock. At the sinking stream above mapped Jordan Sandstone, the depth to bedrock was determined to be 6.4 meters. The depth at the location mapped above the St. Lawrence Formation was determined to be 5.2 meters. These data suggest colluvium and alluvium layers are thicker than what was previously conceptually modeled in this setting. The results of these dye traces are consistent with others in southeast Minnesota showing that the siliciclastic St. Lawrence and Lone Rock Formations have conduit-flow properties similar to those found in carbonate karst aquifers.

Groundwater flow systems in multiple karst aquifers of central Texas

Brian A. Smith, Barton Springs/Edwards Aquifer Conserv. Dist.
Brian B. Hunt, Barton Springs/Edwards Aquifer Conserv. Dist.
Doug A. Wierman, Blue Creek Consulting
Marcus O. Gary, Edwards Aquifer Authority

Increased demand for groundwater in central Hays County is prompting studies to evaluate the availability of groundwater in the Trinity Aquifers of central Texas. These aquifers, consisting mostly of limestone, dolomite, and marl, exhibit varying degrees of karstification. Near the surface, karst features such as caves and sinkholes are evident, but are widely scattered. Even at depths greater than 400 m (1,300 ft), units that are mostly limestone show some degree of karstification where dissolution along fractures has caused development of conduits. Studies are being conducted to better understand the horizontal and vertical flow components of the Trinity Aquifers. These studies involve aquifer testing, groundwater geochemistry, geologic and structural mapping, flow-loss/gain measurements in streams, hydraulic head measurements, dye tracing, and installation of multiport monitor wells. The Middle Trinity Aquifer meets the definition of a karst aquifer due to its conduit permeability within soluble rocks. However, the same aquifer has contrasting properties that are separated by the complex Tom Creek Fault Zone. The westerly Hill Country Middle Trinity Aquifer is a shallow karst aquifer system characterized by rapid conduit flow and active surface and groundwater interactions. In this area, Middle Trinity units are situated at or near the surface. To the east, the Balcones Fault Zone Middle Trinity Aquifer is a deeply confined karst aquifer system with more limited conduit development, slower groundwater flow, and no direct surface-groundwater interactions. In this area, Middle Trinity units are encountered at depths of 150 m (500 ft) or greater. The results of this study will influence future hydrogeologic and resource evaluations and modeling of the Middle Trinity Aquifer.

Wednesday, April 4th

10:30 am - 12:00 am

Sinkhole Litigation and Liability Panel Discussion (Michael Byle)

Karst, Scientific Uncertainty and the Law

Jesse Richardson, West Virginia University

Courts struggle to deal with evidence relating to the existence of karst terrain and the impact of human activities on karst terrain. Although courts often must hear cases involving complex scientific issues, karst seems to prove especially problematic, perhaps because of the lack of uniformity and the site-specific nature of the resource. *Helping Others Maintain Environmental Standards (HOME) v. Bos*, 406 Ill.App.3d 669, 941 N.E.2d 347 (2010) ("Bos"), represents the most extreme example of a court struggling with evidence relating to karst matters. The court found against the plaintiffs, primarily because the expert witness admitted that additional testing could have been done, but was not, due in part to financial constraints. One legal treatise referred to the defense's "relentless theme of studies not done" as "raging, fuming, 'it's-all-an-environmental-conspiracy' presentation" (Rogers Environmental Law, 2d., Section 4:18). This case explicitly raises the questions that many others implicitly raise. How many studies are enough? Which studies are sufficient? The Bos case and a variety of other published opinions involve courts analyzing expert testimony as to karst matters and determining whether such evidence is sufficient. Examination of these cases proves useful for future litigants and experts. The cases examined involve a variety of situations, including Environmental Impact Assessments and various citizen challenges to development. The review reveals that courts apply inconsistent standards and then use inconsistent analysis in the application. Some of the inconsistency can be explained by the context of the case, while others cannot. Analysis of the court cases indicate that courts are generally ill-equipped to deal with expert testimony related to karst matters and that this testimony may prove to be more problematic than other technical, scientific evidence due to the nature of karst as a heterogeneous resource depending upon site-specific studies and examination. This circumstance further raises the issue of the cost of expert testimony relating to karst in court cases and whether karst investigations should instead be conducted by state or federal agencies. However, if these agencies should conduct the investigations, do the agencies have adequate resources to do

so? The paper recommends that the scientific karst community further educate lawyers, judges and citizens on the scientific aspects of karst, including the heterogeneous nature of karst. Ultimately, however, expert witnesses in karst matters will be forced to incorporate education of the court into their reports and testimony, to the extent that the court allows.

When Sinkholes Become Legal Problems

Steven Miano, Hangley Aronchick Segal Pudlin & Schiller

Sinkholes can cause property damage, injury to people and harm to the environment. It is therefore not surprising that myriad legal issues arise in the context of sinkholes and the actual and potential harms they present. This paper will focus on those legal issues and will include a discussion of potential causes of action (i.e., legal claims), both under statutory laws (e.g., state laws like in Pennsylvania under which sinkholes can be deemed a nuisance) and common law (i.e., claims derived from longstanding judicial precedent), and available damages (i.e., monetary compensation) and other remedies. Mining activities and water supply wells for industrial, commercial and residential uses, which pump groundwater in karst and other sinkhole prone areas, are often a direct cause of sinkholes. Yet most government agencies regulating mining and other related industries are ill-equipped, either technically or politically, to manage the potential, and in some cases, inevitable damage. Few, in fact, recognize the direct relationship between activities they typically permit, the formation of sinkholes, and the resulting harms. This paper will also discuss both bringing a case for sinkhole remediation (direct lawsuits and mining permit appeals) and defending sinkhole-related claims. Because cases involving karst terrain and sinkholes tend to turn on the presentation of highly technical scientific principles, educating the court is critical, as is the experience and expertise of a top-notch expert witness. This paper will discuss the ways to effectively present such cases in court, including the presentation of technical witnesses/experts. Two case studies will be examined. One case involves a school and a neighboring quarry, in which the court found that a quarry was the direct cause of sinkholes opening in the surrounding area. As a result, the court held that the quarry constituted a nuisance, and therefore denied a permit extension allowing further mining. Another case study will examine sinkholes opening near a major roadway in an area where no mining is known to have occurred.

Litigation and the Complexities of Sinkhole Insurance Claims in Florida

Larry Madrid, Madrid Engineering Group, Inc.

The entirety of peninsular Florida is underlain by relatively young limestone bedrock and overlain by sands that easily ravel into voids and cavities within the limestone. Surficial expressions of karstic activity are immediately evident in its thousands of circular lakes, wetlands, and cypress heads. Additionally, Florida has had literally tens of thousands of subsidence-related insurance claims over the past two decades, far surpassing the entire history of property insurance before that. The peak came around 2011, the year that new legislation made it much harder for a homeowner to prove a claim. The issue was essentially ‘what is the definition of structural damage?’ as defined by Florida Statute related to property insurance and specifically sinkhole coverage. Prior to 2011, a clear definition of structural damage did not exist, consequently the attorneys maintained that the plain definition (structural damage is damage to a structure) held, in spite of many geotechnical and structural reports that defined structural damage as an engineer would deem – loss of load carrying capacity. Consequently, cosmetic damage that was not remotely “structural” was considered damage by the courts, and legal cases blossomed out of control. In 2011, Florida Statutes redefined “structural damage” using five separate criteria. These criteria include, for example “interior floor displacement or deflection in excess of acceptable variances as defined in ACI 117-90 or the Florida Building Code, which results in settlement-related damage to the interior such that the interior building structure or members become unfit for service or represents a safety hazard as defined within the Florida Building Code...”. Other criteria have to do with foundation displacement; leaning or listing of the building; or ground movement that results in portions or all of the building likely to imminently collapse. Of course, there are additional criteria and exceptions. Overall, these statutory changes have resulted in significantly fewer sinkhole claims, in spite of the occasional sinkhole that enraptures the news media (for example, the March 2013 death of Mr. Jeffrey Bush as a result of sinkhole collapse below his bedroom). So while all property insurance companies in Florida still cover “catastrophic ground cover collapse” for all homes, there are far fewer of these claims to deal with as the law has become more sophisticated.

Engineering Assessment of Karst Sinkhole Causation and Prediction in Litigation

Michael Byle, Tetra Tech

Sinkholes in karst environments can cause damage to facilities and structures and pose a health and safety risk. The occurrence of sinkholes is difficult to predict and poses liability to planners, designers, owners, and engineers who practice in these areas. Often times the occurrence of sinkholes leads to litigation over who is responsible and who should have anticipated and designed mitigation to prevent consequences of sinkholes. Where performance does not meet with expectations, individuals are put at risk, or where damage occurs, litigation frequently ensues. The critical components of the litigation often revolve around causation, predictability, and cost to remediate and/or prevent future sinkholes. Causation is important to identify responsible parties. Since the number of factors that influence the frequency, severity, and locations of sinkholes are many and involve geology, geotechnical engineering, surface water hydrology, and groundwater hydrology, a multidisciplinary approach is needed. A logical and prioritized basis is best to assess the relative merits of various mechanisms and determination of the one or two primary factors that either caused a condition to develop, or exacerbated an existing condition, and those factors that could reasonably have been anticipated using the appropriate standard of care. From an engineering perspective, it is essential to understand the causative factors to develop and estimate the costs for mitigation and restoration. The presentation will address the factors important to this assessment and approach to prioritization to deduce the key causative factors for covered carbonate karst. The presentation will also address the measures to identify the certainties and address the uncertainties in karst conditions for litigation.

