austin geological society

bulletin

volume 1

2004-2005

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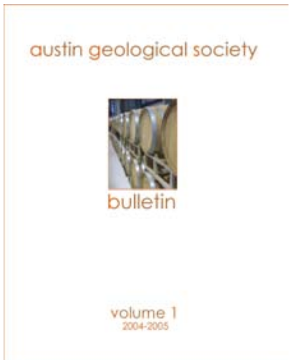

Photo on preceding page: Barrels of wine aging at Becker Vineyards east of Fredericksburg, one of the stops of the wine field trip (photo by Robert Mace).

note from the president

Welcome to the first edition of the Austin Geological Society Bulletin.

Every geologic society seeks to communicate with its members and the public with monthly newsletters, special publications, and email and websites. The AGS has our Newsletters, with meeting presentation abstracts and current activities, and our Field Trip Guidebooks. Last fall, AGS Vice-President Brian Hunt proposed that AGS publish a yearly technical journal of articles relating to Central Texas geology, with additional content regarding AGS activities such as meeting presentations, field trips, events, and awards. The AGS Executive Committee voted to begin work on the new Austin Geological Society Bulletin, and Dr. Robert Mace agreed to be its Editor.

Dr. Pete Rose had generously encouraged AGS to have him lead a repeat of the popular 1998 AGS and 2002 GCAGS Wine Trips before he became the busy current President of AAPG. On April 23, 2005, Pete and Dr. Chock Woodruff led participants on a wine-lovers trip through Central Texas geology, visiting three wineries and numerous outcrops. We thank Pete and Chock for leading this enjoyable trip. Many non-geologists attended, and we hope to repeat the wine trip soon. We think it could be a great way to appeal to the wine- and geology-loving public and raise funds for AGS.

The University of Texas Bureau of Economic Geology has provided a lot of manpower and resources to AGS. AGS Members from BEG provided leadership and labor for the GCAGS Conventions hosted by AGS. BEG also provides meeting space for most AGS meetings. As a token of our appreciation to BEG, we presented a beautiful mineral globe to Dr. Scott Tinker, BEG Director, at our November 2005 Meeting. We would not be the organization we are without their help, and we hope to continue the productive partnership we have enjoyed with BEG.

And for parties, we had a reprise of our AGS Fajita Party on October 30, 2004, at Dr. Robert Mace's home, and President-elect Al Cherepon hosted "Fossilized Geologist" informal meetings at several Austin eateries.

Many of our Members worked to produce the Bulletin. I particularly want to thank Dr. Robert Mace for the outstanding and copious work he has provided in producing the Bulletin as Editor. He accepted the task of creating the Bulletin, and the Bulletin might not have been produced without his dedicated involvement. Robert has performed the daunting work of creating a first version of editorial and formatting standards that we think will last for many future Bulletins. Brian Hunt, April Hoh, John Mikels, and Cindy Ridgeway provided essential editorial input as Associate Editors, planning and creating the Bulletin and collecting and reviewing articles and other submitted materials. Much thanks to Brian for his inspiration to create the Bulletin. And of course we are indebted to the many authors present here, and we thank them for their work, and their faith in what we think will be the first of important yearly contributions to Central Texas geological study.

We hope you enjoy this splendid document from the Members of the Austin Geological Society.

Craig Caldwell
2004–2005 AGS President

the austin geological society would like to thank the following sponsors:

note from the editor

Central Texas brims with geologic talent. We have the Jackson School of Geosciences at The University of Texas at Austin consisting of the Department of Geological Sciences, the Bureau of Economic Geology, and the Institute of Geophysics. We have Austin Community College, and Texas State University is just down the road. We have the state's natural resource agencies including the Texas Commission on Environmental Quality, the Texas Water Development Board, Texas Parks and Wildlife Department, the General Land Office, and the Railroad Commission. We have groundwater conservation districts, a river authority, and the central office for the U.S. Geological Survey in Texas. We have a number of environmental and petroleum consulting and service firms. We have part of the hill country and the culture that is attractive to recently retired geologists. Undoubtedly, all of these people, from the students to the professors to the professionals to the retirees, have something to say.

Our Vice President, Brian Hunt, recognized this and proposed that the Austin Geological Society produce a yearly bulletin—a home for the thoughts and ideas coursing through Austin's geologic community. Brian presented his idea to April Hoh, Cindy Ridgeway, John Mikels, and me over a perfectly cooked basket of fried okra (and a number of perfectly brewed beers) at Scholz's Biergarten in early December of 2004. We all agreed that Brian's idea was a great one. Excited by the potential—and weakened by two pints of Guinness—I agreed to be editor.

This first volume captures most of Brian's vision as amended by the Scholz committee and by the realities of putting something like this together for the first time. It includes a summary of the Society's year: the list of speakers and their abstracts or papers, a summary of the field trips, and news items of interest. It also includes technical papers submitted by Society members concerning local topics. The primary home for this journal is our Web page. This allows the journal to be easily accessed by the public and the research community. However, we will print a limited number of these journals so that they can be properly archived in various libraries. Dennis Trombatore at the Geology Library at The University of Texas has graciously agreed to help us get into GeoRef so our bulletin can be seen by the world's geologic community. No matter its media, we are certain that the journal will be useful to geologists and lift the status of the Society.

Putting together the first volume of the Society's bulletin has been an exciting and rewarding experience that required the dedicated efforts of a number of people. First and foremost, I want to thank the authors that agreed to extend abstracts and submit papers to the bulletin—I admire their bravery in donating their time and hard work to an unproven endeavor. Without them, this bulletin would not have been possible. I also want to thank the associate editors April Hoh, John Mikels, and Cindy Ridgeway and president Craig Caldwell for guidance and assistance in assembling the bulletin and Sarah Davidson for being a final reader. And last, but not least, I thank Brian Hunt, also an associate editor, for his vision on this project and his drive to make it a success. I continue to be impressed by what Brian is able to make possible. This bulletin has been a lot of work, but it has been worth it. Nevertheless, I'll have to be careful who I share okra and beer with in the future…

Robert E. Mace
Editor

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mission: The mission of the *Austin Geological Society Bulletin* is to (1) summarize the previous year's activities of the Society and (2) publish technical papers, comments, and notes concerning the natural sciences of Central Texas.

publication information: The *Austin Geological Society Bulletin* is published once a year in August and is available through the society's Web page (www.austingeosoc.org) and select geological libraries in Central Texas. The *Austin Geological Society Bulletin* is owned and published by the Austin Geological Society, P.O. Box 1302, Austin, Texas 78767-1302. There is no cost for digital access to the bulletin. Hard copies are available by print-on-demand.

information to authors: The Editor of the *Austin Geological Society Bulletin* invites contributions relating to the natural sciences of Central Texas in the form of technical papers and discussions. If you would like to submit to the bulletin, please see the instructions to authors at the end of this document. All submissions should be sent to the editor in digital format to editor@austingeosoc.org.

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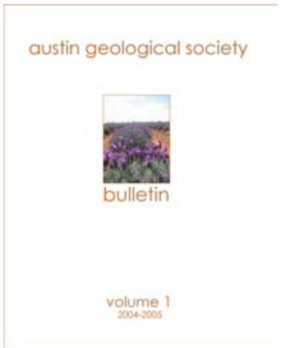

Cover photo: Lavender growing on soils of the Hill Country at Becker Vineyards east of Fredericksburg, one of the stops of the wine field trip (photo by Robert Mace).

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austin geological society

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Steve Ruppel—Bureau of Economic Geology

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Clark Thompson—The University of Texas at Austin

Student Liaison—Undergraduate:
vacant—The University of Texas at Austin
vacant—Austin Community College

Endowed Scholarship:
vacant

Education:
vacant

Awards:
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Officers 2005–2006

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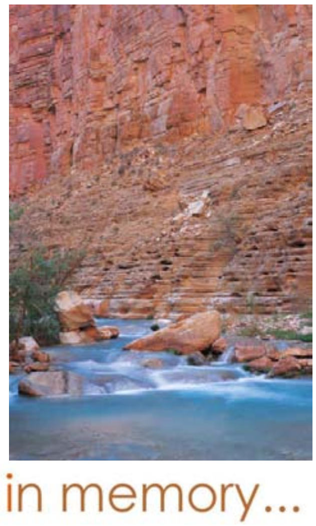


In memoriam—Keith Young

Longtime and renowned Austin geologist Keith P. Young, PhD died Friday, August 20, 2004, at the age of 86. He retired as Professor Emeritus in 1988 from the Department of Geological Sciences at The University of Texas at Austin after a 40-year career of teaching. He was a Mesozoic stratigrapher and paleontologist. Keith published numerous papers on ammonites and local Central Texas Cretaceous stratigraphy. He did geologic mapping of several U.S. Geological Society quadrangle sheets and published field trip guidebooks in the Central Texas area. Some of his field trip guidebooks were written for and published by the Austin Geological Society.

A Keith Preston Young Memorial (1918–2004)

Ann Molineux
The University of Texas at Austin, Texas Memorial Museum

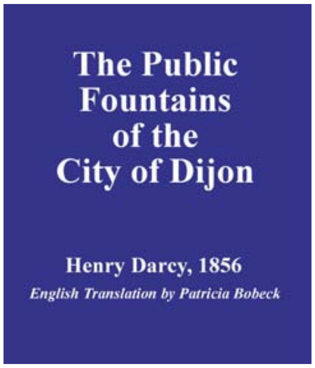
Keith Young's academic contribution to ammonite biostratigraphy is world renowned:

> *"With the death of Keith Young, we have lost the leading worker on the Cretaceous of the Gulf Coast region of his generation."*
>
> – J. Kennedy, Oxford University, United Kingdom, August 2004

He published over 100 papers and contributed to numerous symposia and field guides dealing with Mesozoic biostratigraphy. He supervised 50 graduate students, many who went on into geology related industry or academics. Keith was responsible for describing a significant number of the type specimens in our collection, and his contribution to these collections is enormous. In addition he found the time to teach numerous courses within the Department of Geological Sciences in The University of Texas at Austin.

Keith Young was the honoree at the Seventh International Congress on Rudists held in Austin in June 2005. Although his publication record on rudists was limited, his research interest—and that of many of his students—resulted in several theses and dissertations. He and his students amassed a large rudist collection (amounting to about 10,000 specimens) from field research throughout Texas and northern Mexico. This entire collection is now held as a taxonomic collection and is searchable via computer—eventually, as with other parts of the collection, to be available via the Web. Keith was fully aware of the importance of provenance data and the cataloguing of specimens for later reference. In contrast to many segments of our collections, we have an excellent catalogue for specimens that have passed through his care. He organized ten catalogue volumes and almost 90,000 records covering between one and two million specimens. Specimens that bear the *UT* or *WSA* acronym do so because of his diligence—a practice that was passed onto his students. That same rigorous research created an incredible 60,000-card reference index of ammonites and their suture patterns—a reference library that we shall try to make accessible to others in some Web format. My introduction to Keith Young was not as a student but as the 'keeper of non-vertebrates' at the Texas Memorial Museum. He was a most helpful and fascinating mentor. We retraced the lively history of geological research in Texas. Long hours were spent in his laboratory on the old 4^{th} (new 5^{th}) floor of geology and later in NPL as we sifted through the nuances of the collections and probed into the lives of the collectors. Each specimen seemed to have an intimate history and each collector an intriguing characteristic. Keith knew it all and was prepared to share his knowledge with a novice. Without his guidance I should certainly have floundered into these collections lacking those vital perspectives that Keith had developed through his love of geology, his sense of history, and his appreciation of literature. "The Keith and Ann Young Endowed Fund for the Curation of Non-vertebrate Collections" is a tangible tribute to the immense legacy that Keith Young has left in our trust.

news from the society



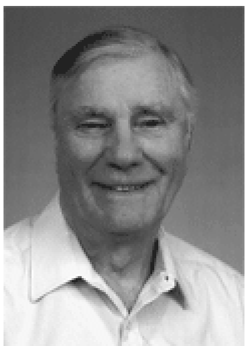
Bobeck awarded for Darcy book

Patricia Bobeck was awarded the S. Edmund Berger Prize for Excellence in Scientific and Technical Translation by the American Foundation for Translation and Interpretation for the English translation of Henry Darcy's *Public Fountains of the City of Dijon.* The award was presented at the American Translators Association 2004 annual conference in Toronto.

Patricia is past president, president-elect, and vice-president of the Austin Geological Society (1995–1998). She received master's degrees in geology and linguistics from the University of Texas and the University of Michigan, respectively, and a bachelor's degree in French from Rosary College (now Dominican University). For her master's thesis, *Igneous Petrology and Structural Geology of Nine Point Mesa, Brewster Country, Texas*, she mapped 40 square miles of the Chihuahuan desert. She has worked for the State of Texas as a geologist for 13 years. She translates French and Spanish into English, specializing in the earth sciences. Other books include the French to English translation of *1000 Photos of Minerals and Fossils* for Barrons in 1999.

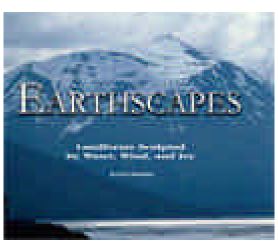
Mace receives distinguished Texas hydrogeologist award

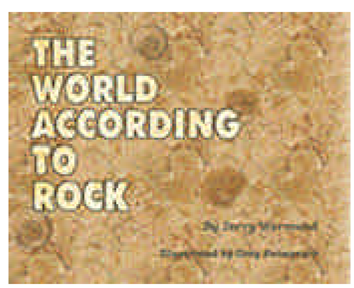
The Texas Groundwater 2004 conference recognized Dr. Robert Mace as the 2003–2004 Distinguished Texas Hydrogeologist. "During his tenure at TWDB, he has overseen the implementation of the Groundwater Availability Modeling program," announced Marshall Jennings of Texas State University after Robert's luncheon presentation on groundwater availability modeling on November 18, 2004, at the State Capital. "Under Robert's leadership, the GAM program recently reached an important milestone in completing models for all major aquifers in Texas." In his luncheon speech about the GAM program, Robert acknowledged the contributions of Texas Water Development Board staff, management, and the board as well as the legislature, stakeholders, universities, and consultants. "We couldn't have done it without your help," Robert explained. The Texas Groundwater conference is the first in what is planned as an every other year event by the International Institute for Sustainable Water Resources (now the Rivers Systems Institute) and the Edwards Aquifer Research and Data Center at the Texas State University–San Marcos. The conference plans to recognize a distinguished Texas hydrogeologist at each event.



Wermund publishes geology books for children

Member Jerry Wermund has authored and published two geologic books for elementary school children. "EARTHSCAPES—Landforms Sculpted by Water, Wind, and Ice" is a 48-page picture book illustrated by color photographs. EARTHSCAPES explains the variety and origin of landforms for fifth graders. "The World According to Rock" is also a 48-page picture book illustrated by water color paintings. This book tells about the different kinds of rock, their uses by man though history, and some fun activities for third and fourth graders. Rocks are defined below photographs in a glossary. For more information, visit Jerry's Web site: www.rockonpub.com.





AGS thanks BEG

In appreciation of the support the Bureau of Economic Geology has given the Austin Geological Society, Craig Caldwell, president of the Society, presented Scott Tinker, Director of the Bureau and past president of the Society, a globe. The Bureau provided a tremendous amount of support in holding the Gulf Coast Association of Geological Societies annual meeting in Austin a couple years back and continues to provide meeting space and visual tools for the Society at no cost.

Al Cherepon, Jim Sansom, and Scott Tinker admire the globe.

AGS holds fajita party

The Fall AGS Fajita Party was held on Saturday, October 30, 2005, at the home of past-president Robert Mace and was attended by a fair number of our members. Dr. Mace generously offered his home for our event. Delicious fajitas were enjoyed by all.

agency news

TCEQ publishes new guidance document for Edwards aquifer

The Texas Commission on Environmental Quality published a new guidance document for the Edwards aquifer in February 2005 titled "*Optional enhanced measures for the protection of water quality in the Edwards aquifer—An appendix to RG-348.*" The document outlines optional actions that exceed the requirements of the Edwards Aquifer Rules (30 Texas Administrative Code, Chapter 213) that a developer can take over the Edwards aquifer recharge zone to be protective of water quality. The U.S. Fish and Wildlife Service has written a concurrence letter stating that projects that adhere to these optional protective measures should prevent the developer from "taking" an endangered species. Both the letter and the guidance document can be found on the Commission's website at: http://www.tnrcc.state.tx.us/EAPP/.

New proposed boundaries for Edwards aquifer

The Barton Springs/Edwards Aquifer Conservation District petitioned the Texas Commission on Environmental Quality to revise the Edwards aquifer recharge, transition, and contributing zone boundaries in Hays and Travis counties. The Commission determined that it was beneficial to open up the Comal and Bexar counties portion of the aquifer for revision as well. As a result of the petition, the Commission has been going through the rule revision process for 30 TAC 213—*Subchapter A: Edwards aquifer in Medina, Bexar, Comal, Kinney, Uvalde, Hays, Travis, and Williamson counties* and has been drafting the newly proposed Edwards aquifer boundaries for certain U.S. Geological Survey topographic quadrangles. The Commission has an anticipated adoption date of August 17, 2005. The new maps can be viewed on the Commission's website at: http://www.tnrcc.state.tx.us/EAPP/mapping.html.

News from Barton Springs/Edwards Aquifer Conservation District

The District completed a major evaluation of the sustainable yield of the Barton Springs Segment of the Edwards aquifer for drought-of-record conditions. A groundwater flow model was developed to support the determination of sustainable yield. These evaluations led to the District's Board of Directors making a substantial policy change creating conditional production permits for all new permits granted by the District. These permits are subject to possible interruption during severe drought conditions.

In 2004 the District was awarded a three-year grant from the Fish and Wildlife Service to conduct a Habitat Conservation Plan for the Barton Springs Salamander. The District is working with various public agencies and contractors to complete the plan.

In May 2004 the District and the City of Austin injected non-toxic dyes into four major sinkholes and caves that contribute recharge to the Barton Springs aquifer in order to delineate groundwater flow paths and velocities. The District recently hired Kirk Holland, P.G., as General Manager. Kirk brings many years of experience in environmental and operations management to the District. For further information please contact the District at (512) 282-8441, bseacd@bseacd.org. http://www.bseacd.org/

News from Blanco-Pedernales Groundwater Conservation District

The Blanco-Pedernales Groundwater Conservation District was approved by Blanco County voters in January 2001 and has been staffed and operational since January 2002. In early June 2005 the District moved into its new office at 601 West Main in Johnson City. The District-owned property and office are located on the southwest corner of US 290 and Avenue N on the west side of town. The District also had a monitor well drilled on the office property. This well is 460 feet deep and will be used to monitor water levels and water quality of the Ellenberger aquifer. The District also monitors five Trinity aquifer wells, conducts basic water-quality testing, is developing a groundwater and well database, conducts occasional aquifer tests, and is involved in a variety of other programs typical of local groundwater districts. For further information, contact Ronald G. Fieseler, General Manager, at (830) 868-9196 or at manager@blancocountygroundwater.org.

News from the United States Geological Survey

One of three U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program study units in Texas includes the San Antonio segment of the Edwards aquifer. NAWQA is expanding its study-unit support to include the Barton Springs and northern segments of the Edwards aquifer. In 2005, the USGS is drilling 32 ground-water monitor wells to provide data for study of the effects of urbanization on shallow ground-water quality of the Edwards aquifer in the recharge zone in the Austin area (northern Hays, Travis, and Williamson counties). The USGS is collecting rock samples and geophysical logs from the monitor wells, which will provide data to improve understanding of the subsurface geology of the aquifer in the region.

Also involving the northern segment of the Edwards aquifer, the USGS, in cooperation with the Texas Commission on Environmental Quality (TCEQ), recently began a project to measure water-levels in the Edwards aquifer in northern Travis, Williamson, and Bell counties. A database of 77 wells in areas with little or no historical data was created as a part of the TCEQ Source Water Assessment and Protection Program. Water-level measurements in the wells were obtained by electronic sensor, steel tape, or calibrated airline. The data will be used in studies of the hydrogeology of the Edwards aquifer in the region.

The USGS is working in cooperation with TCEQ and the U.S. Environmental Protection Agency on a study of nutrient loading in small streams in the Edwards Plateau ecoregion of Central

Texas. Fifteen sites will be sampled this summer with approximately one-half upstream from a potential source of nutrient loading (reference sites) and one-half downstream from the potential source of nutrient loading. The primary response variables of interest are those related to algal cover. The study also will involve assessments of the benthic invertebrate community, the fish community, and stream habitat quality.

The USGS currently is working with the Texas Department of Transportation, Texas Tech University, Lamar University, and the University of Houston to assess gravel transport in streams in the Edwards Plateau (Edwards, Kimble, and Real counties). This project was initiated to address the considerable reconfiguration of gravel during high-magnitude flows and the associated structural problems and maintenance along low-water (road) crossings. Channel morphology and particle-size analyses, coupled with flow velocity and video monitoring, are being conducted.

Hydrogeologic news from Texas State University's Edwards Aquifer Research and Data Center

Under the direction of Dr. Glenn Longley, the hydrogeology section of the Edwards Aquifer Research and Data Center (EARDC) at Texas State University is continuing its ecological characterization of the 500-square mile Blanco River Basin in central Texas. Funded jointly by the Nature Conservancy of Texas and the River Systems Institute (RSI) at Texas State, the Blanco River study includes the collection, analysis, and interpretation of aquatic biology and water-quality data, as well as other hydrologic research by graduate school students. The hydrologic component includes streamflow measurements and watershed modeling using the SWAT 2000 rainfall-runoff model developed by the U. S. Department of Agriculture.

With additional funding from the Wimberley Valley Watershed Association, EARDC is sponsoring a related study to establish a scientific baseline of relations among groundwater, surface water, and aquatic (fish and macroinvertebrates) habitats in the Cypress Creek tributary of the Blanco River Basin. In addition to water-level observations and streamflow measurements, fish and macroinvertebrate samples are being collected below Jacob's Well and Blue Hole, two of the more prolific springs in the Cypress Creek watershed.

EARDC hydrogeology is partnering with Sul Ross State University to investigate major springs in West Texas and sponsor graduate student studies of aquifer properties in the West Texas Bolsons and Igneous (minor) aquifer systems in Brewster, Culbertson, Hudspeth, Jeff Davis, and Presidio counties. Additionally, EARDC and Sul Ross have teamed up with several groundwater conservation districts in West Texas to install and operate new groundwater monitoring stations using satellite telemetry.

As part of a joint project with RSI to establish a National Science Foundation Hydrologic Observatory at the old Aquarena facilities in San Marcos, EARDC is installing meteorological instrumentation and lake-level recording devices on Spring Lake. Alternatives are being considered for estimating inflows from Sink Creek.

Groundwater studies in cooperation with RSI and Texas A&M University–Kingsville and funded by the U.S. Environmental Protection Agency are being established to aid groundwater conservation districts in South Texas with groundwater science, training, and policy issues associated with the Gulf Coast aquifer.

Former EARDC hydrogeologist Marshall Jennings has transferred to RSI. Marshall has been replaced by Raymond Slade and Rene Barker, both recent retirees from the U. S. Geological Survey. While Raymond's primary expertise is surface-water hydrology, Rene's is groundwater hydrogeology.

News from the Texas Water Development Board

In 2001, the 77th Texas Legislature handed the Texas Water Development Board (TWDB) a challenging task: develop or obtain groundwater availability models (GAMs) for the major aquifers by October 1, 2004. Thanks to the dedication and hard work of TWDB staff, a number of contractors, and numerous stakeholders, the TWDB is happy to declare: Mission accomplished!

The Texas Legislature funded the GAM program to develop numerical groundwater flow models to help groundwater conservation districts, regional water planning groups, and others assess groundwater availability and the effect of pumping and drought on the State's groundwater resources. Unlike previous modeling efforts, new models developed under the GAM program had substantial stakeholder involvement. In some cases, the GAM represented the first modeling work for the area. All of the models, reports, and support data are available either on the Web page (www.twdb.state.tx.us/gam) or by request.

The nine major aquifers required seventeen different models to provide full coverage. TWDB staff developed five of the models: (1) the Hill Country segment of the Trinity aquifer, (2) the northern and (3) San Antonio segments of the Edwards aquifer, (4) the southern part of the Gulf Coast aquifer, and (5) the Edwards-Trinity (Plateau) and Cenozoic Pecos Alluvium aquifers. TWDB contractors developed eight of the models: (6) the northern and (7) southern part of the Ogallala aquifer; the (8) northern, (9) central, and (10) southern parts of the Carrizo-Wilcox aquifer; (11) the Seymour aquifer, (12) the northern segment of the Trinity aquifer, and (13) the Barton Springs segment of the Edwards aquifer. TWDB staff and a contractor developed a model of (14) the central Gulf Coast aquifer. The TWDB and Harris-Galveston Coastal Subsidence District funded a project for the U.S. Geological Survey to develop a model of (15) the northern part of the Gulf Coast aquifer. El Paso Water Utilities and the U.S. Geological Survey supported or developed the models for the (16) Mesilla and (17) Hueco Bolson aquifer, respectfully. The Edwards Aquifer Authority is currently developing a new model for the San Antonio segment of the Edwards aquifer in cooperation with the U.S. Geological Survey.

Although the models for the major aquifers are done, work is not completed. Models need to be 'living tools' that are updated with new data and refined to better meet stakeholders' needs. In addition, the 77th Texas Legislature also required TWDB to develop and obtain GAMs for the minor aquifers of the state, a task we are already making progress on. Finally, the TWDB supports the models by assisting groundwater conservation districts, regional water planning groups, and other political subdivisions with model runs and interpretation of model results. Although the TWDB accomplished a major mission for the GAM program, there is still a lot of work to ensure that Texas has the best possible tools to manage its groundwater resources more effectively.

about the technical content

The technical content in the Bulletin consists of abstracts or extended abstracts for presentations, summaries of the field trips, technical papers, and notes.

presentation

The Austin Geological Society hosts technical presentations from invited speakers concerning the natural sciences. We publish an abstract in the Society's newsletter and allow for an extended abstract in the Bulletin.

posters

The Austin Geological Society hosts a poster session each spring. Presenters can submit an abstract concerning their poster topic. This year, we received abstracts from young scientists from local schools.

field trip

The Austin Geological Society tries to have at least one field trip per year. This year, there were two field trips. The summaries included here provide an overview of the trips. Interested readers are encouraged to purchase the guide books for additional information and details.

technical paper

The Bulletin accepts technical papers for publication provided that the papers meet technical and editorial requirements.

note

The Bulletin also accepts notes, which may be technical or anecdotal.

presentation

august 30, 2004, bureau of economic geology

Engineering geology in the Austin area— Some selected examples

C. M. Woodruff, Jr.
Woodruff Geologic Consulting Incorporated

Bedrock and soil properties are highly variable in the Austin area, owing to juxtaposition of strata across the myriad faults composing the Balcones Fault Zone. Notorious engineering properties are associated with weak claystone bedrock units and their associated expansive soils: Taylor/Navarro Groups, Eagle Ford Formation, and Del Rio Clay. But locally severe engineering constraints also are associated with limestone bedrock units that are generally assumed to comprise stable ground. This is illustrated by several examples that involve carbonate rocks of the Edwards Formation/Edwards Group. Despite wide recognition of karst voids as zones of potential engineering/construction problems, many geologists and civil engineers still regard these strata as stable and durable substrates—which they generally are. The Edwards forms a resistant caprock that marks the edges of extensive plateau uplands west of the Balcones Escarpment, and it is quarried extensively for construction aggregate, thus meeting stringent durability standards. But this rock unit is not homogeneous. Subtle changes in lithology resulting from original depositional environments have been accentuated by chemical and physical changes owing to long-term storage and transmission of groundwater within the Edwards aquifer. Heterogeneity of this rock unit is readily noted in cores or in fresh excavations, revealing a diversity of materials: competent beds of limestone and dolomitic limestone; chert nodules up to boulder size; intervals of carbonaceous clay; extremely weak and friable beds of dolomite; karst voids; plastic clay (terra rossa) soil infill; fault breccia; and fault gouge. This heterogeneity contributed to the dramatic failures of the Austin Dam in 1900 and 1915.

C. M. Woodruff, Jr. runs his own consulting firm out of Austin.

presentation

october 4, 2004, bureau of economic geology

Aorounga to Zimbabwe—Scientific observations from Expedition 2, International Space Station

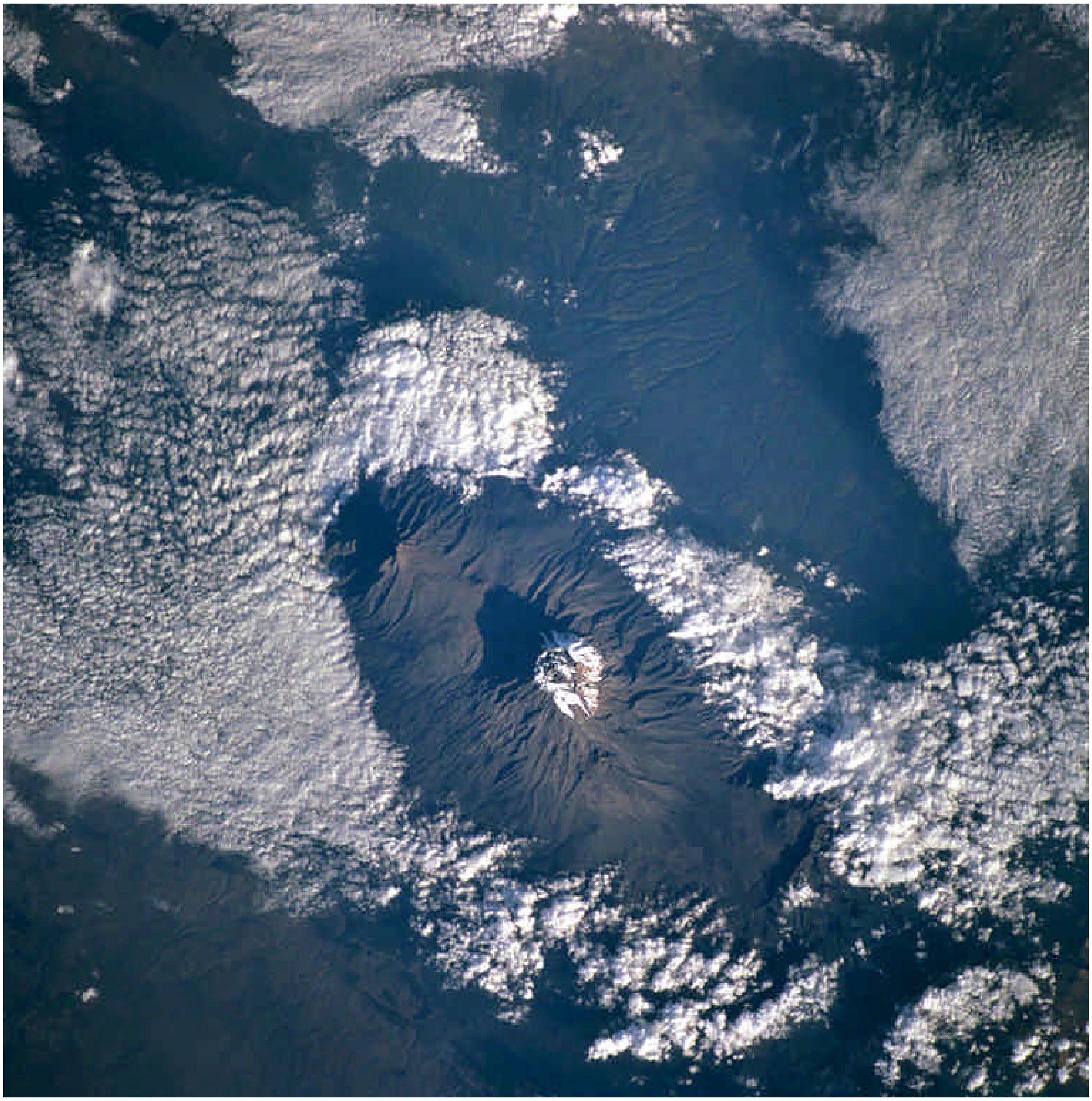
Patricia Wood Dickerson

Visiting Research Fellow, The University of Texas at Austin

Affiliate, Smithsonian Institution and American Geological Institute

Orbiting space stations are windows to global and local geological phenomena, as well as to natural and human-induced changes to the planet and atmosphere. An International Space Station expedition lasts from four to six months, and the Station orbits Earth every 90 minutes, affording opportunities to document seasonal variations as well as singular events. The present curriculum for astronaut and cosmonaut crews of the Station includes briefings on the global fresh-water supply (lakes, glaciers, ice sheets, etc.), on the great river systems and deltas of Asia, on El Niño/Southern Oscillation cycles, on coral reef ecology and health, on atmospheric phenomena, on rift basins and transform fault zones, on the East African rift system, and on episodic events such as volcanic eruptions. Requests for photographs of the research areas over which the International Space Station will pass during the coming 24 hours are uplinked to the crew daily. Jim Voss, Susan Helms, and Yuri Usachev, the Expedition 2 crew who observed Earth from March into August 2001, downlinked 3,415 digital images and returned 7,521 frames of 35- and 70-mm film. All Earth images are reviewed, and a briefing is held to report the principal scientific findings to the crew, who can incorporate the new data into their lectures throughout the world. The complete list of Expedition 2 debriefing photos can be downloaded from eol.jsc.nasa.gov/debrief (go to 2001 and select ISS002). From the Rungwe volcanic field at the junction of the Malawi rift and Rukwa transform fault zone to sea-ice breakup off Newfoundland, these publicly available views (http://eol.jsc.nasa.gov) constitute a rich resource for research and teaching.