Wednesday, April 4th

2:00 pm - 3:00 pm

Karst Hydrogeology Session II

(James Lolcoma)

Using stable isotopes to distinguish sinkhole and diffuse storm infiltration in two adjacent springs

James L Berglund, Temple University
Laura Toran, Temple University
Ellen Herman, Bucknell University

Two karst springs, Tippery Spring and Near Tippery Spring, have similar discharges (~ 0.1 m³/s, 5 cfs) and are only 30 meters apart, yet they show unique behaviors in terms of water chemistry and discharge response to storms. Near Tippery has higher Mg/Ca ratio and Tippery Spring has more variable temperature response to storm events. This contrast was further extended to differences in recharge pathways based on stable isotope analysis (δD & $\delta^{18}O$) of spring water samples collected using ISCO automated samplers during a May (3 cm, 1 inch) storm and June (8 cm, 3 inch) storm in 2017. Increased spring discharge preceded the arrival of storm water as conduits were purged of pre-storm water, indicated by no change in isotopic composition on the rising limb. The isotopic signature then became progressively more enriched at both springs, indicating storm water recharge. At Tippery, this enrichment began around peak flow, sooner than at Near Tippery where enrichment began during the descending limb. Thus, isotopes indicated a stronger surface connection at Tippery. Storm water recharge at both springs then progressed to a greater relative fraction of total discharge before recovering to pre-storm values within 24-36 hours. Storm intensity also affected the relative contribution of recharging water reaching both springs, with the June storm producing a larger recharge signature compared to the May storm. At Tippery, for a short time the majority of emerging water is storm water, with the absolute pre-storm contribution falling below its baseflow value. This reduction in pre-storm water may indicate a reversal in water exchange between the conduits and the surrounding matrix, an important consideration in karst contaminant transport. While both springs can be traced to sinks, their isotopic signatures reflect how storm water infiltrates and travels within each spring's recharge area. Tippery is fed by a perennial sinking stream and more developed conduit network, while Near Tippery has a more diffuse recharge area with mixing of different surface inputs. As stable isotopes are unaffected by redox or dissolution processes, they can provide a conservative tracer with which to characterize how other parameters, such as temperature,

alkalinity, and turbidity, are reflected in different spring recharge behaviors.

The hydro-chemical characteristics of a karst faulted basin: Case study of the Baiyi Basin, Kunming, China

Liu Hong, International Joint Research Center for Karstology, Yunnan University

A fault-controlled karst basin is a special type of karst landform. It is defined as a basin-like topography surrounded by mountains, which is fully or partly karstified. Fault-controlled karst basins play a great role on urbanization and economic development of Yunnan Province which is located in a mountainous region. Baiyi Basin is a sub-basin of the Kunming faulted Basin with typical hydrogeological characteristics for a fault-controlled karst basin. It is also one of the most important drinking water source protection zones of Kunming City. In order to better understand the hydrogeological nature of this fault-controlled karst basin and to better protect the valuable groundwater resources, a pilot study focusing on the hydrochemical characteristics of fault-controlled karst basin springs was carried out in Baiyi Basin. A total of 10 springs in the basin are selected in this study. Water Temperature, Electric Conductivity (EC), and pH value were measured in situ. Water samples from these 10 springs were analyzed for Ca²⁺, HCO₃⁻, F⁻, Cl⁻, NO₃⁻, Br⁻, DOC, DIC contents and stable isotopic ratios ($\delta^{18}O$ and δ^2H). Results show that (1) the hydrochemical characteristics of fault-controlled karst basin are more complex than for a normal basin owing to the intense tectonic activities. Within the Baiyi fault-controlled karst basin, there are not only epikarst springs, shallow karst springs, and confined karst springs, but also non-karst springs. Even deep groundwater may be involved in the water cycle. (2) Water isotopic data reveal that Qinglongtan (QLT) Springs (QLT1 to QLT4) and a Heilongtan Spring (HeiLT1) share a common recharge water source. (3) Among 9 of 10 studied springs, nitrate concentrations slightly exceed of the drinking water standard (10mg/l).

Surface to cave dye tracing: lessons learned from the Belgian karst

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Arnaud Watlet, Royal Observatory of Belgium
Gaëtan Rochez, University of Namur
Olivier Kaufmann, University of Mons
Michel Van Camp, Royal Observatory of Belgium
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The vadose zone (unsaturated) of karst aquifers is critical for several reasons. (i) It is the main pathway for karst groundwater recharge from the surface to the phreatic zone (saturated), (ii) it forms the transition zone between surface human activities (potential contamination) and the groundwater resource, and (iii) it gives a support for karst fauna and flora through its hydrogeological dynamic. The hydrogeological functions of the vadose zone are of growing interest for these reasons but, also, because this highly heterogeneous media is still poorly understood by hydrogeologists and karst researchers. In order to more fully apprehend the function of this zone, surface to cave dye tracing was performed above the Rochefort Cave in south Belgium. The goal was to explore the hydrological processes of the 30-meters vadose zone between the surface and the cave by mean of dyes and drip-water monitoring. These methods enable us to discover information about groundwater dynamic. A maximum velocity of around 10 meters/hour was calculated in absence of rainfall and without significant flush during the injection of the dye. A multimodal breakthrough curve was recorded in the percolation water, the tracer being remobilized by every rainfall event during more than 120 days. The dye tracked the reaction of the percolation to rainfall events at the surface. Separation and analysis of the different peaks and their related rainfall events revealed a clear trend. The higher the rainfall intensity, the faster the reaction of the percolation. The effect of the rainfall gives infiltration velocities from 10 to 55 m/h for the higher rainfall intensities. Additionally, the dye tracing allowed us to compare the effect of snowmelt and rainfall on the infiltration efficiency. Snowmelt has a higher remobilization effect on the dye, thus a higher infiltration potential compared to rainfall events. The effect of rainfall intensity on infiltration velocity and the difference between snowmelt and rainfall when considering infiltration efficiency seems of primary importance in a context of global climate changes. These results emphasize the importance of evaluating vadose processes in karst terrain.

Wednesday, April 4th 3:30 pm – 4:50 pm GIS-Mapping-Management of Karst (Clint Kromhout & John Barry)

Photolinears, fractures, and fallacies: A Case Study of a 'Ground-Truthed' Photolineament Assessment Study, Hillsborough County, Florida

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Sam B. Upchurch, SDII Global Corporation
Thomas L. Dobecki, Dobecki Geosciences, LLC

There is a misconception by some in the geologic and non-geologic communities of Florida that photolineaments and vertical bedrock fractures are one and the same. The main objectives of this paper are (1) to document a case study where a comprehensive geophysical and geotechnical exploration program was undertaken to verify a high-quality photolinear analysis; and, based on the case study, (2) evaluate the validity of photolinears as indicators of vertical bedrock fractures in the covered karst terrain of west-central Florida. The case study, an investigation by Upchurch et al. (1999), was an analysis of photolineaments at a 445-ha site intended for construction of an above-grade reservoir in west-central Florida. The photolineaments were ground truthed using ground penetrating radar (GPR), refraction and reflection seismic profiling, standard penetration testing (SPT), and cone penetrometer testing (CPT; Dobecki and Upchurch 2010). The post hoc review, based on the comprehensive site geophysical and geotechnical testing and resulting data, determined that fifty-eight percent of the photolinears do not correspond to vertical fractures in the limestone bedrock. This review demonstrates the fallacies of assuming all photolinears represent vertical bedrock fractures in the covered karst terrain of west-central Florida. Based on this case study and the post hoc review, it is our belief that in the covered karst terrains of Florida, all photolinear evaluations should have some form of field verification in order to equate them to vertical bedrock fractures or karst features.

Assessment of historical aerial photography as initial screening tool to identify areas at possible risk to sinkhole development

Clint Kromhout, Florida Geological Survey
Michael C. Alfieri, Water Resource Associates, LLC

Use of historical aerial photography to perform desktop site assessments to mitigate cover-collapse sinkhole risk is not a new concept in the geoscientific arena. Unfortunately, it has not been a routine part of the decision matrix for land-use planning and development. This paper demonstrates the importance of historical aerial photography analysis as a preliminary tool to identify site-specific sinkhole risk. Three case studies are presented to underscore this observation. In sinkhole-prone regions in parts of Florida and many other states across the county, infrastructure siting and other land-use planning activities would be well-served to include this type of analysis.

Mapping of Potential Show Caves in the Racha Limestone Massif (Country of Georgia)

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Vakhushti Bagrationi Institute of Geography
Zaza Lezhava, Ivane Javakhishvili Tbilisi State University,
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George Gaprindashvili, Department of Geology, National
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Guranda Avkopashvili, Ivane Javakhishvili Tbilisi State
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The Racha limestone massif is located in the eastern part of the karst zone of western Georgia. The massif is a typical example of Georgian mountain karst regions, where diverse surface and subsurface karst landforms are found. The main aim of this research is to present mapping of two potential show caves, and document speleological information from the Racha limestone massif. The morphological parameters and tectonic directions of the Muradi and Usholta Caves were mapped using the compass-clinometer and laser distance meter, to compile 3D models of the caves. To our knowledge these are the first 3D models of karst caves in Georgia.

A comparative study of karst sinkhole hazard mapping using frequency ratio (FR) and artificial neural network (ANN) for east Central Florida

Yongje Kim, University of Central Florida
Boo Hyun Nam, University of Central Florida

Sinkholes are one of the most common geohazards occurring in East Central Florida (ECF). Identifying areas prone to sinkholes is vital for land use planning in the ECF area, and thus, sinkhole hazard mapping plays a critical role. The present study presents (1) sinkhole hazard maps of ECF by using frequency ratio (FR) and artificial neural network (ANN) models and (2) a validation and comparison of the performance of two models. An inventory map with a total of 757 sinkhole locations was prepared from Florida subsidence incident reports (FSIR). 70% (530 sinkholes) were randomly selected to calibrate the sinkhole hazard models, and the remaining 30% (227 sinkholes) were used for the model validation. Five sinkhole contributing factors were considered including age of sediment deposition, hydraulic head difference, groundwater recharge rate, overburden thickness, and proximity to karst features. The relationship between sinkhole occurrence and sinkhole contributing factors was investigated through a GIS-based statistical analysis.