Pat Dickerson was born at a very early age in Waukegan, Illinois. She has worked as a geologist, editor, photographer, writer, dancing instructor, and apricot cutter for a California fruit-packing firm (not in that order). Her research in rifts and mountain chains of the world, including doctoral studies (The University of Texas at Austin) in the Big Bend of West Texas, has provided opportunities for wide-ranging explorations: the Rocky Mountain, Rio Grande Rift, Iceland, Norway, the Cordillera of western North America, Mexico, Belize, Argentine Precordillera, Appalachian chain from the Canadian Maritimes through west Texas, and the Southern Alps of New Zealand. She has drawn from those investigations in petroleum, gold, and water exploration and now applies those passions in field mapping, astronaut crew training, academic teaching, and leading natural history field seminars for students, professional *scientists, and nonscientists. Pat collaborates with NASA on field training to prepare for lunar and Martian exploration and serves on task forces to develop scientific strategies for exploring Mars.*

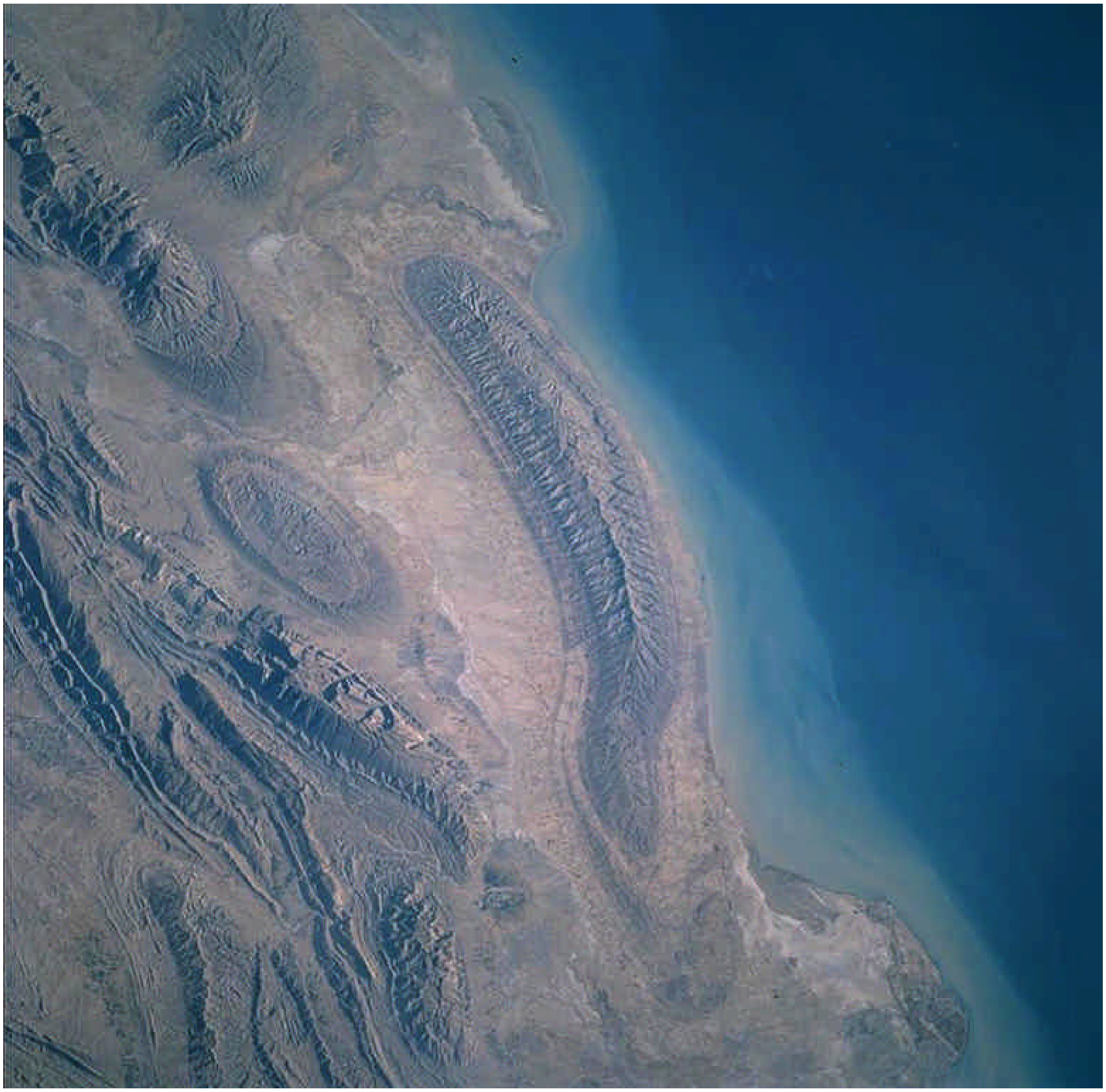


Mount Kilimanjaro, Tanzania

This 19,000 ft volcanic peak is located in Northern Tanzania, near the border with Kenya. The mountain's ice cap and small glacier features, visible here, are the subject of intense investigation and measurement by glaciologists and climatologists. It is estimated that 85 percent of the ice mass has been lost since 1912 and that it may all but vanish in another 15 years.

Aral Sea, Central Asia

Waters of the Amu Darya and Syr Darya (rivers) are almost completely diverted for agricultural irrigation—little reaches the inland Aral Sea. By 1990 the surface area of the sea had decreased by about half, and the salinity has tripled since 1960. Our lengthy time series of photos from orbit permits monitoring and quantification of changes in this disappearing body of water.



Southern Zagros Mountains, southern Iran

The broad, open folds of the Southern Zagros are characteristic of folded mountains with rock salt, gypsum, or similar materials at their cores. Such salts behave plastically when mountain-building forces are applied. This detailed photo shows several breached folds, from which the salt cores have been eroded away. In the narrow up-arched fold (anticline) at the right, individual rock layers can be seen to dip away from the center of the structure and to be pervasively fractured.

Mount Etna, Sicily

Etna boasts one of the world's longest documented records of historical volcanism, dating back to 1500 BC. The episode of activity recorded here lasted from November 2000 through January 2002—this telephoto view was taken on July 22, 2001. Two styles of eruptive activity typically occur at Etna: persistent explosive eruptions from the three prominent summit craters and flank eruptions from fissures.

presentation

november 1, 2004, bureau of economic geology

Oil production in the 21st Century: Are we running out of oil?

Amos Salvador

The University of Texas at Austin, Department of Geological Sciences

In this presentation Dr. Salvador presented data on oil production and consumption and made some predictions of future trends based upon his work. Contrary to recent published books he stated that oil and gas will continue to be the main sources of energy and that trends may not be as grim as they have been made out by other authors. This talk represented a portion of his recently (2005) published book, *Energy: A Historical Perspective and 21st Century Forecast* (AAPG Studies in Geology, No. 54).

Dr. Amos Salvador was born in Spain and moved to Venezuela in 1938. He graduated with the equivalent of a B.S. in Geology from Venezuela and worked for Gulf Oil until he went to Stanford for his Ph.D. (1950) on scholarship from Gulf Oil. After his Ph.D. work he continued work for Gulf and did fieldwork in North Africa, Peru, Italy, and Paraguay. In 1955 Dr. Salvador went to work for Exxon until 1980 when he retired as Chief Geologist from Exxon USA and came to The University of Texas at Austin, Department of Geological Sciences. Dr. Salvador is the editor of the International Stratigraphic Code.

presentation

november 1, 2004, bureau of economic geology

Play analysis and digital portfolio of major oil reservoirs in the Permian Basin

Shirley P. Dutton
The University of Texas at Austin, Bureau of Economic Geology

Researchers at the Bureau of Economic Geology and the New Mexico Bureau of Mines and Mineral Resources have completed a new digital oil-play portfolio of the prolific Permian Basin of west Texas and southeast New Mexico. The Permian Basin has produced oil for more than 80 years, and it is still one of the largest petroleum-producing basins in the United States. In 2002, it accounted for 17 percent of the total oil production in the United States. Because of the substantial amount of oil remaining in the basin, this new oil-play portfolio was developed as part of the Department of Energy's Preferred Upstream Management Program (PUMP). The portfolio defines 32 oil plays in the Permian Basin and assigns all significant-sized reservoirs that had cumulative production of more than 1 million barrels through 2000 to a play. Each of the 1,339 significant-sized reservoirs was mapped in a geographic information system. The portfolio contains a description of each play, including illustrations of key reservoir characteristics, reservoir data tables, and successful reservoir development methods. Enhanced-recovery methods that have been demonstrated to work well in one reservoir in a particular play should be applicable to analogous reservoirs in that play. The oil-play portfolio will be available soon as a Bureau of Economic Geology Report of Investigations on a CD-ROM.

Dr. Shirley P. Dutton is a Senior Research Scientist at the Bureau of Economic Geology, The University of Texas at Austin. Her technical expertise is in clastic sedimentology and reservoir characterization. She received a Bachelor's degree from the University of Rochester and Masters and Ph.D. degrees from The University of Texas at Austin, all in geology. Dr. Dutton has been at the Bureau since 1977.

presentation
december 6, 2004, bureau of economic geology

Hydrologic function of karst features in the uplands of the Edwards aquifer recharge zone—A view from the field

Adrien Lindley[1] and Susan D. Hovorka[2]
[1]The University of Texas at Austin and the [2]Bureau of Economic Geology

Abstract

Mass balance shows that most of the recharge into the Edwards aquifer occurs where major streams cross the Edwards recharge zone. However, the uplands contain abundant evidence of active karst dissolution, including sinkholes, caves, and solution-enlarged fractures. What is their hydrologic function? How much and what kind of protection do such features need as urbanization proceeds across the recharge zone?

A series of measurements of infiltration comparing karst features with paired non-karst control plots using a large-diameter single-ring infiltrometer provide direct evidence of the hydrologic function of these features under undisturbed conditions. Selected karst features are small and include soil-floored sinkholes, sinkholes having cobble-filled drains, and an excavated solution cavity. We have tested eight pairs in the Barton Springs segment of the Edwards recharge zone and plan in the next phase of the study to measure similar features in the San Antonio area.

Introduction

The vulnerability of karst aquifers to contamination is commonly known to be higher than other types of aquifers as a result of the focused flowpaths that provide rapid and direct recharge to the aquifer. These flowpaths include large-aperture karst features such as swallow holes, open-fracture zones in riverbeds, caves, and sinkholes having closed drainage basins, found across the recharge zone (Figure 1). However, the most commonly occurring karst features in the upland are subtle soil-floored depressions that commonly lack large-aperture openings. These features include sinkholes, closed depressions, solution cavities, and soil-filled fractures. Many of these features are small (less than 10 feet in diameter) and shallow (less than 8 inches in depth). Though they may have little topographic relief, they may indicate a larger, well-developed flow system located in the top few meters of soil and bedrock. The role of these features in providing a flowpath to the aquifer, in terms of either recharge or water quality, is not well known.

Currently, State law (Edwards Rules [Title 30 Texas Administrative Code (TAC) Chapter 213]) regulates activities having potential for polluting the Edwards aquifer. A key part of implementation of the Edwards Rules is the requirement for management of **“**sensitive features,” which are defined as permeable geologic or manmade features located in the recharge zone or transition zone where potential exists for hydraulic interconnectedness between the surface and the Edwards aquifer and rapid infiltration to the subsurface may occur. The initial step in managing sensitive features is to identify them through a process known as geologic assessment. Instructions to conduct the assessment are provided by the Texas Commission on Environmental Quality (TCEQ), the State regulatory agency charged with implementing the Edwards Rules. These instructions specify methods for closely inspecting a tract of land to identify geomorphic indicators of sensitive features. On the basis of the geologic assessment, the developer proposes plans for implementing “best management practices” (BMPs) to mitigate the impact of development. The hydrologic function of very common but subtle, small, soil-floored features on the upland, the correct method of classifying these features during the geologic assessment, and the determination of what, if any, BMPs are applicable are problems identified during the recent revision of the instructions for conducting geologic assessments. This study focuses on these features to determine how the Edwards Rules apply to them.

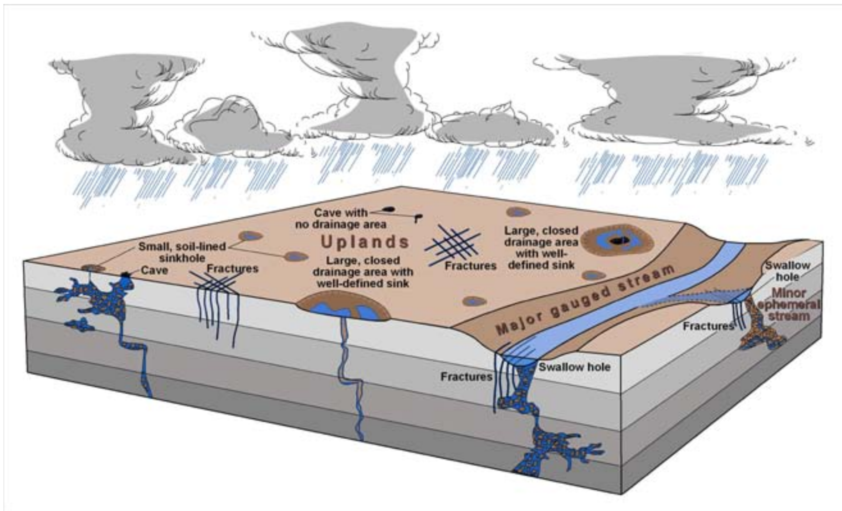


Figure 1. Schematic diagram of the Edwards aquifer recharge zone including several types of karst features that have the potential for interconnectedness with the subsurface and where rapid infiltration to the subsurface may occur.

This project determines hydrologic function directly by testing the infiltration rates of a population of small, subtle karst features and inducing recharge on them. This project is designed to evaluate the hydrologic function of these subtle features, specifically sinkholes in the uplands of the Edwards recharge zone, to determine what role they play in recharging the aquifer and to what extent they should be protected to mitigate water-quality degradation or reduction of recharge volume as the uplands undergo urban development.

Methods

Initially, surveys of representative karstic sites on the Edwards outcrop were conducted, with landowner cooperation, to identify subtle features and associated typical background areas to study. These surveys were conducted by walking transects 50 feet apart through the property. Potential features were photographed, and their locations were surveyed using Global Positioning System (GPS). Brief descriptions of the feature's dimensions, setting, and soil cover were collected. Microtopographic and soil thickness surveys were conducted within the feature to reveal the features of interest more clearly, as well as to quantify the volume of soil that overlies the feature. Constant head ring infiltrometer experiments were conducted in order to determine and quantify an area's connectedness with the subsurface.

There are three factors that must be quantified in order to determine the sinkhole infiltration capacity as a function of depth of ponding: the volume of water added, the time required for infiltration to occur, and the area on which the water is added. These three factors may be quantified by conducting a constant head ring infiltrometer test. Ring infiltrometers are devices used to determine the infiltration rate of an area enclosed by an impermeable boundary. A metal ring is placed around an area of interest (Figure 2), which includes a sinkhole defined by topographic depression or a background area. The ring is inserted into the ground to minimize lateral leakage by digging a trench to match the circumference of the ring and packing it with bentonite or other relatively impermeable material. Water added to the enclosed area is added quickly so that it ponds at the surface to a depth of several inches within the ring, and then water is added as needed to maintain constant head on the feature of interest.

Figure 2. Ring infiltrometer ponding water on a sinkhole with flow meter and control section.

Water supplied from a reservoir is gravity fed through a 3-inch diameter water hose to a flow-control section. Flow-control sections are required to reduce turbulence and maintain laminar flow across the paddle wheel of the flow meter. The flow-control sections are constructed from PVC pipe of varying diameters (3, 2, and 1 inch). There are three different sizes of flow-control sections to accommodate three different flow rates. Flow is regulated into the ring manually via a ball valve downstream from the flow meter.

A data logger records the volume of water that is introduced into the ring by electrical pulses sent by the paddle wheel of the flow meter. Every time the paddle wheel makes one rotation, a known volume of water passes through a specific diameter of pipe. Therefore, the volume of water that passes for one rotation in a 3-inch pipe will be different from that in a 1-inch pipe. The number of rotations is converted into a volume and logged at 5-liter intervals. Thus, by dividing the volume per time by the area, a sinkhole infiltration rate is achieved (length per time). Infiltration rate is then normalized for head by dividing the infiltration rate by maximum ponding depth.

Site description

Two main sites have been utilized for testing small karst features in the uplands of the Edwards recharge zone, J-17 Tract and Rutherford Ranch. These two sites are part of the Water Quality Protection Lands program managed by the City of Austin Water Utility. Site J-17 is located in southern Travis County, and Rutherford Ranch is located in northern Hays County west of Buda. Outcrops at both locations are principally Kainer and Person Formation limestones. Four sinkholes and their paired control plots have been tested at each site. In addition to the sinkholes, one recently excavated solution cavity was also tested. The dominant soil type for the J-17 tract is Speck stony clay loam (SsC), and the dominant soil type for the Rutherford Ranch area is the Rumple-Comfort association (RUD). These clay loams contain 30 to 40 percent clay.