Wednesday, April 4th 6:30 pm - 9:00 pm Karst Hydrology and Geochemistry Posters (Jack Hess)

Bulk chemistry of karst sediment deposits

Mohammad Shokri, West Virginia University
Dorothy Vesper, West Virginia University
Ellen Herman, Bucknell University
Ljiljana Rajic, Northeastern University
Kimerly Hetrick, Northeastern University
Ingrid Y. Padilla, University of Puerto Rico – Mayaguez
Akram Alshawabkeh, Northeastern University

Sediments are ubiquitous in karst systems and play a critical role in the fate and transport of contaminants. Sorbed contaminants may be stored on immobile sediments or rapidly

dispersed on mobile sediments. Sediments may also influence remediation by either enhancing or interfering with the process. To better understand the potential effects of sediments on remediation, we conducted physical and chemical characterizations of 11 sediment samples from 7 cave and spring deposits from karst regions of Tennessee, Virginia and West Virginia. The samples were analyzed for particle-size distribution using sieves and laser diffraction particle analysis. The sediment size fraction <2 mm> (sand, silt, and clay) was analyzed for slurry pH and specific conductivity (SC) using electrodes and for bulk total carbon, organic carbon, nitrogen and sulfur on an ElementarTM Vario MAX Cube CNS. The same <2 mm fraction was subjected to a pseudo-total extraction using aqua regia with subsequent solution analysis by inductively coupled plasma-optical emission spectrometry (ICP-OES). Most of the samples were dominated by the <2 mm size fraction. Their slurry pHs ranged from 6.8 to 8.4 and their SCs ranged from 45 to 206 $\mu\text{S}/\text{cm}$ with the exception of two high SC samples (726 and 8500 $\mu\text{S}/\text{cm}$). The fraction of organic carbon (Foc) in the sediments ranged from <0.1 to 2%. The sample from a saltpeter cave historically used for gunpowder production contained the highest concentrations of N and S (~3 g/kg) but lower total C than some of the spring samples. The pseudo-total extractions were analyzed for Al, Ca, Fe, Mg, and Mn. Of those elements, Mg was the most consistent across the locations (2.0 - 6.1 g/kg), and Ca was the most variable (1.4 - 52 g/kg). Given the importance of particle size and elemental concentrations in chemical reactions and remediation, more data of this type are needed to predict contaminant fate and transport and to plan successful remediation projects.

Geochemical Comparison of Karst and Clastic Springs in the Appalachian Valley & Ridge Province, southeastern WV and central PA

Emily Bausher, West Virginia University
Autum R. Downey, West Virginia University
Dorothy J. Vesper, West Virginia University

The Appalachian Valley and Ridge (V&R) Province extends over 11 states and is an essential water supply. The regional geology consists of more resistant clastic rocks, typically sandstones and mixed shales, which form the ridge tops and mountain flanks, and carbonate rocks that underlie the valleys. In this study, we report the geochemistry of different types of springs on and near Peter's Mountain in Monroe County, WV. More than 250 springs have been mapped in the ~225 km² study area on and adjacent to Peter's Mountain. These data are compared with preliminary data collected from sandstone-sourced springs from central PA and northcentral WV. Six sandstone springs in WV and PA were sampled and monitored for comparison to the Monroe County springs. Springs were

grouped by geologic and geomorphologic location: Group 1: sandstone-sourced springs in WV and PA; Group 2: springs in the Martinsburg Formation on the western flank of Peter's Mountain; and, Group 3: springs in the carbonate valley west of Peter's Mountain. In general, Group 1 springs are smaller and more ephemeral than the other groups; their waters have low pHs (4.1-6.0), low specific conductivities (24 to 55 $\mu\text{S}/\text{cm}$), and low concentrations of dissolved ions. Group 2 springs are also small and ephemeral but have higher pHs (6.7 -8.4) and specific conductivities (73-308 $\mu\text{S}/\text{cm}$) due to the mixture of shales and carbonates in the source formation. Temperatures in these springs range from highly consistent to highly variable. Although the Group 2 springs along Peter's Mountain have Ca and Mg concentrations similar to the Group 3 carbonate springs, they can be distinguished by higher Ca/Mg mole ratios. In contrast, Group 3 springs have higher pHs (6.6-8.4) and higher specific conductivities (144-750 $\mu\text{S}/\text{cm}$).

An Unusual Spring in the Jackson River, Bath County, Virginia

William K. Jones, Karst Waters Institute
Philip C. Lucas, Virginia Speleological Survey

Boiling Spring rises in the bed of the Jackson River about 0.5 km (0.3 mi) downstream of the USGS gaging station on the Jackson River near Bacova, Virginia. Five tracer tests to the spring have been conducted on sinking upstream tributaries to the Jackson River. The longest trace was 12.5 km (7.75 mi) from Muddy Run with the dye injected on the east side of the Cobbler Mountain Anticline. Additional traces to Boiling Spring are from Muddy Run on the west side of the anticline, Chimney Run, Creek Bed Cave, and Warm Springs Run. Travel times were greater than one mile per day. The gaging station is missing about one third of the total flow under low flow conditions. Discharge measured in October 2005 was 0.36 m³/s (12.8 cfs) from the spring, and 0.77 m³/s (27.0 cfs) at the Bacova gaging station. The ungaged discharge is probably not a significant part of the total flow at higher river levels. However, the annual runoff for the Jackson River station at Bacova—with a drainage area of 409 km² (158 mi²)—is 371 mm (14.6 in) per year, well below the 480 mm (18.9 in) per year for the nearby Bullpasture River at Williamsville that has a smaller drainage area of 285 km² (110 mi²).

Study on early recognition methods of cover-collapse sinkholes in China

Long Jia, Institute of Karst Geology, CAGS

Cover-collapse sinkholes pose a major geohazard occurring in mantled karst regions in the south of China in recent years. Cover deposits generally mask the subsurface development and propagation of the deformation to the topographic surface. Human security and land-use planning in sinkhole-prone areas need to be preceded by detailed investigations focused on the identification of pre-existing sinkholes, subsurface dissolution, subsidence features and groundwater condition. The abnormal early hidden danger signs (ground, underground and hydrodynamic) of karst collapse are studied. Further, the corresponding identification techniques and methods are presented, such as surface surveying techniques (satellite remote sensing, the drone, etc.), underground detection technology (ground penetrating radar, microgravity, micro tremor, etc.), and monitoring of groundwater conditions. Finally, all kinds of techniques and methods can be combined to form a comprehensive system for identifying hidden dangers of karst collapse. This paper aims at identifying the early hidden dangers of karst collapse geological disasters. This has important theoretical, technical and social significance in order to minimize the impact of disasters on the people and the environment.

Advances in ultra-portable field fluorometry for dye tracing in remote karst

Amaël Poulain, Department of Geology - University of Namur
Geert De Sadelaer, Royal Meteorological Institute of Belgium
Gaëtan Rochez, Department of Geology - University of Namur
Lorraine Dewaide, Department of Geology - University of Namur

Vincent Hallet, Department of Geology - University of Namur

Dye tracing is a powerful tool in karst hydrogeology, allowing to specify groundwater connections, drainage organization and groundwater flow characteristics in impenetrable places (underground rivers, flooded caves...). The use of in situ monitoring devices enables improved investigation quality and efficiency during field work. Autonomous field fluorimeters developed in the last decades now give reliable data for dye tracing with fluorescent tracers, with a limited investment on the field and limited human resources. Nevertheless, the karst environment remains difficult to access and explore with scientific equipment. The size, weight, robustness and user-friendliness of the tool is determinant to improve the efficiency of field work and allow the acquisition of reliable data. In order

to tackle this issue, we developed the Fluo-Green field fluorometer. This is a compact, extra-light and 2-in-1 field fluorometer (probe and data-logger) designed specifically for karst environment. The fluorometer allows the monitoring of fluorescein, turbidity and water temperature with a user-defined resolution (1 minute to 1 day). An improved management of energy gives an extended lifetime that is useful for monitoring in remote locations. The compact device is especially useful to carry into the field and facilitates the monitoring of multiple sampling points. Several dye traces in Belgian karst show the field performance of the Fluo-Green (precision, accuracy, resolution, lifetime...). Different karst environments were investigated using dye tracing: underground rivers, flooded caves, karst springs, vadose percolations. Those experiences illustrate the routine use of the Fluo-Green in various remote karst environments.

The Role of Suspended Sediments on the Electrochemical Remediation of Karst Groundwater

Kimberly Hetrick, Northeastern University
Ljiljana Rajic, Northeastern University
Akram Alshawabkeh, Northeastern University
Dorothy Vesper, West Virginia University
Mohammad Shokri, West Virginia University

Due to the complicated nature of karst aquifers, many groundwater treatment technologies are difficult to implement successfully. A particular challenge arises because sediments are ubiquitous and mobile in karst systems and may either facilitate contaminant transport or act as long-term substrates for storage via sorption. However, electrochemical remediation is a promising technology to be optimized for karst aquifers due to easy manipulation and control of groundwater chemistry, low cost, ability for in situ application, and performance under alternative power sources. This study investigates the effects of suspended karst sediments on the groundwater electrochemical remediation via electro-Fenton (EF) mechanism. The EF mechanism relies on electrochemical (i.e. water electrolysis and ferrous iron release) and electrochemically-induced processes (i.e. Pd catalyzed H₂O₂ production) to produce hydrogen peroxide and support its activation to hydroxyl radicals - a powerful oxidant capable of degrading and transforming of wide range of contaminants (e.g., chlorinated solvents). Sediments were obtained from different karst locations with a range of concentrations of Fe, Mn and buffering capacities; these sediments were characterized to provide a "library" of substrates for laboratory testing. When the sediments were introduced into the EF experiments, there were adverse effects on the electro-generation of hydrogen peroxide: at steady state (120 min), Pd catalyzed formation of hydrogen peroxide

decreased by 60%, 57%, and 75% in the presence of sediment leaching respectively 32, 37, and 33 ppb Fe and 4, 2, and 48 ppb Mn. Presented results imply that while sediments' presence influences EF mechanism in electrochemical systems, the technology can be optimized in terms of electrode materials, current intensities and current regimes to address these challenges.

The water chemical characteristics of Qinglongdong karst spring, Kunming China

Binggui Cai, Institute of Geography, Fujian Normal University
Hong Liu, International Joint Research Center for Karstology, Yunnan University

Karst water plays a very important role in providing a municipal water supply in Kunming City, Yunnan Province, China. It contributes approximately 50% of the drinking water for the city. Given the rapidly growth in urbanization and of the economy of Kunming City in the last decades, most karst springs have been suffering from human impact, in both quality and quantity. Qinglongdong Spring (QLDS) is located in Dabanqiao village, Northwestern Kunming, 23 km away from Kunming downtown and is an important component of the water supply system of Kunming City. It was previously abandoned in 2003 and 2004 due to high levels of organic contamination. In order to better understand factors impacting the spring water quality and quantity, a Greenspan CTDP300 multi-parameter data logger (water level, pH, EC and T), and a rain gauge were installed. Water samples were manually collected and analyzed between May and August of 2003 to 2009. The test results revealed that the Qinglongdong Spring study area not only has a well-developed groundwater drainage system, but also the vadose zone is very thin. Given this hydrogeological situation, QLDS has a rapid response to rainfall events, and therefore, the pollutants are transported inside the aquifer rapidly as well. Manual sampling indicates an increasing trend of nitrate content in the spring from 2006 to 2009. It is possible that this area may be influenced by sewage, which is being disposed of illegally, but this would need further investigation.