J-17 features

The four sinkholes studied at the J-17 tract are subtle features having little topographic relief. Features J17SH1 and J17SH2 and their associated background control plots are developed in the Person Formation, whereas J17SH3 and J17SH4 and their associated background plots and J17SC1 are developed in the Kainer Formation as mapped in the March 2000 geologic assessment prepared by HBC Engineering, Inc. Feature J17SH1 is approximately 6 feet by 5 feet and 4 inches deep. It is one of three sinkholes that form a complex of small sinkholes that trend N38W. There was no leaf litter or evidence of rapid recharge in the sinkhole, and the soil is clay dominated with abundant organics. At the surface there were a few rocks present in the base of the bowl, but nothing to indicate an open drain. When digging the trench to install the ring infiltrometer, we encountered well-weathered, smoothed, and rounded rocks ranging in size from about 4 inches in diameter to 2.5 feet by 1.5 feet large. Feature J17SH2 is more obvious. It is 3.5 feet by 5 feet and 10 inches deep. A large cactus was growing in the bowl of the sinkhole. The loose clay loam soil had an abundance of organic detritus, and there was no direct evidence of flow into the sinkhole. Few pebbles were observed in the bowl, and few fist-sized cobbles were observed at the surface and in the immediate subsurface. J17SH3 is 5 feet by 6 feet and 6 inches deep with clay loam in the bowl and organic detritus. There were fist-sized cobbles in the near subsurface around the rim of the bowl and few larger rocks at the surface near the rim and at the base of the bowl. J17SH4 is 7 feet by 4.5 feet and 8 inches deep. It is elongated in the NNE direction. J17SC1 is a solution cavity 3 feet by 4.5 feet by 4 feet deep. It is a well-developed feature having a cylindrical shape that widens near the base and is elongated along a trend approximately N55W. This feature has recently been excavated, and the soil removed is a silty clay loam.

Rutherford Ranch features

Four sinkholes and their associated background control plots were studied at the Rutherford Ranch. RRSH1, RRSH3, and RRSH4 are developed in the Grainstone Member of the Kainer Formation, Edwards Group limestone, and RRSH2 is developed in the Leached and Collapsed Member of the Person Formation, Edwards Group limestone, as mapped in the October 1999 geologic assessment prepared by SWCA Inc., Environmental Consultants.

RRSH1 is a broad, 8-foot by 8.5-foot, shallow, 5.75-inch-deep sinkhole that was identified by a contrast in vegetation. Within the sinkhole, low grasses and knee-high lush green plants were observed. In the surrounding area, waist-high plants dominated the grasses, and those that were visible were noticeably less lush from their brown color. Desiccated algae were also observed in the base of the bowl. Few rocks were observed in the base of the bowl, though 6- to 10-inch-diameter rocks were not uncommon around the rim of the sinkhole. RRSH2 is a relatively large sinkhole that has a diameter of about 25 feet. The base of the bowl contains one drain containing fist-sized angular shaped cobbles. A 3-foot soil probe was inserted into the gaps between cobbles to a depth of about 2 feet. Leaf litter and grasses around the sinkhole indicate rapid flow to the drain. Two animal burrows were observed near the base of the bowl after a large cactus was removed. RRSH3 and RRSH4 are part of a complex of three sinkholes that trend WNW. RRSH3 is a 7.5-foot by 6-foot diameter and 7-inch deep, oval-shaped sinkhole with fist-sized weathered cobbles near its base. RRSH4 is a 7-foot by 5.5-foot and 6-inch deep, oval-shaped sinkhole with weathered rocks near the surface and in the subsurface.

Background plots for each sinkhole were located nearby on typical flat grassy upland. Soils are similarly 8 to 12 inches deep with some rocks at or near the surface.

Results

The goal was to determine the hydrologic function of the soil and bedrock system contained by the ring for both karst and non-karst features in the Edwards aquifer recharge zone. The karst features tested include soil-floored sinkholes, a cobble-drained sinkhole, and an excavated solution cavity. The results for each experiment are shown in Table 1 and include the average infiltration rate, in centimeters per minute (cm/min), as well as inches per hour (in/hr), which has been normalized for depth.

The excavated solution cavity and cobble-filled sinkhole exhibit infiltration rates that exceed 15 and 30 times background, respectively. The excavated solution cavity infiltration rate was compared with the average of all the background plots at J-17. The average infiltration rates of the soil-lined sinkholes are slightly lower than the average infiltration rates of the control plots, 0.061 and 0.097 in/hr (1.55 and 2.46 mm/hr), respectively, but the majority of the control plots lie within the range of infiltration rates for soils in the area and nearly half of the soil-lined sinkhole infiltration rates are below the range of the soil rates. The dominant, Speck stony clay loam (SsC) soil type for the J-17 tract is described in the Travis County Soil Survey as having a permeability of 0.06 to 0.20 in/hr (or 1.524 to 5.08 mm/hr), and the Rumple-Comfort association (RUD), dominant soil type for the Rutherford Ranch area, is described in the Comal and Hays County Soil Survey as having a permeability range of 0.06 to 0.20 in/hr (or 1.524 to 5.08

mm/hr). Although maintenance of a depression suggests active karst processes like soil sapping or soil piping occur, the 30 to 40 percent clay in the clay loam soil appears to retard infiltration.

Table 1. Resulting infiltration rates of features and control plots.

Feature name	*Feature type*	*Average infiltration rate (cm/hr)*	*Average infiltration rate (in/hr.)*
J17BG1	Background	0.3091	0.122
J17BG2	Background	0.2410	0.095
J17BG3	Background	0.0616	0.024
J17BG4	Background	0.2133	0.084
RRBG1	Background	0.3962	0.088
RRBG2	Background	0.1796	0.071
RRBG3	Background	0.4263	0.168
RRBG4	Background	0.2475	0.097
J17SH1	Sinkhole	0.0587	0.023
J17SH2	Sinkhole	0.1460	0.057
J17SH3	Sinkhole	0.1103	0.043
J17SH4	Sinkhole	0.2039	0.080
RRSH1	Sinkhole	0.0841	0.019
RRSH2 (3in)	Sinkhole	5.6873	2.239
RRSH3	Sinkhole	0.2359	0.093
RRSH4	Sinkhole	0.2860	0.113
J17SC1	Solution Cavity	3.4382	1.354

Discussion

Most of the control plots have a somewhat higher infiltration rate than their associated sinkholes. Only the solution cavity, J17SC1, and the well-developed sinkhole RRSH2 have higher infiltration rates than their control plots. Similarly, only the J17BG3 control plot shows an infiltration rate that is significantly less than that of soil-lined sinkholes. The infiltration rate, normalized for head, has been plotted to effectively show the differences between feature types in Figure 3. The solution cavity is in the Kainer Formation and had an infiltration rate of about 1.354 in/hr, which is higher than any of the background control plots and all but one of the sinkholes tested. The one sinkhole that did indicate an infiltration rate higher than the solution cavity had an open drain in the base of its bowl with little soil to slow the flow of water to the subsurface.

Conclusions

Maintenance of numerous small depressions suggests that active karst processes such as soil sapping are focused. Experience of karst specialists in the area suggests that excavation of these subtle sinkholes will lead to discovery of more extensive karst, including potentially enterable caves. However, the results of the infiltrometer tests demonstrate that the few inches of clay loam soil dominate the infiltration of this soil/ bedrock system.

The subtle features maintain some significance in their roles as recharge features because of their maintained microtopography. Under natural conditions these features will collect and pond water during rain events. As ponding occurs, the increase in head from ponding allows for a larger volume of water to infiltrate to the subsurface.

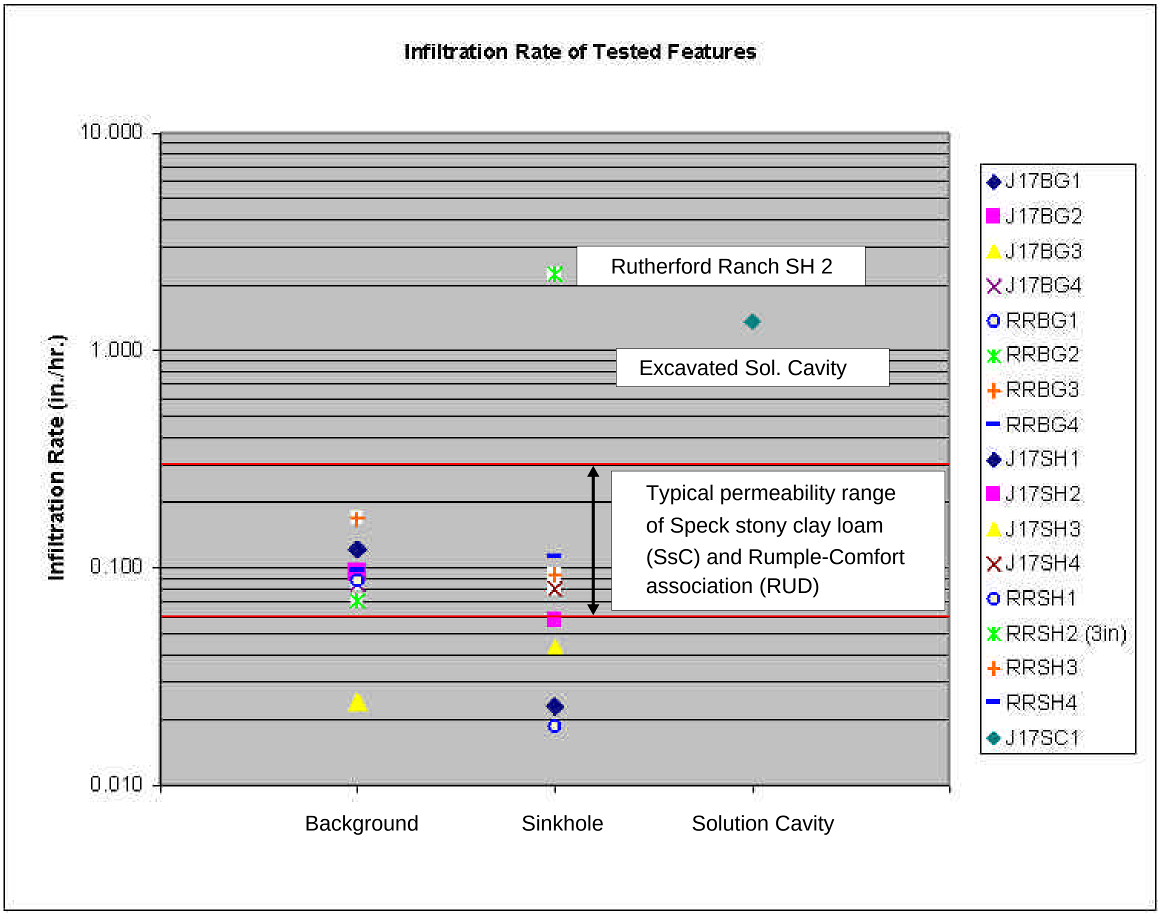


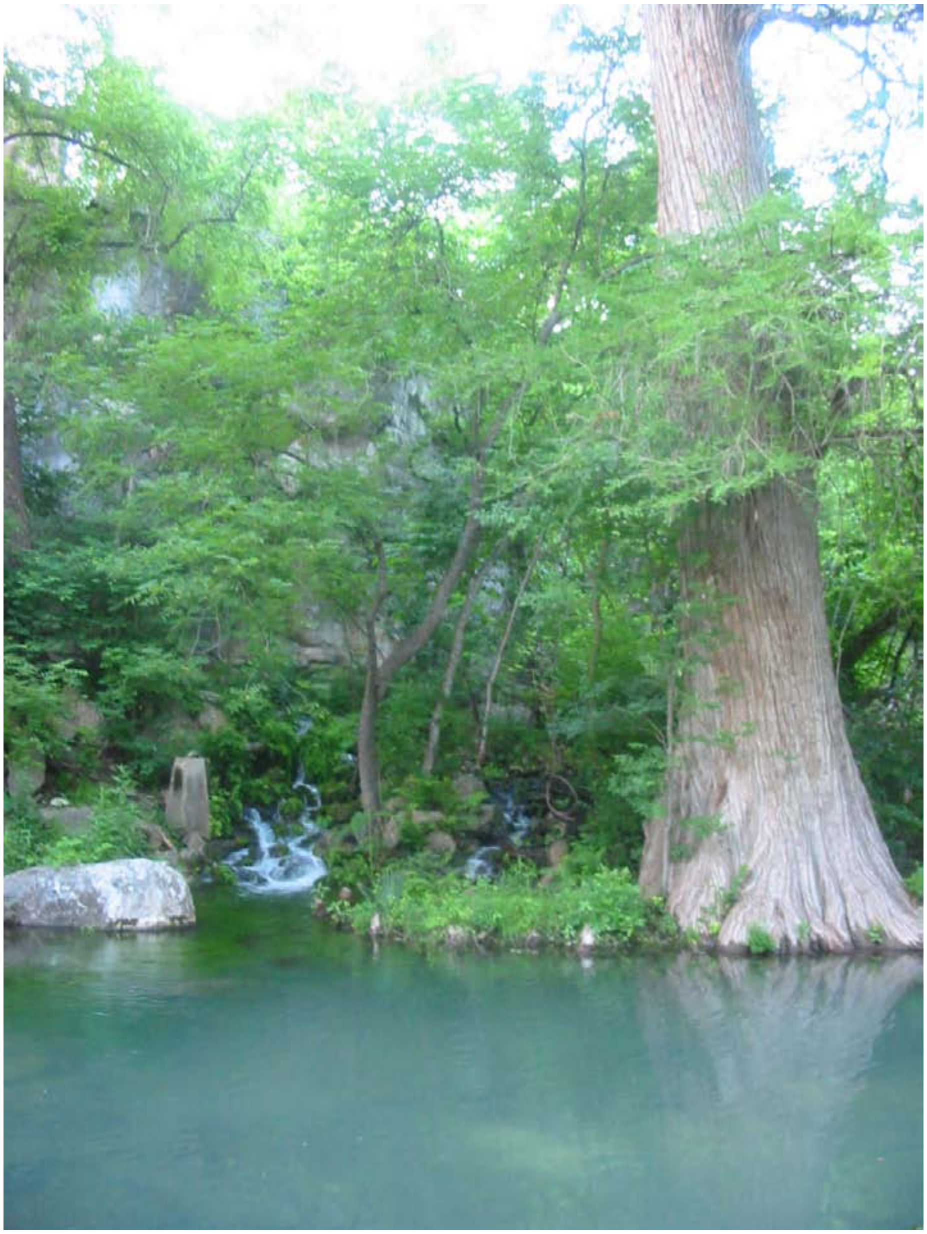
Figure 3. Infiltration rates versus feature type for J-17 tract and Rutherford Ranch.

Additional work is required before we define these common upland karst features as not sensitive according to the Edwards Rule definition. One question that arises is: Are these subtle features that we tested really of karst origin and not artifacts of past land management? If some or all of the small sinkholes are connected to highly transmissive karst systems beneath the soil, then a second question arises: What type of BMPs should be applied to protect the aquifer if these thin soils are modified during development?

Future research is designed to investigate these questions. Ground-penetrating radar surveys across features before and after ponding will explore the geometry of the soil and rock and distribution of water during recharge. Ponding tests with water-soluble dye will allow us to determine the area of wetting and preferential flowpaths within the sinkholes and control plots. Subsequent excavation of features will enable us to investigate the hydrologic function of the epikarst. Additional field sites in the San Antonio area are required for a more region-wide comparison of sinkhole and background control plot infiltration rates.

Adrien Lindley is a geology graduate student at The University of Texas at Austin and a graduate research assistant at the Bureau of Economic Geology. He is interested in understanding recharge via small karst features and how they may impact water quality in the Edwards aquifer. Research for his thesis includes the quantification of infiltration rates in small (12-foot diameter) sinkholes in the uplands of the Edwards aquifer Recharge Zone.

Susan Hovorka is a Research Scientist at the Bureau of Economic Geology, John A. and Katehrine G. Jackson School of Geosciences. She has been working on Edwards aquifer issues since 1992.



Rebecca Creek Springs in the Hill Country of Texas (photo by Robert Mace).

presentation
december 6, 2004, bureau of economic geology

The Public Fountains of the City of Dijon by Henry Darcy

Patricia Bobeck
Geotechnical Translations

The book *Les Fontaines publiques de la ville de Dijon* is best known to modern-day hydrogeologists as the book in which Darcy's law first appeared. The five pages of the book describing Darcy's experiment were translated into English by Allan Freeze in 1983 (Freeze and Back, 1983). An English translation of Darcy's entire book was published in 2004. The translation reveals a wealth of information about the history of water and Henry Darcy.

Henry Darcy (1803–1858) wrote the book in 1856 to describe the water-supply system he built in Dijon, France in 1839–40, and, in my opinion, to leave a record of his lifelong research into water issues. Darcy's water supply system provided abundant pure spring water to Dijon through a network of street fountains. The street fountains also made it possible to wash refuse from city streets and to fight fires. The water was free and the fountains were a maximum of 100 meters apart, so no one had to walk more than 50 meters to fetch water. In 1840, Dijon ranked second only to Rome in terms of the quantity and quality of water available to its citizens.

As a native of Dijon, Darcy spent his early years drinking the putrid water that was the only water available. At that time, Dijon collected water from roofs and from wells located in the alluvium of the stream that ran through town. The water from the shallow alluvial wells was contaminated by nearby cesspools.

After studying at the École Polytechnique and the School of Bridges and Roads in Paris, Darcy returned to his native city and worked as an engineer in the Corps of Bridges and Roads. Shortly after returning to Dijon, he began gauging springs in the area. He worked for the Corps his entire life, advancing to the position of Inspector General of Bridges and Roads at the time of his death.

Darcy states in the introduction of the book that he wrote it as a guide for other engineers in the construction of water-supply systems. The 650 pages of the original French book include a variety of historical and technical topics and numerous insights into Darcy's personality. In preparation for building the water supply system, Darcy conducted research on the history of Dijon water supply projects back to the 1400s, and he compiled an inventory of springs which makes up Appendix A.