Review of monitoring and early warning technologies for cover-collapse sinkholes

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Xiao Zhen Jiang, Institute of Karst Geology, CAGS
Ming Tang Lei, Institute of karst geology, CAGS
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Yuan Bing Wu, Institute of Karst Geology, CAGS
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Sinkhole collapse has become a major geohazard in many karst areas. The development of monitoring and early warning technologies is essential to investigate mechanisms of sinkhole formation. This paper reviews latest research on monitoring and early warning technologies surrounding cover-collapse sinkholes. Monitoring the hydrodynamic conditions in areas susceptible of sinkhole collapse has proven to be useful to help understand the relationship of rainfall, surface water, and groundwater in karst areas. Monitoring hydrodynamic conditions of karst groundwater includes rainfall monitoring, groundwater level monitoring, air pressure monitoring, and groundwater quality monitoring. Observations from the monitoring system and known sinkhole collapses could be used to simulate and predict hydrogeologic, geologic, and atmospheric conditions favorable to sinkhole formation. Monitoring technologies of deformation for the overburden soil include Ground Penetrating Radar (GPR), Time Domain Reflectometry (TDR), and Brillouin Optical Time Domain Reflectometer (BOTDR). GPR is more suitable to investigate relatively flat terrain with dry soil cover. TDR and BOTDR were more suitable for linearly distributed monitoring sites because of the cohesion between soil mass and optical fiber.

Electronic Access to Minnesota Springs, Karst Features and Dye Traces Information

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John D. Barry, MN Department of Natural Resources
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Minnesota karst related information has been made electronically accessible through three interrelated databases, the Minnesota Karst Feature Database (KFD), the Minnesota Groundwater Tracing Database (MGTD), and the Minnesota Spring Inventory (MSI). Collectively, this information is a

significant asset for use in water resource planning and management in the State of Minnesota. The KFD and MGTD focus primarily on the karst regions of southeastern Minnesota while MSI has extensive coverage within the karst regions of Minnesota, but also extends to all other areas of the state. Reporting associated with four decades of collaborative work pertaining to karst is also available via the Dye Trace Reports Collection on the University of Minnesota Library's Digital Conservancy. Much of the recent work was funded by Minnesota's Clean Water Fund, Land and Legacy Amendment and by the Minnesota Environmental and Natural Resources Trust Fund.

Thursday, April 5th 8:10 am - 11:50 am Appalachian Karst (Dave Weary & Dan Doctor)

Studies of the Appalachian Karst: 1770 – Present

Ernst H. Kastning, Radford University

The Appalachian region, extending from New England to Alabama, includes one of the most extensive regions of karst in the United States. It is a complex geologic terrain and has been studied for nearly 250 years. The history of karst study in the region is organized into eight frames of time: (1) Early American Notes and Records, (2) Age of Curiosity, (3) Exploration and Early Tourism, (4) Birth of Modern U.S. Speleology, (5) Landmark Speleogenetic Studies, (6) Organized Caving and Science, (7) Speleological Inflation, and (8) Applied and Environmental Science. Karst science has progressed from merely descriptive accounts to detailed scientific study. The beginnings of cave exploration, cave tourism, and development of organized speleology is rooted in this region. Environmental issues regarding karst in the Appalachians have intensified in recent decades, making the understanding of karst processes and historic perspective much more important.

Factors affecting karst spring turbidity in eastern Washington County, Maryland

David K. Brezinski, Maryland Geological Survey
Johanna Gemperline, Maryland Geological Survey
Rebecca Kavage Adams
David W. Bolton, Maryland Geological Survey

Infrequent and episodic turbidity events within the karst spring at the Albert Powell Trout Hatchery in Maryland's eastern Great Valley threatened late winter fry populations. Turbidity events in early winter 2016-2017 prompted detailed geologic, dye tracing, and resistivity studies. The hatchery spring lies at the juncture of a northeast trending thrust fault and a northwest trending cross strike fault. Dye tracing study along these structures produced mixed results. Fluorescein tracing, injected 1,500 m north, and upstream of the spring was used to test the conductivity along the Beaver Creek fault and Beaver Creek. This dye was not conclusively identified at any of the surrounding recovery sites. Rhodamine WT injected more than a kilometer northwest of the spring, and along the trend of the cross fault, was detected at both the hatchery spring and surrounding recovery sites after about one week. 2D resistivity studies attempting to identify subsurface voids along the cross-fault trend show a high resistivity anomaly possibly indicating an air-filled void and warrant further investigation. The study suggests that while faulting plays a role in direction of ground water movement, turbidity events appear to be most prone during periods of lowered flow.

Patterns of heterogeneity within phreatic karst aquifers of the Great Valley, Virginia and West Virginia: evidence from time series hydrologic monitoring, groundwater chemistry, and stygobite site occupancy

Wil Orndorff, VA Dept. of Conservation and Recreation
Daniel H. Doctor, U.S. Geological Survey
Thomas E. Malabad, VA Dept. of Conservation and Recreation
Katarina Kosič, VA Dept. of Conservation and Recreation
Zenah W. Orndorff, Virginia Tech
Andrea Futrell

Phreatic karst waters in the Central Appalachian Great Valley are the subject of an ongoing habitat monitoring project across the geographic range of the federally threatened Madison Cave Isopod (MCI, *Antrolana lira*), a stygobitic crustacean previously documented at each monitoring site. Eight caves and five wells were monitored, via instrumentation, hourly from June, 2016 thru October, 2017 for water level (WL), temperature (T), and specific conductivity (Cs.) Sites were

visited quarterly to download data, collect water samples, and deploy baited traps to assess occupancy by stygobitic fauna. Samples were analyzed for major ions, inorganic carbon, and stable water isotopes. Precipitation data from National Climate Data Center stations were used to evaluate response to precipitation events. There is significant variation between sites in water chemistry, in baseline WL, Cs, and T values, and in the response of these parameters to precipitation. Median temperatures varied from 11.6 to 13.8 °C, with ranges within sites of 0.7 to 15.5 °C. Median Cs values varied from 442 to 726 uS/cm at 25 °C, with ranges within sites of 16 to 573 uS/cm. Ranges of WL within sites varied from 0.9 to 9.6 m. Ten sites exhibited rapid WL increases following precipitation, accompanied by spikes and/or dips in Cs. Six of these sites exhibited significant T changes. Sites with negative Cs response typically exhibited T changes reflecting precipitation temperature, with several exhibiting a compound response to larger events. Samples analyzed as calcium-magnesium-bicarbonate type waters, with Ca:Mg ratios from 9 to 5.5:1 and Ca + Mg values from 1.8 to 4.1 mmol/l. Geochemical parameters grouped more by site than by season. Chloride, nitrate, sulfate and sodium levels at some sites suggest significant land use influence from agricultural and stormwater management practices. Average $\delta^2\text{H}$ and $\delta^{18}\text{O}$ compositions suggest winter-dominated (Nov-April) recharge. Over the course of the study, site occupancy of these known MCI sites ranged from 0 to 100%, both for MCI and other stygobitic invertebrates. Occupancy rates appeared unrelated to geochemical or hydrodynamic patterns. Data are consistent with a complex, compartmentalized phreatic aquifer, reflecting the folded, faulted, and fractured bedrock structure. Water levels determine inter-compartment connectivity, facilitating episodic migration of stygobitic species. Characterization of such a system to support groundwater and habitat management decisions would require a much higher spatial density of monitoring stations than presently exists in the Great Valley.

Cold-air trap temperature records support simple high-density air-flow mechanisms at an Appalachian limestone cave entrance sinkhole

J. Steven Kite, West Virginia University
John Tudek, West Virginia University

Many Appalachian caves act as cold-air traps, widely open systems chilled by high-density cold air during chilly weather that evolve into density-stratified, nearly closed systems in warm weather. Like algific talus slopes, rock cities, and other cold-air traps in the region, these caves appear to function in accordance with a simple natural refrigeration model popularized by Balch (1900), in which circulation is dominated by static, thermally stratified conditions intermittently

disrupted by sinking cold air. Crowder Cave, in Monroe County, West Virginia, hosts two separate cold-air traps in chambers contiguous to an entrance pit, a ~12,000 m³ sinkhole lined with 6 to 18 m high limestone cliffs. The sinkhole and both cave chambers appear poorly connected to surface or subsurface streams. Davies (1958) reported historical accounts of seasonal ice in the small room as late as July, but our ongoing hourly temperature monitoring indicates ice regularly has disappeared by late April in five of the last six years. The entrance pit functions as a relatively open cold-air trap system with a mean annual temperature of ~7°C, well below mean annual surface temperatures of ~10°C recorded at nearby weather stations. In summer, both cave chambers are virtually closed systems with very gradual increases (<0.1 to 0.2 °C/day) in temperature; neither experienced a temperature reading greater than 9.2°C during our monitoring. In stark contrast, both chambers commonly experience brief winter episodes of rapidly plunging (4 to 8 °C/day) temperatures, reaching as low as -13 to -15° C. Icicles, columns, frozen lenses, and other ice accumulations have been observed in the small ~350 m³ chamber at the northeast end of the cave, where mean temperature has been ~2.7° C. Ice stalagmites and various other ice forms have been seen on the floor of the large ~12,000 m³ chamber on the south end of the pit, where the mean temperature has been ~3.5° C. Entrance pit temperatures respond very quickly when atmospheric conditions are appreciably colder than pre-existing air in Crowder Cave; temperatures in the two adjacent chambers seldom lag more than 1-3 hours behind. Despite similar timing, the amplitude of temperature response in the large chamber is considerably less than the small chamber, presumably because of a 35-fold difference in chamber volume. The amplitude of temperature change decreases and mean temperature increases with distance from the mouth of the large chamber. More characteristic of typical cave conditions, temperatures near the end of a narrow 85 m long side passage varied little (9.8° to 10.6° C) during the last 4.5 years. Crowder Cave data show the interplay between density-driven cold air flow, karst topography, and cave geometry lead to wide variability in winter conditions that may give rise to very different bat hibernacula conditions in a single cave. The ecological significance of cold air traps associated with sinkholes may be profound, both as climate change indicators and for a potential role they may play in the course of the ongoing white-nose syndrome (*Pseudogymnoascus destructans*) epidemic. Conference Topic: Investigation, Monitoring, and Remediation in Karst

Investigating Vadose Zone Hydrology in a Karst Terrain through Hydrograph and Chemical Time Series of Cave Drips at Grand Caverns, Virginia

Joshua R. Benton, U.S. Geological Survey
Daniel H. Doctor, U.S. Geological Survey

Caves provide useful access points for sampling and monitoring of vadose groundwater to better understand the hydrologic conditions controlling the timing and magnitude of critical recharge events. In this study, two cave ceiling drips within a single room at Grand Caverns, Virginia have been monitored simultaneously for changes in drip rate, electrical conductivity, and geochemistry from February, 2014 to July, 2017. The results show distinctly different behavior in the discharge between the two drip sites. One site exhibits seasonal changes in flow rate while the other site has remained nearly constant at 0.018 L/h. The dynamic site has a lower flow regime during the summer, fall, and winter (0.004 L/h - 0.008 L/h) until precipitation or snow melt events in the early spring triggered a sudden increase in discharge up to 0.328 L/h. There is an apparent volumetric soil moisture threshold of approximately 30% that must be exceeded before there is a response in the drip rate within the cave. Both the peak discharge rate and duration of the annual recharge period depends upon what time of year it occurs, with larger recharge events beginning in February and March and smaller recharge events occurring as late as April and May. This higher flow regime continues until the summer when an increase in evapotranspiration on the surface creates a soil moisture deficit that corresponds to a drop in discharge within the cave. This moisture deficit is usually not fully recharged again until winter and early spring when surface precipitation continues and evapotranspiration is low. Stable oxygen and hydrogen isotopes of the drip water and of precipitation above the cave were measured as potential tracers for determining the seasonality of recharge to the cave drips. Despite there being large seasonal shifts in the isotopic composition of rain waters collected above the cave, the oxygen isotope composition for both drip sites have remained nearly equal and constant at -8.0 ± 0.1 permil. This value is similar to the cool-season amount-weighted average of precipitation collected at the surface, and thus supports the hypothesis of a cool-season recharge bias to the drips.

Geologic framework of karst aquifer systems in Alabama

Gheorghe M. Ponta, Geological Survey of Alabama

Extreme droughts in recent years have highlighted the need to enhance management and protection actions for the water resources of Alabama. The Groundwater Assessment Program

(GAP) of the Geological Survey of Alabama investigates the availability and quality of the states' groundwater resources working in cooperation with other state and federal agencies, local governments and water systems, industry, educational institutions, and citizens. Alabama is located in the humid region of the United States, with numerous karst features, such as caves, sinkholes (dolines), and springs occurring in carbonate (limestone and dolomite) rocks, which underlie about 25 percent of the state. In the Interior Low Plateaus (Western and central part), Appalachian Plateaus (Jackson County), and Valley and Ridge Physiographic Provinces, which are in the northern half of the state, carbonate rocks underlie many areas and groundwater is contained mainly in karstified aquifers with high secondary porosities. The southern half of the state is situated in the Coastal Plain physiographic province, where around 7.5 percent of the aquifers are located in carbonates rocks. All wells installed in carbonate rocks and karst springs obtain water from solution cavities in these strata or the regolith above them. These solution cavities are not uniformly distributed, making prediction of their occurrence extremely difficult. To better understand the geologic framework of karst aquifer systems in Alabama, a series of hydrogeological cross-sections were constructed depicting stratigraphy and aquifers in the area. The selection of cross-section lines and wells were based on their geographic location, with preference given to wells having a greater total depth and with supporting geophysical and sampling logs. These cross-sections were used to identify geologic structure, aquifers (depth and elevation) and their production intervals, and determine where deeper aquifers might be located. The economic future and quality of life for Alabamians, as well as sustainable ecosystem functions and services, are dependent upon the availability and protection of the state's water resources. Therefore, future water source development will require significant scientific research, substantial logistical planning, and infrastructure development to find and manage water sources.

Packer Testing and Borehole Geophysical Characterization of Observation Wells in a Vertically Integrated Karst Aquifer in Augusta County, Virginia.

Joel P. Maynard, Virginia Department of Environmental Quality
Brad White, Virginia Department of Environmental Quality

Geophysical borehole logging and zone-isolation packer testing at adjacent State Observation Wells (SOWs) in Augusta County, Virginia, indicate the presence of shallow and deep horizontal karst conduits that are hydraulically connected by a highly transmissive, vertical fracture network. Despite the presence of a downward open-hole hydraulic gradient, ambient- and pumping-induced water level responses were identical

during zone isolation tests in two conduit zones measured in SOW 70 and one conduit zone measured in an adjacent observation well (SOW 70A). Identical hydraulic responses between all 3 monitoring points is interpreted to be the result of a solution-enlarged, vertically oriented fracture network that is capable of muting measurable head differences during zone isolation tests. Results from multiple open-hole flow logging tests within SOW 70 have also shown distinct variations in vertical flow that correspond with seasonal groundwater recharge. The occurrence of these vertically oriented, highly transmissive fracture sets is thought to be coincident with folding within the Staunton-Pulaski thrust sheet, and could be an important mechanism for the vertical integration of distinct hydrologic features in similar structural settings. The series of tests on SOW 70 and SOW 70A has resulted in a better practical and conceptual understanding of the monitored karst aquifer near Staunton and demonstrates the utility in collecting multiple types of borehole geophysical data during different times of the year on karst wells.

Using Geophysics to Map Bedrock Faults, Dikes, and Surficial Geology in Relation to Karst Features in the Briery Branch Quadrangle, Rockingham County, Virginia

Brent B. Waters, Golder Associates Inc.
Daniel H. Doctor, U.S. Geological Survey
Joel P. Maynard, VA Department of Environmental Quality

Several faults have been identified in the Cambrian and Ordovician carbonate sequence in western Rockingham County, Virginia. These faults were recognized by mapping offsets between stratigraphic units in the hanging wall of the North Mountain fault system. Portions of these faults are associated with karst features, but are covered by alluvium and thick soil development in the floodplains of Dry River and Briery Branch; therefore, the position of the faults could not be located with accuracy through surface mapping alone. In an earlier study, ground penetrating radar (GPR) and audio-magnetotellurics (AMT) geophysical methods were used to locate the expression of these faults at depths greater than ~5m. Here, we employ electrical resistivity imaging (ERI), and borehole video to examine the influence the faulting may have on near-surface karst expression. These geophysical datasets also help in the identification of igneous dikes and karst features present in the subsurface, and shed light on how these structures may affect the local groundwater flow regime and karst development. The ERI surveys were useful in identifying the precise position of inferred bedrock faults, as well as karst features in the shallow subsurface. On the ERI profiles, the faults inferred through geologic mapping appear as sub-vertical low resistivity zones, indicating increased fracture porosity and

weathering along the fault surface. Enhanced fracturing in these zones was also observed in adjacent borehole video logs. Diabase dikes appear as sub-vertical high resistivity features, and were verified at the surface through outcrop observation. Sinkholes and other karst features were also identified in the ERI profiles, generally expressed as low-resistivity anomalies. A pseudo-3D ERI survey was completed over a closed depression in highly weathered alluvium overlying limestone bedrock that clearly images the outline of the depression in the subsurface, as well as a possible water or mud-filled solutional conduit. The surface expression of the depression was approximately 165 ft (50 m) in diameter, while the low-resistivity anomaly was 15 to 50 ft (5 to 15 m) wide and appeared at depth of 15 to 80 ft (5 to 25 m).

Investigating Subsurface Void Spaces and Groundwater in Cave Hill Karst Using Resistivity

Jacob A. Gochenour, James Madison University
R Shane McGary, James Madison University
Gregory J. Gosselin, James Madison University
Ben S. Suranovic, James Madison University

Grand Caverns Natural National Landmark lies in the southeastern Shenandoah Valley and is home to the oldest show cave in the United States. The park and adjacent private lands include a complex of five known caves: Grand Caverns, Madison Cave, Steger's Fissure, Jefferson Cave, and Fountain Cave, all encompassed within the northern section of Cave Hill. The cave complex lies below a series of sinkholes that run in two approximately north to south parallel lines. One sinkhole, the site of a U.S. Geological Survey study, was selected as a location of interest due to the possible existence of a perched aquifer between it and Grand Caverns below. The southern section of Cave Hill lacks sinkholes and large known caverns, although a few smaller caves exist in the area. The southern section does contain a large karstic swale feature, which we selected as a second location of interest to look for unknown void spaces associated with groundwater. Understanding groundwater distribution can give insight into the relationship between the geomorphologic karst features at the surface and the caves below. We conducted an electrical resistivity survey to investigate the spatial relationship between groundwater and karstic features at both locations. Electrical resistivity is useful in karst because we can generate a model of resistivity distribution in the subsurface that allows us to identify groundwater and void spaces based on the conductive nature of water and the high resistance of air filled voids. A total of ten resistivity lines, consisting of 14, 28, and 56 -electrodes spaced 6.25 m apart, were deployed in and/or around the features at both locations. Both dipole-dipole and Schlumberger arrays were collected during each deployment; these arrays were then merged and inverted using AGI EarthImager 2D-Inversion

Software. Inverted resistivity sections were correlated to geologic cross-sections, high resolution airborne-derived LiDAR digital elevation models, known surface features, and cave depth survey data. By using the different data types, we were able to correlate many of the features present in the resistivity sections. The results indicate that bedding geometry and rock type are the dominate factors that define groundwater distribution and type of karstic features found within Cave Hill. In the northern section, the images showed several perched aquifers, two of which were dry, situated above the Grand Caverns and correlated with individual sinkholes. We also imaged the water table approximately 61 meters below the surface. The images correlated to the digital elevation model and cross-sections suggests that the sinkholes formed along a calcareous arenite confining ridge to the east which blocks the northwest flow of surface water off Cave Hill. In the southern section, the resistivity sections suggest that groundwater flows along bedding planes with trend of an antiform fold axis which is situated approximately parallel to and beneath the swale feature. The images also show that long and narrow void spaces exist beneath the areas of groundwater saturation on the flanks and within the swale. These void spaces appear larger in areas where water enters beneath the swale and in areas where the swale diverges course.

Thursday, April 5th 1:00 pm - 3:50 pm Formation of Karst and Sinkholes (Eric Peterson & Douglas Aden)

Role of floods on sinkhole occurrence in covered karst terrains: Case study of the Orléans area (France) during the 2016 meteorological event and perspectives for other karst environments.