By 1832, Darcy had selected the Rosoir Spring as Dijon's water source. Darcy gives a detailed account of the gauging of the spring, including how he gauged the spring during droughts to determine the minimum flow. Darcy also discusses the mid-nineteenth century state of the art

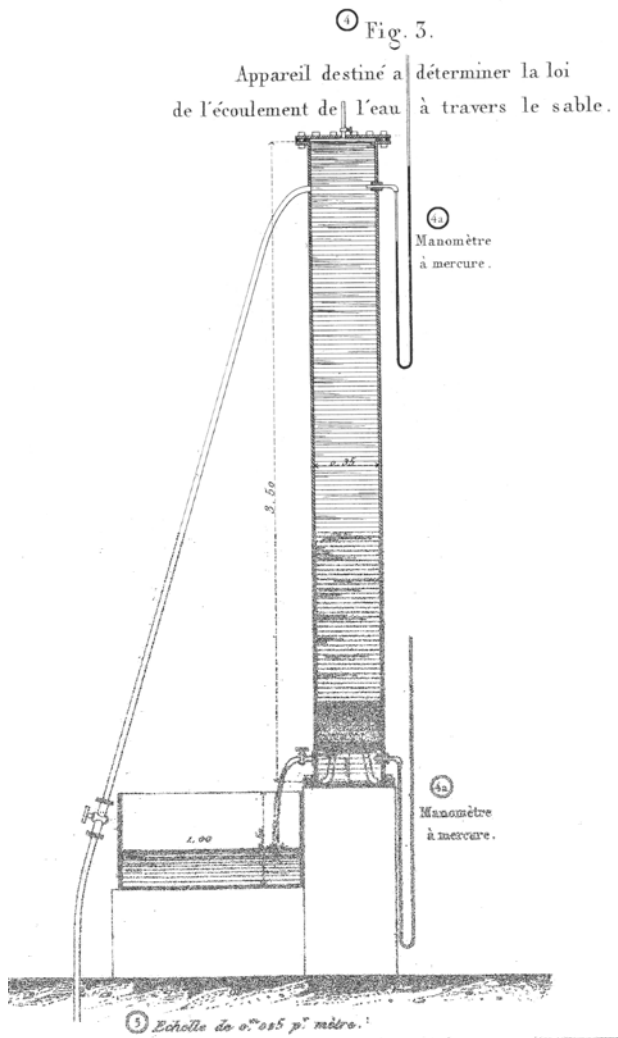


Figure 1. **Darcy's experimental apparatus. This the equipment used for Darcy's experiments on water flow through sand. The column is 3.5 meters high, and the basin is 1 meter square. Water entered through the pipe on the left. The column was packed with sand. The manometers on the right were used to gauge water levels.**

of finding springs and Roman methods of locating springs. Darcy presents contemporary ideas on the origin of artesian water and construction of artesian wells.

A third of the book is devoted to the construction of the 12-kilometer underground masonry aqueduct that brought the Rosoir water to Dijon and the internal distribution system within Dijon. The gravity-driven internal distribution system consisted of two reservoirs and a grid of interconnected conduits—a system Darcy pioneered. Darcy provides minute details on pipe sizes and valves and the cost of every component of the project. An appendix contains information on the types of pipes available at the time and pipe manufacturing.

Darcy also conducted experiments on water flow in the aqueduct and the internal distribution system to solve problems of air in the pipes, which could stop the flow of water. Darcy wrote with obvious pride about the fact that all 110 original fountains flowed with almost equal water pressure and provided cool water in summer and warm water in the winter because the aqueduct and pipes were underground.

The 200-page appendix contains eight sections on various topics: the water-supply systems of London, Paris, Brussels, and other cities and their water sources, distribution systems, and financing; water filtration and the distinction between “natural” and “artificial” filtration; a constant volume weir intake to obtain a constant volume of water from a river; spring gauging to determine the flow rate of a spring; modification of pitot tubes for stream gauging; and pipe manufacturing and testing among other topics.

The section on filtration contains a description of the experiment that led to the formulation of Darcy’s law. Darcy was aware that the large areas required for filtration beds in a city like London were a major obstacle to using surface water as a water-supply source. Filtration was inevitably necessary because of turbidity caused by flooding. His experiment was designed to establish how water flowed through sand, and he used the results to propose a filtration tank that occupied a smaller area than the filtration beds in use at the time.

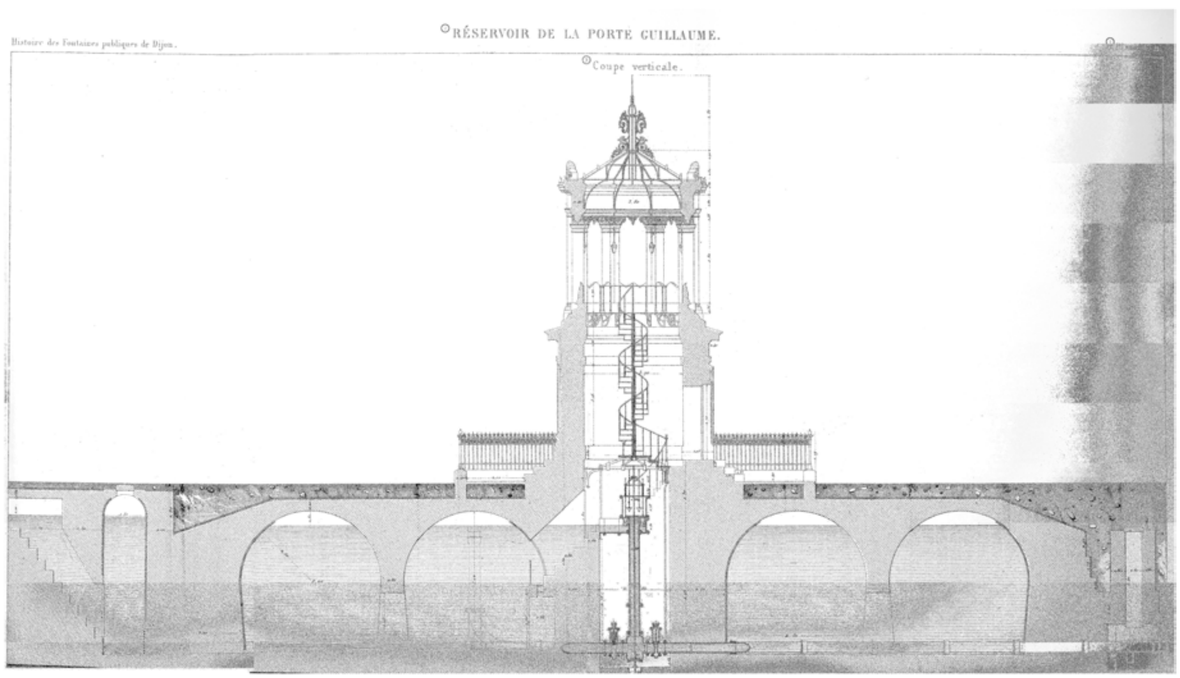


Figure 2. **Cross section of the Porte Guillaume Reservoir. The Porte Guillaume reservoir is located at the end of the aqueduct in Dijon. It is circular in shape with two concentric chambers. There is a central well at the center. The water enters on the left by cascading down the stairs. The water goes to the central well via a pipe on the floor. At the central well, the water goes up a pipe and then cascades down another stairway. The water can freely move from chamber to chamber through openings made for this purpose. The height of each chamber is about 5 meters. The structure on top of the reservoir provides access. Water leaves the reservoir on the right through the main artery. The main artery connects this reservoir with a second reservoir. Distribution lines off the main artery supply the street fountains.**

Dijon's water supply system was evidently expensive, because there is a discussion in the book in which city officials are trying to get more revenue from the water system. Darcy suggests a marketing plan to city officials to increase revenue by encouraging more subscribers to have water piped into their homes and voices his support for the continued availability of free water for the poor.

Darcy's 28-plate atlas of engineering drawings, originally published as a separate volume, is included in the English translation. The atlas contains a map of the city showing the locations of all the street fountains, drawings of the aqueduct, reservoirs and the branches of the internal distribution system, a drawing of the apparatus Darcy used in the experiments that led to Darcy's Law, a drawing of the filtration tank described above, and illustrations of other topics Darcy discusses.

The book provides insight into Darcy's personality and sense of humor. Darcy discusses dowsing and analyzes the success of a priest who was well known for his ability to find water. Darcy criticizes London's water corporations for poor water quality, high cost and exorbitant profits, and the lack of free street fountains. Darcy devised a system for negotiating with landowners to purchase 556 parcels of land for the construction of the aqueduct, and all the landowners were satisfied with the settlements. He shared water generously with towns located along the aqueduct. Above all, he was concerned that the less fortunate classes have access to abundant pure water.

The French original has been a rare book for decades, and, in any event, most American hydrogeologists would not be able to struggle through the antiquated French. The English translation makes Darcy and his ideas accessible to today's scientists and engineers.

The Public Fountains of the City of Dijon by Henry Darcy—English Translation by Patricia Bobeck is available from Kendall Hunt Publishing Co. of Dubuque, Iowa. 1-800-338-8290. www.kendallhunt.com.

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Patricia is past president, president-elect, and vice-president of the Austin Geological Society (1995–1998). She received master's degrees in geology and linguistics from The University of Texas and the University of Michigan, respectively, and a bachelor's degree in French from Rosary College (now Dominican University). For her master's thesis—Igneous Petrology and Structural Geology of Nine Point Mesa, Brewster Country, Texas—*she mapped 40 square miles of the Chihuahuan desert. She has worked for the State of Texas as a geologist for 13 years. She translates French and Spanish into English, specializing in the earth sciences. Other books include the French to English translation of* 1000 Photos of Minerals and Fossils *for Barrons in 1999.*

presentation
february 7, 2005, bureau of economic geology

The origin of relict, thick soils in Central Texas

M. Jennifer Cooke, L. A. Stern, J. L. Banner, and L. E. Mack
The University of Texas at Austin, Department of Geological Sciences

Introduction

In contrast to the thin rocky soils that typify the modern Edwards Plateau landscape, thick red soils occur on isolated Edwards Limestone-capped uplands in central Texas. These thick soils are interpreted to be relicts of a formerly more extensive soil cover that was eroded away during the late Pleistocene to middle Holocene. Red clay deposits in central Texas caves and fossils of burrowing mammals contained in these cave-fill sediments provide evidence that thick red soils were once more extensive on the Edwards Plateau (Toomey an others, 1993). Sr isotope variations among fossil plants and animals contained in sediments in Hall's Cave, Kerr County, Texas provide a record of the gradual erosion of the former thick soil cover from 21,000 to 5,000 cal. years before present (Cooke and others, 2003).

Because the relict thick soils are most commonly found on the relatively pure carbonates of the Edwards Limestone, they could not have formed solely from the weathering of the underlying limestone bedrock. Instead, these thick soils may have formed from silicate material derived from eolian dust, alluvium, and/or stratigraphically-higher, clay-rich strata that have been subsequently removed by erosion. Rabenhorst and Wilding (1986) studied the mineralogy and grain morphology of soils overlying resistant limestones on the Edwards Plateau and concluded that neither the underlying limestone nor local dusts were significant sources of silicates to the soils, but suggested an overlying stratum was the potential parent material. We propose that the silicates in the relict thick soils of the Edwards Plateau were derived from the overlying Del Rio Clay. We characterize the geographic distribution of relict soils on the Edwards Plateau and the physical and chemical properties of soils that were collected in Kerr County to help identify the silicate source.

Results and discussion[1]

The geographic distribution of the soils, with respect to topographic position and underlying rock-type, agrees with a Del Rio Clay silicate source. Here I use the distribution of soil types classified by the U.S. Department of Agriculture as Redland range site soils as proxy for the

[1] An extended report of this study will be submitted for publication in 2005 to *Quaternary Research*.

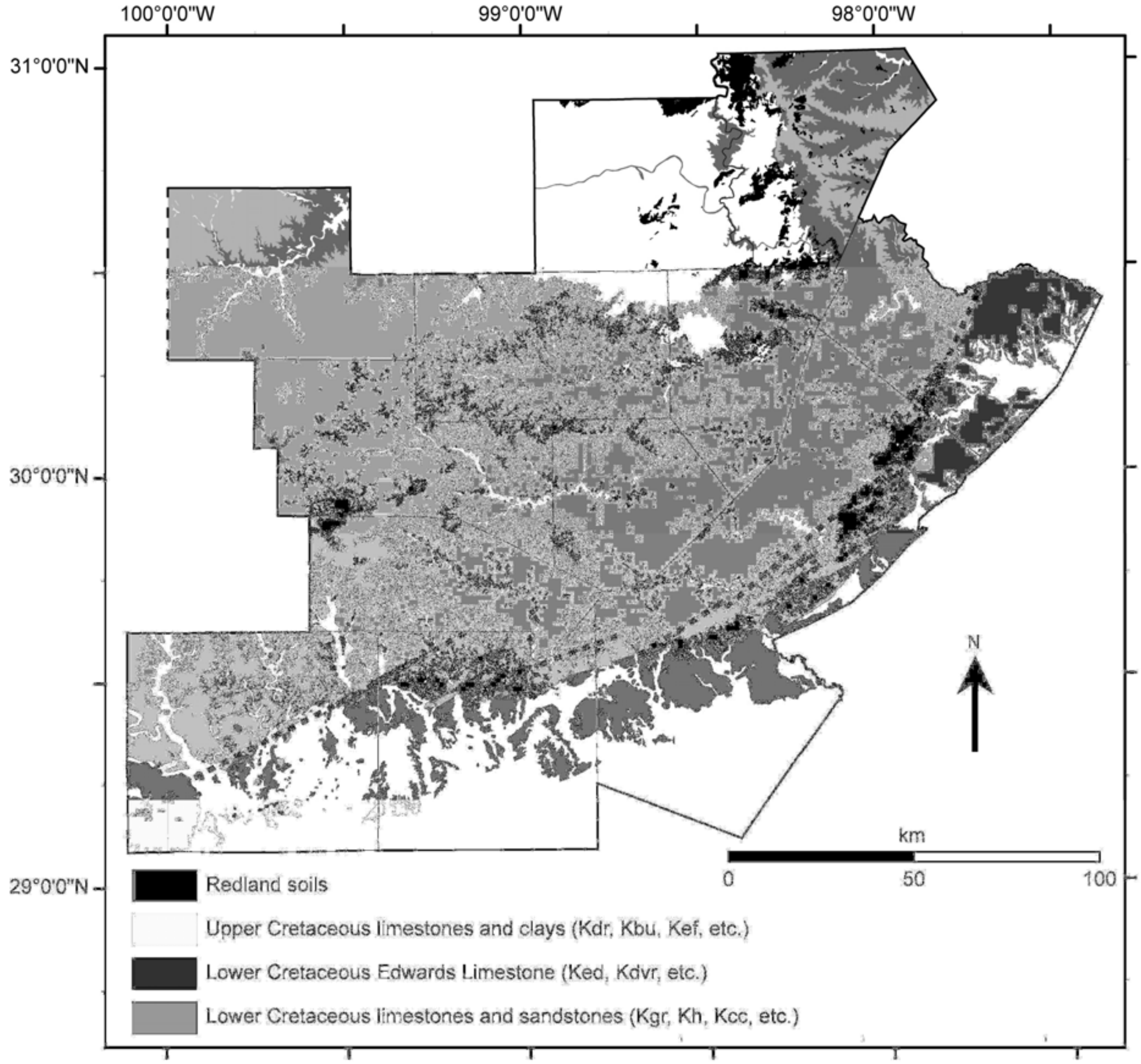

Figure 1. **Map of relict soils (Redland range site soils). Map shows only those soils classified as Redland range-type soils in black. Digital soil maps are from the USDA Natural Resources Conservation Service SSURGO database (available online at www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/). The underlying Cretaceous geology was simplified from the Geologic Atlas of Texas published by The University of Texas Bureau of Economic Geology and digitized by the U.S. Army Corps of Engineers (unpublished data available on CD-ROM). Map area covers Blanco, Bexar, Burnet, Comal, Hays, Gillespie, Kerr, Kendall, Llano, Medina, Travis, and Uvalde counties and the central and eastern portion of Kimble County. Heavy dashed lines indicate the approximate north-easterly trends of faults on the Balcones Fault Zone. Upper Cretaceous limestones and clays include rock types such as the Del Rio Clay (Kdr), Buda Limestone (Kbu), Eagle Ford Group (Kef). Lower Cretaceous Edwards Limestone includes the Edwards Limestone (Ked) and its stratigraphic equivalents such as the Devils River Limestone (Kdvr). Lower Cretaceous limestones and sandstones include rock types such as the Glen Rose Limestone (Kgr), Hensell Sandstone (Kh), and Cow Creek Limestone (Kcc). Precambrian, Paleozoic, and Cenozoic rock types are not mapped (white). Fault contacts that juxtapose the Glen Rose and Edwards limestones also mark an abrupt transition between the absence/presence of Redland soils. This distribution is consistent with an Edwards Limestone or younger silicate source to the relict thick soils.**

distribution of the relict thick soils (Figure 1). Redland soils occur dominantly on uplands north and west of the Balcones Fault Zone and occur at relatively lower elevations within the Balcones Fault Zone. Redland soils sometimes occur in drainages, which may reflect erosion and deposition of the upland soils. In both upland regions and at lower elevations within the Balcones Fault Zone, the Redland soils occur predominantly on the Edwards Limestone and stratigraphically-equivalent limestones and are largely absent on the older Glen Rose

The mineralogy and texture of the relict thick soils are consistent with a Del Rio Clay silicate source. Like the Del Rio Clay, some of the lower horizons of the relict thick soils lack quartz and feldspar. This may indicate that either the Del Rio Clay was providing silicates to the soils or that the soils have experienced diagenetic loss of quartz and feldspar due to intense weathering. The lower horizons of thick soils are clay-rich and have a clay content that is almost identical to the Del Rio Clay (Figure 2). The surface horizon of the relict thick soils is less clay-rich and has a similar texture as the modern thin soils (Figure 2). Thus, the modern thin and relict thick soils likely formed from different parent materials where the lower horizons of the relict thick soils may have been derived from the Del Rio Clay and the surface horizons of the thick and thin soils may have been derived from dust input.

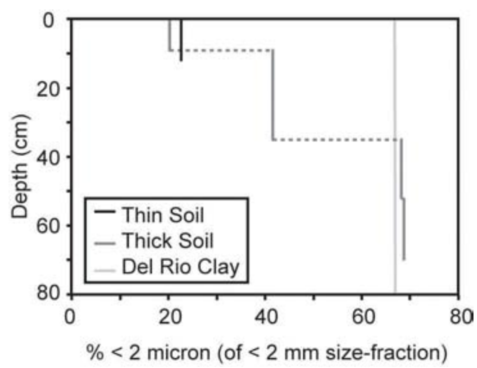

Figure 2. Clay-size fraction comparison. This figure shows variation in the percent clay-sized material with depth in the soil profile of a relict thick soil from the Kerr Wildlife Management Area. Also included are the clay-contents of a thin soil near Hall's Cave and the Del Rio Clay from Shoal Creek in Travis County.

The neodymium (Nd) isotope compositions (expressed as $\varepsilon_{Nd}(0)$ values) and depleted mantle model ages (DM ages) can provide information about the provenance of soil silicates and help identify the parent material. Edwards Limestone bedrock and regolith from Kerr County have $\varepsilon_{Nd}(0)$ values that are higher and DM ages that are lower than the values for the modern thin and relict thick soils (Figure 3). Thus, the Edwards Limestone is likely not the dominant parent material of either the relict thick or modern thin soils in Kerr County. $\varepsilon_{Nd}(0)$ values and DM ages of the lower horizons of relict thick soils from the Kerr Wildlife Management Area (KWMA) are similar to the $\varepsilon_{Nd}(0)$ and DM ages of the Del Rio Clay from Shoal Creek in Travis County (Figure 3). Surface soil horizons of thin and thick soils from the KWMA have Nd isotope compositions and DM ages that are very similar to modern dust collected from attics of historic buildings in Big Spring, Howard County (Figure 3). This supports the interpretation that local dust may be a source of silicates to surface soil horizons of the relict thick and modern thin soils.

The large range of $\varepsilon_{Nd}(0)$ values of the Del Rio Clay samples from several counties in the Edwards Plateau (Figure 3) may reflect the natural heterogeneity in the Nd isotope composition of the Del Rio Clay.

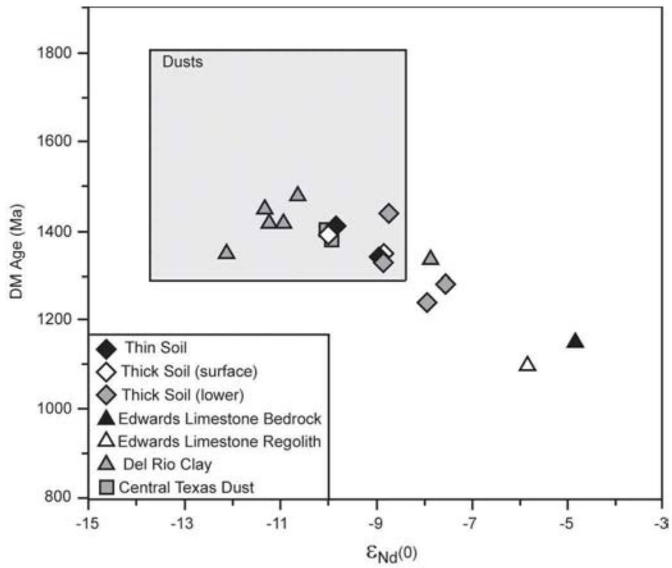

Figure 3. **Nd isotope systematics of soils and potential silicate sources. $e_{Nd}(0)$ and depleted mantle model ages (Ma) for soils and potential silicate sources ($e_{Nd}(0)$ values normalized using a Chondritic Uniform Reservoir $^{143}Nd/^{144}Nd$ ratio of 0.512638). Soils and potential silicate sources were completely digested in HNO_3 and HF; Sm and Nd were separated by ion exchange and analyzed by TIMS at The University of Texas. Thin soils are from the Kerr Wildlife Management Area (KWMA) and the vicinity of Hall's Cave in Kerr County. Thick soils are from the KWMA and road cuts in southwestern Kerr County. Del Rio Clay samples are from Travis, Comal, Val Verde, and Kerr counties. Edwards Limestone (Segovia Member) bedrock and regolith samples are from the vicinity of Hall's Cave and the Kerr Wildlife Management Area. Central Texas dust samples are from attics of historic (early 1900's) buildings in Big Spring, Howard County. Grey box denotes the range of values for modern dust collected over the Pacific and Atlantic oceans reported by Goldstein and others (1984).**

Conclusions

The geographic distribution of the Redland soils as well as the texture, mineralogy, and Nd isotope compositions of the relict thick soils are consistent with a Del Rio Clay silicate source. However, it is important to note that ancient alluvial sediment is another potential silicate source to soils on uplands of the Edwards Plateau (Woodruff and Abbot, 2004). The results presented in this study have not specifically addressed an ancient alluvial silicate source but do not preclude an ancient alluvial source, warranting further investigation.

In agreement with a Del Rio Clay source, Redland soils on the Edwards Plateau do not occur where the Del Rio Clay was never deposited. While most soils forming from the Del Rio Clay today are olive to tan, the pyrite-rich Del Rio Clay may oxidize to produce red soils, especially under more humid conditions in the past. In fact, red soils have been observed forming from the Del Rio Clay (i.e., the Felipe soils over the Del Rio Clay in Val Verde County). The presence of chert in the relict thick soils supports the interpretation that the underlying limestone provides some silicate material to the soil. Thus, we propose that *in situ* weathering of the Del Rio Clay, along with partial weathering of the upper portion of the chert-rich Edwards Limestone, produced the thick red, clay- and chert-rich soils that rest on the more resistant Edwards Limestone. Other studies have found overlying strata, rather than the underlying limestone, to be the parent material for soils occurring over resistant limestones (Driese and others, 2003; Laignel and others, 2002; Durn and others, 1999). These and our results support the conclusion that in other areas in central Texas and around the world an overlying clay-rich stratum may be the parent material for soils over resistant limestones more often than is recognized. If an eroded overlying stratum is the parent material for the relict thick soils on the Edwards Plateau, the soils can be considered a non-renewable resource.

Acknowledgments

We would like to acknowledge Mark Helper for providing assistance with GIS mapping, T. D. and Billie Hall and Bill Armstrong of the Kerr Wildlife Management Area for allowing access to study sites, and Scott Van Pelt of the USDA office at Big Spring for supplying historic dust samples.

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Jenny Cooke is a Ph.D. candidate in the Department of Geological Sciences at The University of Texas in Austin. Jenny graduated with a B.S. in geosciences from Trinity University in San Antonio, Texas, in 1999. In the fall of 1999, she came to The University of Texas to pursue her Ph.D. under the supervision of Dr. Libby Stern. Her research has been focused on using a variety of analytical techniques to better understand central Texas soil erosion and soil formation in the late Quaternary.

Brian Hunt discussing geology at the Elgin-Butler Brink Company (photo by Robert Mace)

presentation

april 4, 2005, wild basin preserve

Geologic mapping in the 21st century

Mark Helper
The University of Texas at Austin, Department of Geological Sciences

Pen-based field tablet computers, hand-held GPS receivers, GPS-enabled Personal Digital Assistants, mapping-grade GPS instruments, GIS software for field data capture, and custom digital field data entry forms: What's it all about? To what extent are these emerging and in some cases mature technologies adaptable to geological field work? What do they have to offer? How robust and practical are they? Is it worth the time, effort and expense to adopt them or is it still too soon? This talk examines experiences over the last eight years in attempts to adapt these technologies to traditional geological field work. These span the gamut from relatively fool-proof, inexpensive GPS receivers and gridded paper maps to GPS-equipped, ruggedized tablet computers running sophisticated GIS software. The advantages, problems and effort involved in three specific approaches will be discussed, with an emphasis on the relatively new and promising aspects of tablet computers, digital ink and pen-based drawing and data capture tools.

Mark Helper holds degrees in Geology from the University of Illinois (B.S.) and The University of Texas at Austin (Ph.D.). He is a Senior Lecturer in the Department of Geological Sciences, The University of Texas at Austin, where, for the past 20 years, he has taught classes in introductory and advanced field geology, GIS/GPS applications in earth sciences, and gems and gem minerals and led countless field trips in central Texas. He also serves as the Department's Field Camp Director, organizing and team-teaching a summer geology field camp that annually visits field localities in west Texas, New Mexico, Utah, Colorado, Wyoming, and Montana and as curator of two large gem and mineral collections. His research interests in mountain building processes have led to NSF-funded field studies of portions of the Klamath Mountains in northern California, the Llano uplift of central Texas, the Picuris Mountains of northern New Mexico, and the Shackleton Range and Heimefrontfjella of Antarctica. He has received several awards for excellence in undergraduate teaching, the Antarctic Service Medal of the U.S. Antarctic Program, the American Federation of Mineralogical Societies Honorary Scholarship Award, and a Faculty Excellence Award from the Houston Oil and Minerals Corporation.

presentation

may 2, 2005, bureau of economic geology

Volcanoes in a capsule: Applying experimental petrology to understanding volcanic eruptions

James Edward Gardner
The University of Texas at Austin, Department of Geological Sciences

One of the most powerful forces on Earth is an explosive volcanic eruption, which can pose serious hazards to the local and global population. Such eruptions are driven by the exsolution of gases that were dissolved in the magma at depth. All of the dynamic degassing processes that occur during eruptions are recorded in the pumice and ash that is produced, yet those are accumulated records, with each event of bubble formation being over printed by the last. To reconstruct the various events that occur during magma ascent and eruption, we are using specially designed experimental petrology techniques in the newly developed Experimental Petrology Laboratory in the Jackson School of Geosciences at The University of Texas at Austin. We use these techniques to investigate the rates and kinetics of bubble nucleation, growth, and coalescence and melt crystallization to constrain the dynamical processes that occur during degassing of magma. In this talk, we will discuss some of the constraints we have placed on bubble dynamics in magmas, and how those processes may control the intensity and style of volcanic eruptions.

Dr. James Edward Gardner is currently Associate Professor at the University of Texas Department of Geological Sciences, Jackson School of Geosciences. He received his Ph.D. in 1993 from the University of Rhode Island Graduate School of Oceanography in Narragansett, Rhode Island. He holds a M.A. in Geology from Washington University in St. Louis, Missouri, and a B.S. from Southern Methodist University in Dallas.

posters

march 7, 2005, bureau of economic geology

The Austin Geological Society participated in the exhibit judging at the Austin Regional Science Festival in February 2005, specifically of the Middle and High School Earth Science and Environmental categories. Six students were given Certificates of Recognition for their projects and were invited to present their exhibits at the annual AGS poster session meeting in March. They were also invited to submit abstracts of their projects for publication in the AGS Bulletin. The students submitted the following abstracts for publication.

Is all water equal?

Trey D. Henninger

Water is an everyday item that most people take for granted. We all rely on water to live. But what do you really know about it? Water can be determined as hard or soft. The hardness of water can be defined as the concentration of calcium and magnesium ions expressed as calcium carbonate. Hard water can even damage water heaters, plumbing, waste soap, detergents, and shampoo. When I found out about the term water hardness, I instantly became curious about this fascinating subject. The purpose of my experiment was to determine the differences in water hardness from different water sources around Texas. Also a purpose was to prove or disprove the fact that water softeners work. Procedures included collecting water from a variety of sources. Water sources were: Austin, Barton Springs, Wimberley Well water, Round Rock (both softened and non-softened), and Hutto water (both softened and non-softened). I measured their hardness using test strips that were color-coded and compared the color to the color chart on the bottle the strips came in. By comparing the hardness of the sources, I verified which source had the hardest water. My results were that the Hutto water non-softened was the hardest tied with Barton Springs and Wimberley Well water with 15 grains per gallon of calcium carbonate ions. The softest were Hutto and Round Rock water softened with no grains per gallon of calcium carbonate ions. My conclusion is that water's hardness does vary when taken from different water sources.

Trey D. Henninger is a student at Clint Small Middle School, Austin, Texas.

The perfect mud pie

Jessica Guest

The purpose of this experiment is to discover how the amount of clay, silt, and sand in soil affects its plasticity. Depending on these amounts some soils will crack and crumble more than others. In this experiment the plasticity of a soil sample is compared to its content.

First, four soil samples were collected. Next, a procedure that revealed the content of each sample was carried out. Sample A was high in both sand and clay with a small amount of silt. Sample B was very high in clay: it had some sand, and was very low in silt. Sample C and D both had little sand, extreme amounts of silt, and almost no clay.

Next, the samples were formed into dome shapes and had several tests run on them. The tests included, cutting the domes in half, separating the two pieces, and finally lifting the halves. All samples, with the exception of sample D, cut smoothly, both sample A and B could be easily separated, but only sample B could be lifted with no cracking or breaking.

The two soils with high silt content crumbled and cracked under a small amount of pressure. The two soils containing large amounts of clay could be moved easily, but only the sample with the most clay and the least silt could be lifted and put under pressure with minimal damage. Thus, soils with larger clay content and less silt have a higher plasticity, making sample B the "perfect mud pie."

Jessica Guest is a 9th grade student at Vista Ridge High School, Austin, Texas.

Pedestrian impact on soil organisms beneath urban park trails: Walnut Creek Metropolitan Park, Austin, Texas

Ami Kumordzie and Tania Rosales

Walnut Creek Metropolitan Park is traversed by several trails carved out for the use of bikers, runners, and dog-walkers. This constant level of human interaction inevitably leads to trampling and compaction of the park's soil, thus affecting the numbers and types of its soil organisms. The purpose of this project was to study the effect of proximity to these biking trails on the abundance and diversity of organisms found in the soil. At the start of this project, it was hypothesized that the abundance and diversity of the organisms would increase as the proximity to the trail decreased.

Six sets of soil samples were collected in different areas throughout the park. At each collection point, four soil samples were taken at different distances from the trail: on the trail, 0.3 m off the trail, 3 m off the trail, and 6 m off the trail. The contents of these samples were then analyzed with three different techniques. First, all of the organisms visible with the naked eye were removed. Next, arthropods were filtered out of the soil with a Burlese Funnel and examined under a dissecting scope. Finally, nematodes and other micro-soil organisms were filtered out of the soil and examined under a compound microscope.

On average, soil organisms found farther away from the trail were more abundant than those found closer to the trail. However, contrary to this trend, Kingdom Protista was very abundant on the trail as well. Soil organisms were most diverse in the location farther from the trail. Overall, the data supports the original hypothesis.

Ami Kumordzie and Tania Rosales are students at the Science & Liberal Arts Academy at LBJ High School, Austin, Texas.

Image quality

Megan M. Pendleton

This project is about improving image quality in a telescope. The particular telescope was built for last year's science fair. The two aspects of good image quality are collimation and focus. The method used for determining good focus also provides a way to measure improvement in image quality. During collimation a tool set was used along with a step-by-step method to achieve good alignment with the two mirrors and focuser/eyepiece. A Web camera was mounted at prime focus of the telescope to capture the star image in order to assess its quality. An analysis of the star image was performed using a computer program called MatLab. This analysis determined the image's degree of focus. Using the analysis, a motor connected to the focuser, and a process written to determine an image's prime focus, the telescope could focus automatically.

Megan M. Pendleton is a student at Vista Ridge High School, Cedar Park, Texas. At the Intel International Science and Engineering Fair, held in Phoenix during May, Megan was awarded second place in the optics and photonics category for her project.

field trip

Fall 2004 Fieldtrip

Tectonic history of Southern Laurentia: A look at Mesoproterozoic, Late-Paleozoic, and Cenozoic structures in Central Texas

trip coordinators:

April Hoh and Brian Hunt

contributors:

Eddie Collins, Tom Ewing, April Hoh, Brian Hunt, Brann Johnson, Leon Long, and Sharon Mosher

The November 13, 2004, fieldtrip to the Llano Uplift of Central Texas focused on the structures that tell the rich tectonic history of the southern margin of Laurentia (Figure 1). Forty-five attendees visited four stops in Burnet and Travis counties where structures reveal three major tectonic events spanning over one billion years!