Gildas Noury, BRGM
Jérôme Perrin, BRGM
Li-Hua Luu, IRSTEA
Pierre Philippe, IRSTEA
Sébastien Gourdier, BRGM

The Loire River basin is regularly impacted by sinkholes because of its specific geological context, karstic limestone

overlain by soft cover deposits. The intense rainfall event and the associated floods that occurred in this area in May and June 2016 triggered tens of sinkholes in a few square kilometers. At least 20 houses, one flood protection dyke of the Loire River and two highways were damaged by collapses. These events highlight not only the vulnerability of the area, especially in the case of a disastrous flood of the Loire River, but also the unexpected kinetics of the collapse process. Two different types of sinkholes occurred in the impacted areas: north of Orléans, collapses of the filling of vertical caves are suspected; in the Loire valley, the flood accelerated the internal erosion of alluvium in the karstic active network, triggering cover collapses (spatial and temporal sinkhole frequency increased by an estimated factor of 16,000 to 24,000). In parallel, an innovative internal erosion numerical modeling approach, based on Discrete Element - DEM and Lattice Boltzmann methods - LBM, has been developed through a partnership between the French Geological Survey (BRGM) and the Environment and Agriculture National Research Institute (IRSTEA). The upward propagation of cavities within the cover were successfully simulated. The role of different parameters (soft cover cohesion, hydraulic head, system geometry, etc.) in the sinkhole occurrence were tested by a parametric analysis.

Quantitative Comparison of Sinkhole Geomorphology of Four Karst Regions in Ohio

Douglas Aden, Ohio Department of Natural Resources, Division of Geological Survey

The Ohio Geological Survey has mapped karst in Ohio since 2009. Field mapping of sinkholes has suggested that geomorphological parameters vary between the Bellevue, Delaware, Hillsboro, and Springfield karst regions. Statistical tests confirm that these parameters distinguish the four regions. An understanding of how they differ and what causes those differences can be used to better manage these karst features. Differences between sinkholes within each region were quantified using nine parameters derived from digital elevation model (DEM) analysis. These parameters included: depth, perimeter, area, volume, length of major and minor axes, eccentricity, circularity index, and orientation of karst features. Of these parameters, orientation was displayed on rose diagrams and the others were graphed on boxplots. The Conover-Iman (CI) test was used to determine if parameters were statistically distinct ($\alpha=0.05$) between karst regions. Bellevue has the largest sinkholes in the state and differs statistically from other regions by perimeter, area, volume, major axis, and minor axis. Delaware has the deepest sinkholes, and depth is statistically distinct from all other regions except Springfield. Springfield has the smallest number of sinkholes, and no parameter distinguishes Springfield from all other regions. Hillsboro has the smallest mean sinkhole size, but the

most sinkholes. Sinkholes in Hillsboro are also statistically more circular than other regions as shown by eccentricity, and circularity index. Three of the four karst regions show alignment with structural lineaments. The exception is the Hillsboro region, where sinkholes are very circular and exhibit no preferred orientation. Variations in sinkhole size, shape, and distribution are influenced by multiple factors. For example, dissolution in the four regions is influenced by bedrock type, with increasing solubility from dolomite to limestone to evaporites. Sinkholes in Bellevue may be highly developed because Bellevue is underlain by evaporites. Bellevue also experienced multiple events that likely lead to increased bedrock fracturing and water availability from melting ice. Conversely, most of Hillsboro was glaciated only once and has less-developed sinkholes. Unlike other regions, Bellevue was affected by ancient lakes as well. Large sinks in Bellevue indicate higher dissolution activity and sinkholes that have merged, while small circular sinkholes in Hillsboro are less active and not developed enough to merge and become irregular. Improved knowledge of the differences between these regions will assist in mitigating and avoiding these geologic hazards

Assessment of Karstification Degree in the Copacabana Group for a Tailings Dam Foundation, South Andes, Peru

Valeria Ramirez, Knight Piésold Consultores S.A., Lima, Peru
Olimpio Angeles, Knight Piésold Consultores S.A., Lima, Peru
Michael W. West, Wiss, Janney, Elstner Associates, Inc., Lakewood, Co, USA

The world-wide occurrence of carbonate rocks is extensive, and Peru is no exception. Many mining facilities are located in or on carbonate rocks. Under specific conditions, carbonate rocks show varying degrees of karstification, which represent a potential high risk of damage or failure to mine facilities, especially tailings and water impoundments due to subsidence or internal erosion problems. Adequate engineering measures, including proper characterization of the foundation materials, should be taken to characterize foundation materials and mitigate the risk. This paper presents the assessment of the potential of karst dissolution in the Copacabana Group underlying about 50% the foundation of a proposed tailings dam and storage facility, located in the South Andes of Peru. A thorough geotechnical site investigation program was carried out in the area, which included regional and local geological mapping, geotechnical drilling, test pits, permeability tests, effervescence test in cores, petrographic analyses, and X-Ray diffraction tests. Hydrogeological studies, such as pumping and tracer tests, were also performed by other consultants to verify the observations, conclusions, and opinions developed from the geotechnical investigation program. The results of the

geotechnical investigation allowed proper characterization of the dam foundation and the tailings storage facility and estimation of the degree of karstification in the carbonate rocks of the Copacabana Group. The completed geological site characterization was then used to locate the tailings dam and impoundment area to avoid areas of pervasive karst and to implement defensive engineering measures, including grout curtains and slush grouting of smaller cavities and joints, among others.

Lithology as an erosional control on the Cave Branch and Horn Hollow fluviokarst watersheds in Carter County, Kentucky

Andrew Francis, Illinois State University
Eric Wade Peterson, Illinois State University
Toby Dogwiler, Missouri State University – Springfield

Cover-collapse sinkholes pose a major geohazard occurring in mantled karst regions in the south of China in recent years. Cover deposits generally mask the subsurface development and propagation of the deformation to the topographic surface. Human security and land-use planning in sinkhole-prone areas need to be preceded by detailed investigations focused on the identification of pre-existing sinkholes, subsurface dissolution, subsidence features and groundwater condition. The abnormal early hidden danger signs (ground, underground and hydrodynamic) of karst collapse are studied. Further, the corresponding identification techniques and methods are presented, such as surface surveying techniques (satellite remote sensing, the drone, etc.), underground detection technology (ground penetrating radar, microgravity, micro tremor, etc.), and monitoring of groundwater conditions. Finally, all kinds of techniques and methods can be combined to form a comprehensive system for identifying hidden dangers of karst collapse. This paper aims at identifying the early hidden dangers of karst collapse geological disasters. This has important theoretical, technical and social significance in order to minimize the impact of disasters on the people and the environment.

Comprehensive investigation and remediation of concealed karst collapse columns in Renlou Coal Mine, China

Shuning Dong, Xi'an Research Institute of China Coal Technology & Engineering Group Corp.

Hao Wang, Xi'an Research Institute of China Coal Technology & Engineering Group Corp.

Wanfang Zhou, ERT, Inc.

Coal mining in China has exposed numerous karst collapse columns of tens of meters in diameter and hundreds of meters in height. Hydraulically conductive collapses have functioned as groundwater pathways between the underground workings and the aquifers, resulting in water inrushes during coal mining. Over the last 40 years, water inrushes through these collapses have caused fatalities, economic losses, and degradation in the environment. Two such collapse features were unexpectedly encountered during operations in Renlou Coal Mine of China. The first encounter caused flooding of the entire mine. Although no serious damages occurred at the second encounter, because of timely and effective grouting measures, the production rate was reduced. Proactive detection of any concealed karst collapses and determination of their hydrogeological characteristics were essential components of a comprehensive investigation program in preventing water inrush incidents and ensuring normal coal production in the mine. The investigation program included surface and underground geophysical surveys with five geophysical techniques and directional drilling of three exploratory boreholes at completion depths ranging from 902 to 986 m. A new collapse feature was identified through systematic analysis of the data collected in the investigation program. Although the bottom of the collapse feature has not been determined, its total height is more than 135 m. The roof was at approximately 785 m depth, and there was an open void 1.5 - 2 m high at the top. Geotechnical properties, results from packer testing and tracer testing, monitoring of potentiometric pressures, and geochemical fingerprinting suggested that this collapse column was hydraulically conductive and still actively developing. Water in the confined thin-bedded limestone and Ordovician limestone aquifer that either overlies or underlies coal seams could flow into the mining areas if this feature were not identified in advance but encountered during mining. A grouting program was designed and implemented to construct a water plug in the collapse that effectively cut off the hydraulic connections from the aquifers to underground workings. Successful construction of the water plug in the collapse was confirmed by water intake tests in the grouting holes, water flow measurements in the mining area, and groundwater level monitoring in the aquifer.

The Extreme Karstification of the Kinta Valley, West Malaysia

Ros Fatimah Muhammad, Department of Geology, University Malaya

Surface limestone makes up only about 7% of the whole karst area; the greater subsurface area lies beneath thick alluvial sediments. The depth of the subsurface varies from 9 m to more than 60 m, and shows various topographies from platforms with flat concordant tops to jagged sharp pinnacles with rounded tops. The ratio of surface to subsurface karst can be used as an indication of the intensity of dissolution that occurs and of advanced degradation. Based on its association with tin-rich alluvium, it is believed that the karst in this area developed mostly under a pluvial environment and the humid tropical conditions since the Tertiary.

Thursday, April 5th 3:50 pm – 5:35 pm Karst Geophysics Session I (Charlotte Krawczyk & Lewis Land)

Sinkhole imaging and identification of fractures with SH-wave reflection seismic

Sonja H. Wadas, Leibniz Institute for Applied Geophysics
Saskia Tschache, Leibniz Institute for Applied Geophysics
Ulrich Polom, Leibniz Institute for Applied Geophysics
Charlotte M. Krawczyk, GFZ German Research Centre for Geosciences

Subrosion can result in depressions and sinkholes, which are a geohazard. To improve the knowledge of subrosion processes, high-resolution geophysical imaging and a detailed characterization of subsurface structures are required. One of the main subrosion areas in Germany is along the Kyffhäuser-Southern-Margin-Fault (KSMF) in Thuringia. Two shear wave (SH) reflection seismic profiles of 300 m length in total were carried out along two sinkholes. The near-surface down to ca. 100 m depth was imaged with a resolution of less than 1 m down to 15 m depth and a resolution of 1 m to 3 m at 50 m depth. The internal structures of the leached anhydrite and

gypsum were imaged. The reflection patterns indicate a heterogeneous near-surface geology around the sinkholes, with mainly lateral and vertical variations of discontinuous reflectors and small-scale fractures, which are necessary for percolation of meteoric water and sinkhole development, especially in areas with a deep groundwater table and no faults. This is the case for one of the two sinkholes. The other is located at a fault with a shallow groundwater table at 37 m depth. The sinkhole margins are characterized by reflectors, which dip towards the focal points of the sinkholes. Previous sinkholes probably generated fractures, which act as additional fluid pathways. As a result, a collapse can be triggered more easily. Indicators for continued collapse are observed in the profile of the fracture-induced sinkhole by the continued migration of focal points of consecutive collapse events over time.

Joint project SIMULTAN - Sinkhole characterization and monitoring with supplementing geophysical methods

Charlotte M. Krawczyk, GFZ German Research Centre for Geosciences
SIMULTAN Research Group

The joint project SIMULTAN (Sinkhole Instability: integrated MULTi-scale monitoring and ANalysis) develops and applies an early recognition system of sinkhole instability, unrest and collapse in Germany. The research approach combines structural, geodetic, geophysical, petrophysical, and hydrogeological mapping methods, accompanied by sensor development, multi-scale monitoring, modelling, and an information platform. Two focus areas are investigated in Germany, for which sinkhole unrest has been identified. The surveyed areas are representative of evaporitic sinkhole formation, and are highly relevant since located in densely populated areas. Shear-wave reflection seismics enables high-resolution structural imaging of critical zones, while additional vertical seismic profiling (VSP) provides hints on subsurface zones by velocity analyses. Spatial detection thresholds for microseismic events were calculated using a combination of synthetic event signals and noise recorded in the field. Improvements of the detection and localization capability due to additional borehole stations and surface mini-arrays were investigated. The potential to detect mass dislocations in the upper subsurface is proven by repeated gravimetry and levelling campaigns, that are supplemented by micro-gravimetry. How combined direct-push and SIP-monitoring will characterize sufficiently the soil-water-interaction in the upper 40 m is still in the testing phase, but stable inversion schemes are yielded. All these petrophysical parameters are fed into modelling and simulation studies that describe dissolution initiation and explain realistic collapse scenarios in the light of overburden strength. These shall support decision processes,

and the cooperation with geological surveys will advance the development of sinkhole instability recognition systems.

Remedial investigation of large scale karstic flow conduits with brine-enhanced resistivity imaging and downhole colloidal borescope methods

James Lolcama, KCF Groundwater, Inc.

Locating conduit-type permeability in karstified limestone and dolomite and measurement of flow velocity and flow direction are key requirements for remediation of groundwater contamination, and sealing of massive inflows to pits, quarries, and underground mines. The massive rates of water inflow to a mine can cause catastrophic flooding in days to weeks, requiring a rapid reconnaissance method that can locate deep karstic permeability in a shortened timeframe as compared to traditional geophysical and drilling methods. Off-site migration of groundwater contaminants can occur by conduit flow in days to weeks as compared to much longer timeframes for diffuse flow permeability, and remediation often requires rapid remedial planning, and strategic grouting of selected conduits to eliminate the major transport pathways. Resistivity profiling was used in conjunction with salt brine enhancement of the conduit flow to locate and image deep-lying karst flow conduit features using the Advanced Geosciences, Inc. (AGI) SuperSting R8 earth resistivity geophysical equipment. The equipment consists of the meter, external power supply, and 112 electrodes at 3 m spacings, for a surveyed length of 333 m (1,092 ft). Ambient resistivity conditions were measured throughout the surveyed area, and the average depth to karst bedrock was determined. Constant-rate injection of saturated NaCl brine solution into the flow conduit was commenced after the background survey was completed, and the conductivity of the conduit water was increased by roughly 10 times background. A second resistivity survey was conducted in which the resistivity readings above the top of bedrock were not collected to reduce the duration of data collection, and to reduce the brine volume requirement. The volume of saturated brine that is required is typically about 57,000 L (15,000 gallons) at a continuous pumping rate of 757 L/min (200 GPM). The 2-D models of subsurface resistivity from the pre-brine, and brine-enhanced surveys are subtracted to produce a conductive anomaly map. For a project site in Hagerstown, Washington County, Maryland, a 2-D anomaly of roughly -500 Ohm-m, with a cross-sectional area of about 1,860 m² (20,000 ft²), was detected. The total survey area was roughly 12X this size. The conductive anomaly was drilled with multiple boreholes, and conduit flow to a nearby mine was identified within weeks. The brine-enhanced 2-D electrical resistivity survey is believed to be the first application of its kind at this scale. The preliminary methodology and initial results from two case studies have been

presented in Lolcama and Stuby (2015). The colloidal borescope instrumentation by AquaVision utilizes natural colloidal particles which are suspended in the conduit flow past a video camera to determine groundwater flow velocity and direction. The system is capable of analyzing flow measurements every 4 seconds, and produces a very large dataset of several thousand particles tracked during an hour long test. The borescope can measure groundwater velocities from near zero up to 1.6 m/min (5 fpm). Testing of deep conduit flow that was encountered by drill holes was completed at a site in south-central Pennsylvania, which is different from the Hagerstown, MD site. Testing showed that the average direction of horizontal flow through the karst conduit features lies at about azimuth 64 degrees, or towards the east-north-east, with an average groundwater velocity of roughly 0.002 m/s (0.3 fpm), with occasional spikes in velocity to 0.01 m/s (1.7 fpm). The velocity is similar in magnitude to point dilution testing results for the same karstic flow field. The results were instrumental in achieving a better understanding of the locations of conduit flow features beneath the site, and the flow velocities and directions which were needed for remedial planning purposes.

Combination of 2d shear wave reflection seismics and travel time analysis of borehole geophone data for the investigation of a sinkhole area

Saskia Tschache, Leibniz Institute for Applied Geophysics
Sonja H. Wadas, Leibniz Institute for Applied Geophysics
Ulrich Polom, Leibniz Institute for Applied Geophysics
Charlotte M. Krawczyk, GFZ German Research Centre for Geosciences

In November 2010, a 30 m wide and 17 m deep sinkhole occurred in a residential area of Schmalkalden, Germany. Subsequent geoscientific investigations showed that the collapse was naturally caused by the dissolution of sulfates below 80 m depth. In 2012, the Thuringian State Institute for Environment and Geology (TLUG) established an early warning system including 3C borehole geophones deployed in 50 m depth around the backfilled sinkhole. During the acquisition of two shallow 2D shear wave seismic profiles in the vicinity of the sinkhole, the signals generated by a micro-vibrator at the surface were additionally recorded by the four borehole geophones of the early warning system and a vertical seismic profiling (VSP) probe in a fifth borehole. Travel time analysis of the direct P- and S-wave arrivals enhances the understanding of wave propagation in the area. Seismic velocity anomalies are detected and related to the structural seismic images of the 2D profiles. In case of travel paths perpendicular to faults, the velocity is decreased, whereas the velocity of waves travelling parallel to the strike direction of faults is not significantly lowered. The combination of receivers located at

the surface recording reflected seismic waves and distributed downhole receivers recording direct waves, enables analyzing of seismic wave propagation and velocities in more detail and beyond 2D. Therefore, the experiment setup will be further extended in future. The presented method shows the potential to locate instable zones in a sinkhole area. In our further research we propose to evaluate the suitability of the method for the time lapse monitoring of changes in the seismic wave propagation, which could be related to subsrosion processes.

Imaging of deep sinkholes using the multi-electrode resistivity implant technique (MERIT) case studies in Florida

David Harro, The G3 Group and Henok Kiflu, Dept. of Geology, University of South Florida

Surface geophysical methods have been extensively utilized for sinkhole investigations. While surface geophysical methods can penetrate to depth where sinkhole development occurs the resolution is typically poor. A detailed understanding of deep raveling zones into sinkhole throat through a new and novel geophysical technique was developed by the authors. The authors performed over 750 sinkhole investigations on residential properties over a five year period of time, in each case geophysical methods of Ground Penetrating Radar (GPR) or Electrical Resistivity (ER) were performed. Over 1500 confirmatory Standard Penetration Test (SPT) drillings were performed of the geophysical anomalies. In a very large percentage of the geophysical surveys performed, the location, size and depth of the raveling zones into the sinkhole throat could be clearly identified. The authors developed a novel geophysical technique called The Multi-Electrode Resistivity Implant (MERIT) to address the need to image deeper into karst formations to help identify the location of deep raveling zones and sinkhole throats. The purpose of this paper is to present case studies of the application of MERIT technology. Three case studies are presented in this paper. The first case study focuses on the first application of MERIT at the Bordeaux Village in Tampa, Florida where a sinkhole swallowed a car in 2010. The MERIT survey was able to image the car in the sinkhole throat. This case study demonstrates the ability of the MERIT technique to identify the location of the sinkhole throat by identifying the depth and location of the car, a large conductive ER anomaly. The second case study focuses on a pipeline in Orlando, Florida being threatened by sinkhole development on the adjacent property. MERIT was able to identify size and depth of raveling of soils into the sinkhole throat near the pipeline. The results of the MERIT image were critical in engineering design to address the treatment to the pipeline. In the third case study MERIT technology was applied to a proposed roadway through an extensive karst region of Lake County, Florida. Initial geotechnical investigation indicated a

potentially large and deep sinkhole feature. MERIT was able to provide a concise geologic structure including the identification of the locations sinkhole throat at 52m deep. MERIT has been shown to identify details of the complex geology and geometry of karst formations. In particular the techniques ability to provide improved image capabilities of the raveling zone and sinkhole throats has significant engineering applications for assessment, risk analysis, and remediation of sinkholes.

Friday, April 6th

8:10 am - 8:50 am

**Karst Geophysics Session II
(Charlotte Krawczyk & Lewis Land)**

Avoiding caverns in the Arbuckle Mountains using electrical imaging methods

Peter Hutchinson, THG Geophysics, Ltd.