Dr. Tom Ewing set the stage with a great structural overview discussing why the Llano Uplift is called an "uplift." His discussion and paper presented a big-picture overview of the numerous regional structures that all intersect at the Llano Uplift.

At Devil's Waterhole in Inks Lake State Park (Figure 2) April Hoh presented her interpretation of the structural history of metamorphic and igneous units exposed at Devil’s Waterhole as well as Dr. Sharon Mosher’s theories on the Precambrian tectonic setting of the Llano Uplift. Fantastic multiple generations of ductile structures are exposed at the picturesque stop and the rain held off long enough for everyone to explore the area. Inks Lake is a popular geologic stop, where we found ourselves surrounded by geology students from Lamar University (we even made some early guidebook sales!).

Next we proceeded to a scenic overlook and lunch stop on the margin of Devil's Backbone (structural graben) where Dr. Brann Johnson (Texas A&M University) explained the late Paleozoic/Ouachita-related faulting throughout the region (Figure 3). From this vantage Dr. Johnson elaborated on his tectonic model for the formation of these prevalent structures and the relationship to reactivation of older structures and crustal weakness.

The next stop was at Hoover's Point (Figure 4), a beautifully exposed section of faulted Cambrian units and the southern end of Devil's Backbone. Dr. Johnson then led the discussion and explained the kinematics and timing of the numerous and complex faults exposed. He presented his detailed maps of the roadcut that illustrate his stratigraphic and structural interpretation of the rocks. Many of his detailed maps and discussion of his preliminary work can be found in the guidebook. Dr. Johnson explained that his work is in progress. We look forward his continued interpretations of this fascinating outcrop in the future.

As we headed home towards Austin and crested the Balcones Escarpment, Eddie Collins closed out the trip by discussing and summarizing much of what is known about Balcones-age faulting. The group made a very brief stop at a spectacular outcrop of faulted Edwards Group and Georgetown Formation at the Mopac–Loop 360 intersection.

AGS Guidebook 29 guidebook contains contributions from many distinguished researchers and experts. Their papers tell part of the story of a rich tectonic history recorded on the southern margin of Laurentia. The guidebook titled: "Tectonic History of Southern Laurentia: A look at Mesoproterozoic, Late-Paleozoic, and Cenozoic Structures in Central Texas" (about 90 pages) is for sale at the Bureau of Economic Geology.

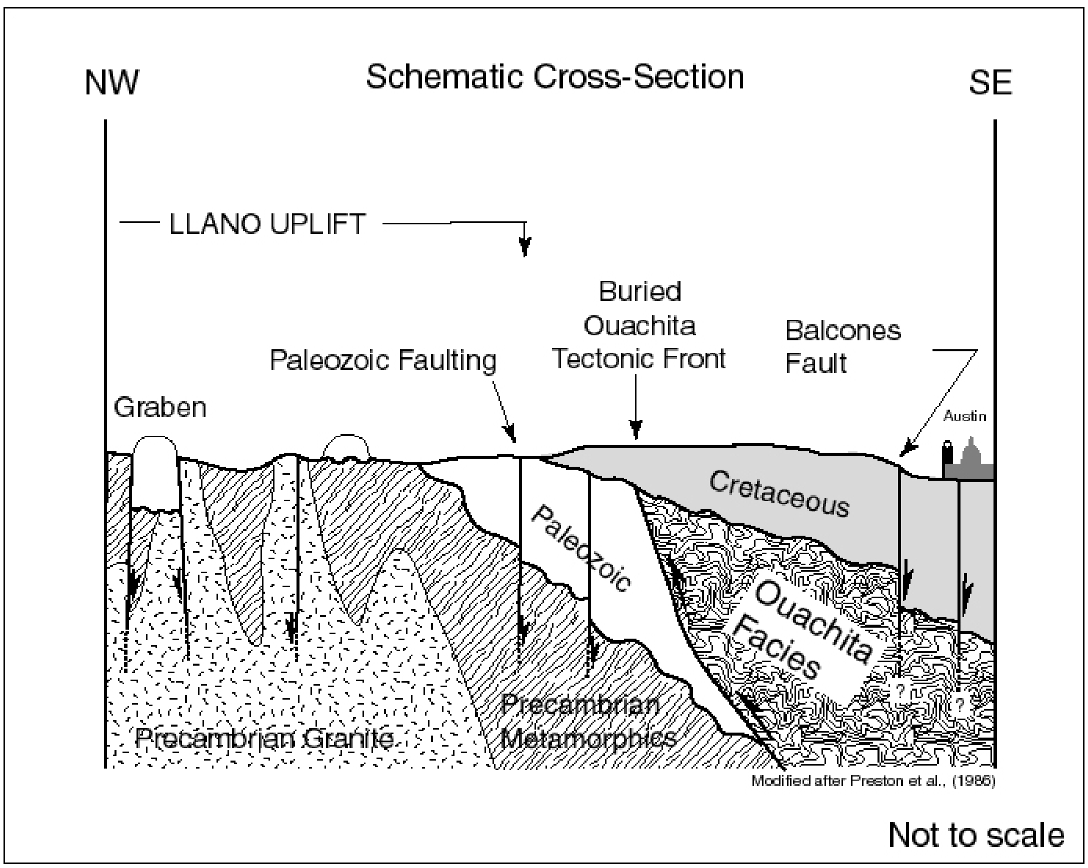

Figure 1. Schematic cross-section and overview of the major tectonic and structural features visited and discussed on the fieldtrip.

Figure 2. Stop 1 Devil's Waterhole, Inks Lake State Park. April Hoh (center) discusses Precambrian tectonic history of the Llano Uplift and the site-specific structures and units exposed at the stop (photograph by Craig Caldwell).

Figure 3. Stop 2 Scenic Overlook on Devil's Backbone. Right to left, Eddie Collins, Dr. Mark Helper, Dr. Brann Johnson, Dr. Thomas Ewing, Brian Hunt, and April Hoh (photograph by Craig Caldwell).

Figure 4. **Stop 3 Hoover's Point Overlook. Dr. Brann Johnson discusses the Paleozoic-age faulting exposed in the roadcut (photograph by Craig Caldwell).**

field trip

Spring 2005 Fieldtrip

Geology, frontier history, and selected wineries of the Hill Country appellation, Central Texas

trip leaders:

Pete R. Rose and C. M. Woodruff, Jr.

trip coordinators:

Craig Caldwell and Rima Petrossian

trip summary:

Robert E. Mace

Central Texas is blessed with great geology, great history, and, fortunately, great wines. The April 23, 2005, field trip offered trip attendees an opportunity to experience (and sample!) all three with a gourmet meal in the middle. Our first (rolling) stop was near the Granite Mountain Quarry, the source of the pink granite in the state capital building. After that, we stopped at Hoover Point Overlook where Dr. Rose discussed local geology and the rich history of the area. We then moved on to Fall Creek Winery, which was just in time as trip attendees were beginning to get thirsty. After a hearty tour of the facilities near Lake Buchanon, we sampled the wares, primarily out of scientific curiosity. After Fall Creek Winery, we rolled through Llano and stopped at the Bell Mountain Vineyards where the owner/operators, Bob and Evelyn Oberhelman, discussed raising grapes (including how they use giant fans to create microclimates to protect the plants from freezes) and making wines. This stop also required a bit of scientific exploration and debate of the vineyard's products. After a gourmet meal, we made our way toward Fredericksburg to learn a little history about the Hoo-Doo War and local landmarks before stopping in at Becker Vineyards east of town. We learned about the wine-making process used by this vineyard, which required ample sampling of their products to better understand the results of their processes.

All in all, the trip was a great success with a friendly crowd that seemed to get more and more friendly (and sleepy…) as the day wore on. Once back in Austin, I admired the dedication of the trip's attendees: many of whom had collected samples, conveniently supplied in large bottles by each of vineyards, for additional study at home.

Figure 1. Pete Rose (in hat and vest, hand outstretched) and trip attendees at Hoover Point Overlook discussing local geology and history (photo by Robert Mace).

Figure 2. Learning about winemaking at Fall Creek Winery (photo by Craig Caldwell).

Figure 3. Bob Oberhelman, who, along with his wife Evelyn, owns and operates Bell Mountain Vineyards, discusses the trials and tribulations of growing grapes in the Hill Country (photo by Robert Mace).

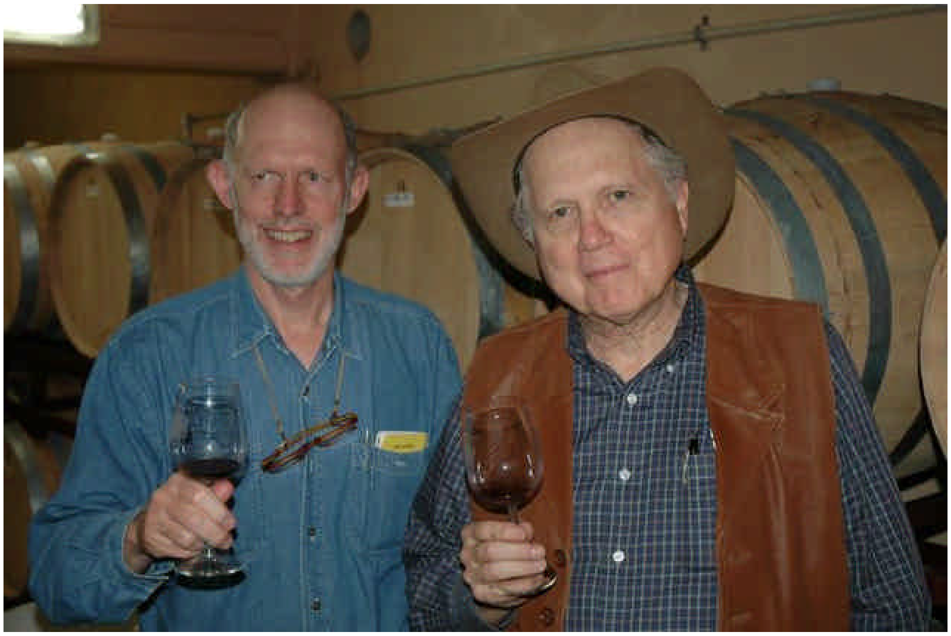

Figure 4. **Trip leaders Chock Woodruff (left) and Pete Rose sampling Fall Creek Vineyard's products (photo by Craig Caldwell).**

Figure 5. **Janie Hopkins waiting to collect a sample from Fall Creek Vineyards (photo by Robert Mace).**

Figure 6. Pete Rose (rear view) discussing local history and paying respects to William Scott Cooley (photo by Robert Mace).

Figure 7. Group photo of field trip attendees "The Terrior-iers" (photo by Craig Caldwell).

technical paper

Inner Space Cave: Discovery and geological and paleontological investigations

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Abstract

In 1963 a large cave was found by the Texas Highway Department while conducting foundation core drilling for a railroad overpass of Interstate Highway 35 south of Georgetown, Texas. A 2-foot diameter access hole was drilled into the cave. Exploration by highway department personnel and members of the Texas Speleological Association found an extensive cavern underlying the site of the proposed overpass. The landowner, Dr. Laubach, received permission from the Texas Highway Department to develop a commercial cavern under the highway, and it was named Inner Space Cave. The cavern is located in the Cretaceous Edwards Formation and within the Balcones Fault Zone, both known for having caves and sinks.

Further exploration by paleontologists discovered numerous bones of prehistoric and extinct vertebrate species. Fossil vertebrates were recovered from five localities in the cave complex. These five locations are the positions of former entrances to the cave that were open at different times during the late Pleistocene. Radiocarbon dates show that three of the entrances were open 23,000; 15,000; and 13,000 years before present.

The fossils represent the fauna that lived in Texas during the late Pleistocene and include a number of extinct species as well as extant species no longer found in central Texas. Some differences in the faunas from the five localities may indicate changes in the fauna through time.

Discovery

During the spring of 1963 when the Texas Highway Department (currently named the Texas Department of Transportation) was conducting foundation core drilling for a railroad overpass south of Georgetown, Texas, a large cavern was discovered (Sansom, 1996). The overpass was a part of the new Interstate Highway 35 bypass of Georgetown. The staff geologist for the Bridge Division of the Texas Highway Department, James Sansom, was contacted and exploration of the cavern was done following the drilling of a two-foot diameter access hole into a large subterranean room. Texas Highway Department personnel from both the Bridge Division and District 14 conducted exploration and surveying of the larger portions of the cave. Subsequently more intensive exploration and mapping were done by local spelunkers affiliated with the Texas Speleological Association (Figure 1).

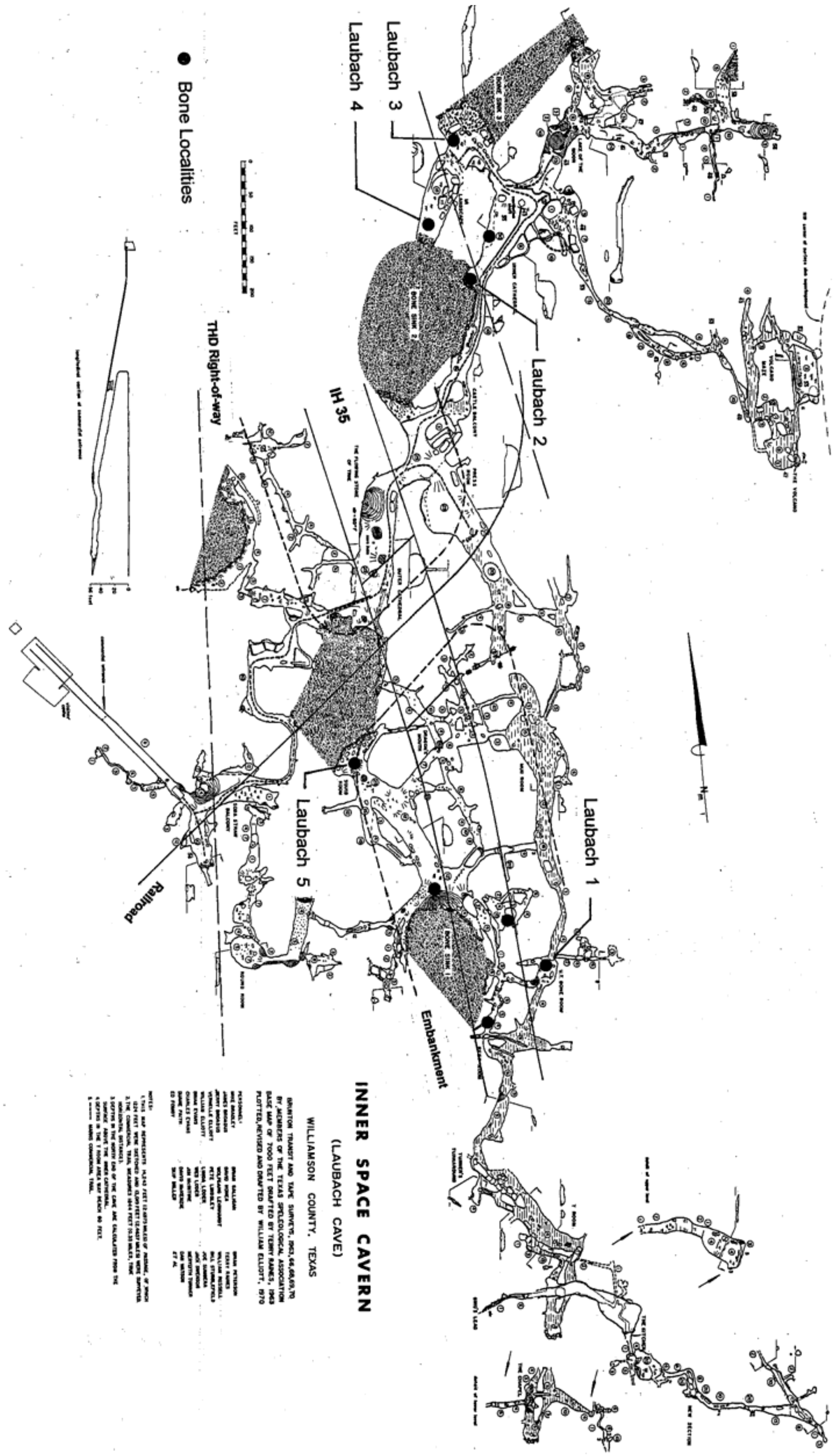

Figure 1. Map of Inner Space Cavern with Bone Locations and the route of IH 35 and its overpass over the Georgetown Railroad super-imposed on it (cavern map prepared by members of the Texas Speleological Association).

Geological Investigation

The first people to enter the cave were Jack Bigham, District 14 technician; James Sansom, Bridge Division geologist; Horace Hoy, Bridge Division foundation engineer; and two engineers with District 14, Bill Schultz and Lawrence Schultz. The five people who entered the cave for the first time were lowered into the cave on the kelly of the auger rig that had drilled the access hole. Jim Cole of District 14 drilled this hole (Figure 2). When core driller Sylvan Turner first drilled into the cave, he drilled through 33.5 feet of limestone bedrock. His bit broke through the ceiling of the cave and fell approximately 25 feet to the floor of the cave where it locked up in some flowstone.