The Arbuckle Mountains in Oklahoma are a unique province with nearly vertical dipping beds of the Upper Cambrian to Lower Ordovician Arbuckle Group. The Arbuckle Group consists of intercalated sequences of thick carbonates and thinner shales and sandstones. Syn-Pennsylvanian mountain building steeply tilted these beds. Subsequently, caves and voids developed within the carbonate beds, presumably by hypogene speleogenesis. Numerous dissolution cavities and several major cave systems have been mapped within the Arbuckle Mountain Wind Farm located 19 km north of Ardmore, Oklahoma. Electrical resistivity imaging was determined to be the most effective method of mapping subsurface voids and caverns due to the strong electrical contrast between carbonate units and void-filling sediments and groundwater. Electrical resistivity imaging during early stages of the wind farm development identified numerous caverns and voids beneath proposed turbine sites; consequently, several wind tower locations were moved. This report addresses the East Access Road to six proposed turbine wind tower sites where three towers and access road near the towers were relocated south of their original proposed locations. Further, the Main Access Road to these six tower sites had to be rerouted due to the presence of two previously unidentified sinkholes and a major cavern system, the Wild Woman Cave Complex. Electrical imaging method identified subsurface anomalies along the proposed access roads and at four of the six towers. The towers were moved away from the subsurface anomalies

and the access roads were relocated to positions where subsurface anomalies would not pose a hazard to the heavy crawler cranes, used to erect the towers. The 50-tower Anadarko Mountain Wind Farm was successfully completed in 2016.

Sinkholes as transportation and infrastructure geohazards in mixed evaporite-siliciclastic bedrock, lower Pecos Region, southeastern New Mexico

Lewis Land, NCKRI

Colin Cikoski, NM Bureau of Geology and Mineral Resources
George Veni, NCKRI

Personnel with the National Cave and Karst Research Institute (NCKRI) and the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) have conducted an assessment of karst geohazards southeast of Carlsbad, NM. The highway 285 corridor in this area is subject to high levels of oilfield traffic, and is particularly prone to sinkholes because of the presence of gypsum bedrock of the Rustler Formation at or near the surface throughout much of the study area. These features pose a geohazard for the transportation and pipeline network in this part of the state. The geotechnical properties of the Rustler Formation are influenced by soluble gypsum strata interbedded with mechanically weak mudstone and siltstone and more rigid dolomite beds. Surface geologic mapping and near-surface electrical resistivity (ER) surveys indicate that most sinkholes formed in the Rustler are relatively shallow (<3>m), without deep roots, probably due to the mixed lithology of soluble and insoluble bedrock. However, longer-array ER surveys have identified additional cavities at greater depths in some areas that do not breach the surface.

Friday, April 6th

8:55 am - 11:50 am

Geotechnical and Modeling Investigations in Karst

(Joe Fischer & Pierre-Yves Jeannin)

Remediation of the Centenary College president's house

Joseph A. Fischer, Geoscience Services
Joseph Jeffrey Fischer, Geoscience Services
Justin Terry, Compaction Grouting Services, Inc.

A week after the New Year 2015, a fire started in the over 125-year-old President's House at Centenary College, Hackettstown, New Jersey. Large quantities of water were used to put out the fire on that freezing night. As a result, a roughly 22-foot diameter sinkhole opened near the back door, causing a fireman to fall into the collapse. Subsequently, approximately 1½ to 2 cubic yards of pumpable, flowable fill was placed into the sinkhole throat. The house was a loss and demolished in the late spring of 2016, leaving the foundation in place. During long delays resulting from local zoning laws being somewhat different than they were in 1910 (when the house was moved to its present location), another sinkhole opened below the rear foundation wall and basement floor slab. Approval was granted to build a similar structure within the existing footprint of the historic home and the old foundation was removed in April 2016. To support the new structure in an area known for sinkhole formation, an exploratory grouting program was employed. 45 probe holes were drilled and grouted with 88.4 cubic yards of site-mixed, fluid grout. The subsurface conditions were erratic and difficult to model as the voids encountered were not large in size, nor very linear, but appeared to extend for distances beyond the house footprint. The new structure was completed in 2016.

Case Histories: Karst Successes and Failures in the Eastern United States

Walter G. Kutschke, DiGioia Gray & Associates

A basic understanding of karst development and sinkhole formation is that water drives everything in karst. Design efforts need to consider this basic karst principle before undertaking any meaningful design. Another aspect of karst often overlooked by engineers is that sinkholes are direct input points where surface water can access the karst aquifer and impact water quality and hibernacula of caving dwelling species. Site characterization activities in karst typically only involve test borings and geophysical methods. These methods provide a valuable snap-shot in time of subsurface conditions, which is important, but they provide no insight into groundwater fluctuations. Case histories involving roadway, pipeline and building projects demonstrate the successes and failures of geotechnical engineering over karst. Several case histories indicate the detrimental impact of altering subsurface water conditions which can result in increased subsurface erosion and new sinkhole development. Case histories also underscore the importance of controlling surface water and when not properly considered the result can be sudden and catastrophic sinkhole development. Experience gained from new and forensic karst projects located along the eastern United States with aggregate construction costs approaching \$1 billion all had a common theme; understand and control surface and subsurface water.

Linking Geology and Geotechnical Engineering in Karst: The Qatar Geologic Mapping Project

Randall C. Orndorff, U.S. Geological Survey
Michael A. Knight, Gannett Fleming, Inc.
Joseph T. Krupansky, Gannett Fleming, Inc.
Khaled M. Al-Akhras, Qatar Ministry of Municipality and Environment

During a time of expanding population and aging urban infrastructure, it is critical to have accurate geotechnical and geological information to enable adequate design and make appropriate provisions for construction. This is especially important in karst terrains that are prone to sinkhole hazards and groundwater quantity and quality issues. The State of Qatar in the Middle East, a country underlain by carbonate and evaporite rocks and having abundant karst features, has recognized the significance of reliable and accurate geological and geotechnical information and has undertaken a project to develop a robust geotechnical relational database and prepare geologic and thematic digital maps. These products will support planning, design, and decision-making processes related to urban infrastructure development in the rapidly growing State

and be particularly useful in the early stages of geotechnical investigations. The U.S. Geological Survey (USGS), Gannett Fleming, Inc., and the Qatar Ministry of Municipality and Environment (MME) have partnered to design a geologic mapping project that will merge geological and geotechnical information to develop a framework to model the geology, karst, and resources important to support growth in the State. The Qatar Geologic Mapping Project (QGMP) has a mission to integrate sound geoscience data for the State of Qatar to address societal, environmental and educational needs that include water and mineral resources management and natural hazards reduction.

Site selection of the world's largest radio telescope within the Dawodang karst depression

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The world's largest single-aperture radio telescope, the Five-hundred-meter Aperture Spherical radio Telescope (FAST), was constructed within an extremely large karst depression, Dawodang, in Pingtang, Guizhou, China. The FAST system will improve the sensitivity and extent of astronomical investigations in the near future. In June 1994, astronomers decided to construct the next generation and largest radio telescope. Many types of topographical depressions such as mine pits, volcanic craters, meteor craters, karst depressions, and extremely large sinkholes were considered during the site selection process. Considering the size, spherical shape, bearing capacities, and ease of drainage of karst depressions, extremely large karst depressions were targeted areas for the FAST system. After careful investigation and site characterizations of more than 1000 large karst depressions, the Dawodang karst depression was determined to be the ideal and unique site for the FAST observatory. Construction of the FAST started on March 25, 2011 and completed on September 25, 2016.

Development of a sinkhole raveling chart based on cone penetration test (CPT) data

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Boo Hyun Nam, University of Central Florida
David Horhota, Florida Department of Transportation

Naturally occurring sinkholes in Florida are formed when the

soluble limestone bedrock weathers and creates cavities at its interface with the overburden finer-grained soils. The overburden soil then erodes into the limestone fissures, thus weakening the strength and holding capacity of the soil above. This initial stage of a sinkhole is referred to as soil raveling and is considered to be the most effective time to perform soil improvements measures, such as grouting, to mitigate further expansion of the subterranean void. Geotechnical engineers and scientists use subsurface exploration techniques such as Cone Penetration Testing (CPT) to stratify soils and estimate soil properties. This paper presents a CPT-based raveling chart, to be used in identifying raveled soils in Central Florida during initial subsurface exploration. The raveling-chart was developed by collecting a large sample of CPT data (i.e. cone tip resistance, q_c , and sleeve frictional resistance, f_s) from multiple sites within the same geological formation. CPT data was grouped within three categories: collapsed sinkholes, suspected raveling, and no 1n-raveled, and plotted using a scatter of data points with coordinates (f_s , Q_{tn}); that is sleeve friction resistance, and normalized tip resistance. A simple statistical analysis was applied for the resulting data group to create envelopes, or threshold lines, which bound the data to create certain categories. The resulting chart provides quantifiable measure of sinkhole raveling due to soil erosion.

Physical and numerical analysis on the mechanical behavior of cover-collapse sinkholes in central Florida

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Adam Perez, University of Central Florida
Boo Hyun Nam, University of Central Florida
Ming Ye, Florida State University

The behavior of cover-collapse sinkholes in Central Florida was investigated in this research by both physical and numerical methods. In the physical model, a head drop between the unconfined aquifer and the confined aquifer was applied, and the cavity propagation due to a fracture at the boundary between the two aquifers was visually monitored. The cavity grew upwards in an inverted triangle shape until ground surface collapse occurred. The same cavity shape was then incorporated into the numerical study. A stress-seepage coupled analysis was carried out using GeoStudio modules: SEEP/W and SIGMA/W, simultaneously. The stress conditions during sinkhole formation were assessed at different groundwater conditions and cavity sizes. Stress redistributions were observed around the cavity due to soil arching. The effective stress significantly increases at the corners of the cavity to compensate for a stress reduction above the center of the cavity. Highest recharge values and seepage forces occur around the cavity corners. The stress paths at the corners show that the stability decreases when the cavity height increases, even when the overburden thickness

decreases. Additionally, the side angles of the cavity affect the stress conditions around it.

A way to predict natural hazards in karst

Pierre-Yves Jeannin, Swiss Inst. for Speleology and Karst Studies

Arnauld Malard, Swiss Inst. for Speleology and Karst Studies

Flooding, ground collapses, subsidence and contamination are hazards often encountered in a karst environment. All are strongly associated to water. A good knowledge of the distribution of groundwater potentiometric heads and fluxes in space and time is necessary to predict and prevent these hazards. A series of karst-specific approaches are being developed by SISKa (Swiss Institute for Speleology and Karst-Studies) in order to provide this type of information within a reasonable effort. Most of these are based on a key-approach (KARSYS) and could be successively applied to address issues in karst environment. Applications for flood and sinkhole hazards are presented. These approaches are organized in a "Karst toolbox" which is being developed first and mainly for karst in temperate and mountainous regions (as we have in central Europe). Adjustments and extensions for other contexts (e.g. lowland karst or hypogenic karst areas) could be developed.



Solutional conduits in the epikarst. Photo by Dan Doctor.