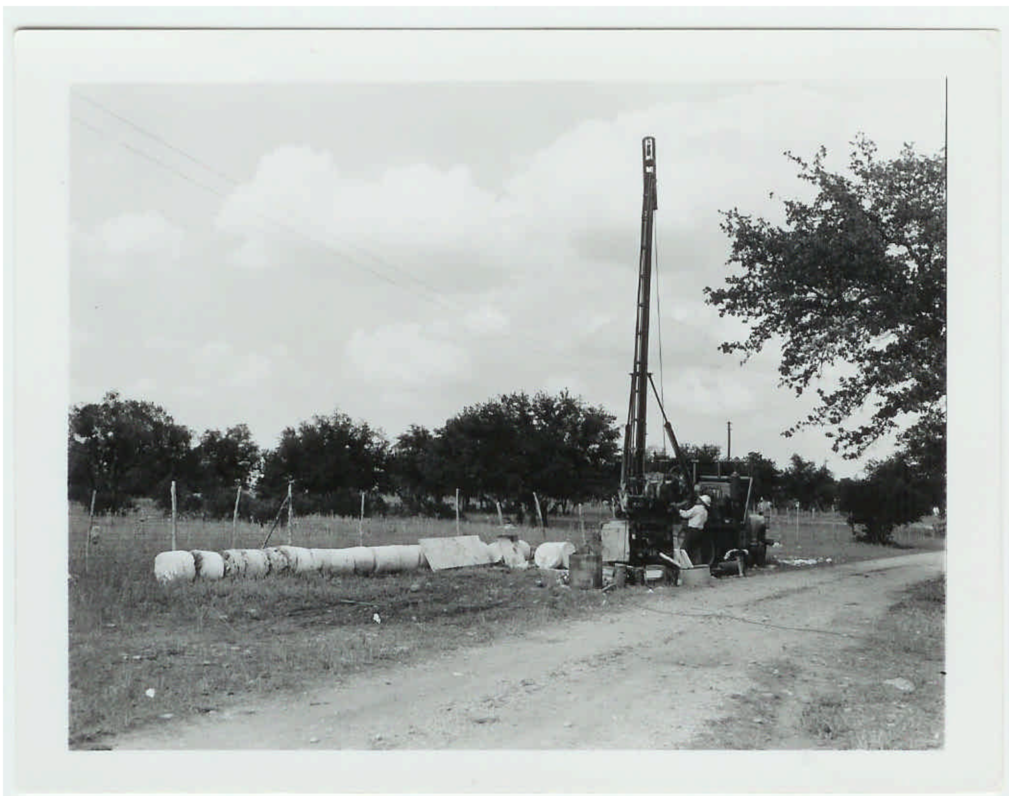

Figure 2. View of the auger rig of the Texas Highway Department District 14 and driller, Jim Cole, when the two-foot access hole to cavern below had been completed (photo taken by Jack Lewis, photographer with the Travel and Information Division of the Texas Highway Department, 1963).

Several trips were made into the cave by District 14 personnel including a survey crew that included Bill Johnson, Don Burch, and Leroy Sumner that mapped the extent of the larger more accessible portions within the right-of-way of the proposed highway and overpass (Figure 3). In the initial exploration of the cave, the air was stagnant and no natural openings to the outside were found. Smoke from a match and old Blue Dot flash bulbs used in photography would not disperse. The survey crew, accompanied by James Sansom, had to go to the surface several times to get fresh air. The numerous core holes drilled into the cave were used to lower light bulbs on cords to provide light for the survey (Figure 4).

Figure 3. View of the inside of the Discovery Room of the cavern where Bill Johnson, Texas Highway Department Survey Crew Chief, was being lowered into the cavern on the auger rig kelly through the two-foot diameter access hole. James Sansom was holding the guide rope on the kelly (photo taken by Jack Lewis, photographer with the Travel and Information Division of the Texas Highway Department, 1963).

After the first exploration and surveying was completed, local members of the Texas Speleological Association and paleontologists visited the cave. Dr. Bob Slaughter of Southern Methodist University was the first paleontologist to collect and study the fossil bones. This resulted in the first publication (Slaughter 1966) on the material recovered from the locality later designated Laubach 1. Later Dr. William Akersten, then a graduate student, and Dr. Ernest Lundelius, both of the University of Texas, explored and recovered animal bones from various localities in the cave (Lundelius, 1985).

Texas Highway Department engineers determined that the hard limestone rock that overlies the cave was of sufficient strength to support the planned overpass, and Dr. William W. Laubach, the landowner, received permission from the Texas Highway Department to develop the cavern commercially into what is now called Inner Space Cavern. An inclined shaft was excavated on Dr. Laubach's land outside and adjacent to Texas Highway Department right-of-way on the west side of Interstate Highway 35 as a new entrance to the cave. Considerable construction was done to create walkways that extend under the Interstate Highway 35 right-of- way and to the east side of it, as shown by Figure 1. On the east side of Interstate Highway 35 a vertical shaft was drilled for an outside air source on the northeast end of the commercial section of the cave.

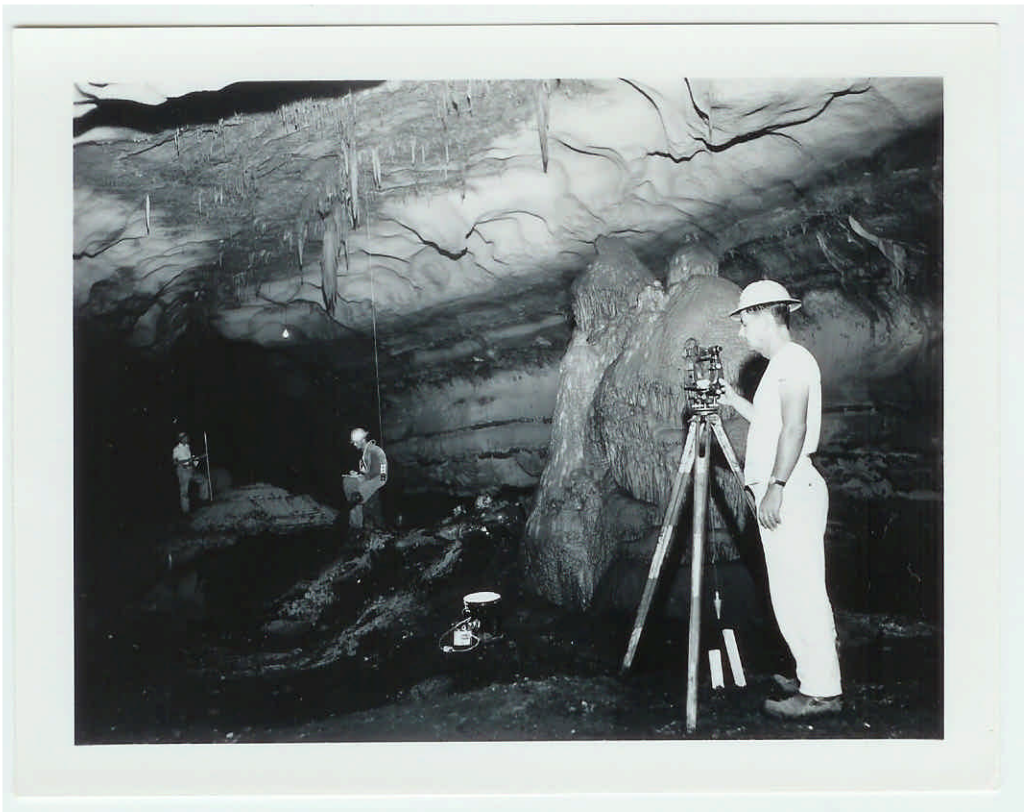

Figure 4. Survey crew working inside the Discovery Room with Leroy Sumner operating the survey instrument, Bill Johnson recording survey data, and James Sansom holding survey rod at a distance. Note light on cord hanging down from roof of cavern providing light for surveying (photo taken by Jack Lewis, photographer with the Travel and Information Division of the Texas Highway Department, 1963).

Geologic Setting

Inner Space Cavern was formed in the Edwards Formation of Lower Cretaceous age, as were numerous caves in Central Texas. The Edwards Formation is composed of a high percentage of calcium carbonate—it is very susceptible to dissolution by acid water over time. Hence caves, sinks, and other solution features are common in this rock unit. The cavern is located in the Balcones Fault Zone, which increases the potential for rainwater to flow into the formation by way of faults, joints, and other fractures and to dissolve the calcium carbonate to form solution features. During periods of high rainfall the water table often rises in the cave and remains for a period of time until it recedes. Geologists suspect in the past, when some of the collapsed areas in the cave were open to the surface, that high rainfall washed in sediment and moved through the caverns rapidly and abraded the cave walls and ceiling in addition to dissolving them. The extensive deposits of red clay in the cavern are derived from terra rossa soils that were washed in from the surface. These red-brown soils characteristic of karst areas are found as relict soils over the Edwards Plateau. Terra rossa soils have been mapped in the Central Texas area by Dr. Keith Young (Young, 1986).

Cave passages are commonly controlled by faulting, cross faulting, and associated joints in the country rock, and this is true of Inner Space Caverns (Figure 1). In the vicinity of the cave, faults have been mapped that strike from N 8 to 23 degrees E (Collins, 1997). Alignments of the predominant structure in the mapped portion of Inner Space Cave range from N 21 to 27 degrees E, which is reflected in the orientation of the passageways of Inner Space Cavern. The displacement along faults of the Balcones Fault Zone near the cavern in Williamson County is reported to be up to 150 feet. When Sansom was lowered into the cavern during the early exploration, he observed that the upper 10 to 15 feet of the rock exposed in the access core hole resembled the limestone of the Georgetown Formation.

The exposure was a dry chalky white nodular limestone of uniform lithology that is typical of the Georgetown Formation. Below this, the rock abruptly changed to a honeycombed, cherty, massive, dolomitic limestone typical of the Edwards Formation. Water was observed flowing out of the vuggy openings, down the wall of the core hole, and dripping into the cavern below. The cave is restricted to the Edwards Formation.

During exploration of the cave, numerous stalagmites, stalactites, flowstone, soda straws, and other speleothems were observed. Many of the speleothems were stained with various shades of red. The floor of much of the cave was covered with red mud and, in places, bat guano where the floor was not covered with water. Numerous nodules and discontinuous beds of chert as well as invertebrate fossils are exposed in the cave walls. Five closed collapsed sinks that were most likely natural openings at some time in the past were mapped by the spelunkers. As shown in Figure 1, most of the animal bones found in the cavern are in the vicinity of the sinks. The bones identified by Dr. Ernest Lundelius and others are discussed in this paper.

Paleontological Investigations

Inner Space Cavern (Laubach Cave) is an important vertebrate fossil locality because it contains fossiliferous deposits from several different time periods in the late Pleistocene and gives an idea of the changes in the fauna of this area. In addition, the chronology of the speleothem growth record overlaps that of the vertebrate fossils and makes possible a comparison of the climatic interpretations based on the two kinds of data.

Location of bones and taphonomy

All the fossil bones are associated with debris cones that mark former entrances to the cave system. They are rare or absent in areas away from the old entrances which is in accordance with the observations that, aside from bats and a few birds that practice echolocation, most animals that enter caves voluntarily do not go far from the lighted areas of the cave. To date five localities within the cave system have produced fossil bones (Lundelius, 1985). The localities with Texas Memorial Museum locality numbers are as follows: Laubach 1 (TMM 40673), Laubach 2 (TMM 40722), Laubach 3 (41343), Laubach 4 (TMM 41505), and Laubach 5 (TMM 41465) (Figure 1).

Laubach 1 is located in the southern part of the cave system at the edge of Bone Sink 1. Bones were collected from several places around the edge of this debris cone (Figure 1). In some places they were concentrated (Figure 5). It is presumed that the bones from the various places around the debris cone are the same age. They were reported by Slaughter (1966).

Laubach 2, located on the northeast edge of Bone Sink 2 (Figure 1), is the only site known to have had an opening to the surface during historic time as evidenced by the presence of some modern garbage along its edge when the cave was first entered by investigators. The entrance shaft is currently plugged by sediment and contains the partial skeleton of a mammoth. Below is a characteristic debris cone with some bone on the surface. These bones are covered by a thin layer of travertine. At the base of the cone is a basin in which one small excavation

Figure 5. Skulls of the extinct peccary (Platygonus compressus) in place at Laubach 1.

was carried out. The material from the surface of the debris cone, the excavation in the basin, and the mammoth lodged in the shaft of the original opening may not be same age.

Laubach 3 is located at the southwest edge of Bone Sink 3 (Figure 1). This is at the base of a debris cone of large limestone boulders that have been heavily cemented by travertine. The fossiliferous sediments are not cemented but seem to be closely related to the part of the debris cone that underlay the cemented boulder layer. The sediments are darker colored than those from the other fossiliferous deposits in the cave, and the bone is stained a dark brown. This is in contrast to the light cream color of bones from the other localities in the cave.

Laubach 4 is located on the north flank of the same debris cone as Laubach 2 (Bone Sink 2). A small trench excavated at the base of the debris cone produced some evidence of aboriginal human activity in the form of a few flint flakes but no recognizable artifacts. These are cataloged in the collections of the Texas Archaeological Research Laboratory under the number 41WM 231. Remains of a number of small animals were also recovered (Table 1).

Laubach 5 is located on the southeast flank of a debris cone approximately 220 feet (67.6 meters) north-northwest of Bone Sink 1. The fauna is similar to that from Laubach 1 and 2.

Age of the faunas

Three radiocarbon dates are available from Laubach localities 1, 2, and 3. They are all based on bone, mostly long bones, of small mammals that have the denser cortical bone. The dates are based on the method developed by Haynes (1968). In this technique, cortical bone is powdered and leached *in vacuuo* with acetic acid before the washed and dried bone is reacted a second time with HCl or phosphoric acid. Dilute acetic acid reacts immediately with calcite and much more slowly with the bone apatite, thereby removing secondary carbonate first but not appreciable amounts of the indigenous carbonate apatite's CO_3^{-2}. When the bone powder is reacted with stronger acids as HCl or H_3PO_4, these reagents dissolve the carbonate apatite and release CO_2, which is subsequently used for radiocarbon dating. The resulting age measurement is an "inorganic bone carbonate date" and contrasts with radiocarbon dates on the organic phase of bone or teeth, the collagen fraction. The procedure is effective for removing pedogenic and groundwater-derived calcium carbonate. However, subsequent studies (Surovell, 2000) have found that the indigenous carbonate in bone apatite will exchange at the molecular level and that bone apatite dates may still be compromised by unknown amounts of molecular-level, secondary carbonate contamination of the hydroxyapatite crystal. In limestone terrains, the common error will be dates being too old, but this is not always the case and there currently exist no criteria to determine the direction or the magnitude of the error. This new research indicates that there is still likely to be contamination of the bone crystallites by carbonate from surrounding sediments and that these dates should be regarded as minimum estimates of the ages of the units dated (Stafford, 1998; Stafford and others, 1991).

The fauna

The faunas recovered to date from the various localities in the cave are summarized in Table 1. The reptiles and amphibians have not been studied in detail, and the faunal lists of these groups should be regarded as provisional. The fauna is typical of the late Pleistocene faunas of Texas, but the presence of assemblages of different ages in one restricted area provides some information on possible faunal changes during the late Pleistocene.

Table 1. Faunal list from Laubach Cave

Taxon	*Laubach locale* 1	2	3	4	5
Class Amphibia					
Rana pipiens (leopard frog)		x	x		
Class Reptilia					
Terrapene carolina (Eastern box turtle)		x			
Sceloporus sp. (fence lizard)		x	x		
Coluber sp. (racer)		x	x		
Elaphe sp. (rat snake)		x			
Heterodon sp. (hog-nosed snake)		x			
Pituophis sp. (bull snake)		x	x		
Thamnophis sp. (garter snake)		x	x		
Agkistrodon contortrix (copperhead)		x	x		
Crotalus sp. (rattlesnake)		x	x		x
Class Mammalia					
Didelphis marsupialis (o'possum)		x	x		
Tadarida brasiliensis (Brazilian free-tail bat)			x		
Myotis sp. (little brown bat)			x		
Cryptotis parva (least shrew)		x		x	
Blarina carolinensis (Southern short-tailed shrew)				x	
Felis onca (jaguar)	x		x		
*Homotherium serum (saber-toothed cat)		x			
Mephitis mephitis (striped skunk)		x			
Spilogale putorius (spotted skunk)			x		
*Canis dirus (dire wolf)			x		
Canis latrans (coyote)			x		
Urocyon cinereoargenteus (gray fox)			x		
*Tremarctos floridanus (spectacled bear)			x		
*Mammuthus sp. (mammoth)		x			x
*Equus sp. (horse)		x	x		
*Platygonus compressus (extinct peccary)	x		x		x
Odocoileus sp. (deer)			x		
*Tetrameryx shuleri (four-horned antelope)			x		x
*Camelops sp. (camel)		x			
*Dasypus bellus (large armadillo)			x		
*Glyptotherium floridanum (glyptodont)			x		
*Megalonyx jeffersonii (ground sloth)			x		
Cynomys ludovicianus (prairie dog)	x		x		
Microtus sp. (vole)		x	x	x	
Neotoma sp. (packrat)		x	x		
Peromyscus sp. (deer mouse)		x	x		
Sigmodon hispidus (cotton rat)		x	x		
Geomys sp. (gopher)		x	x	x	
Perognathus hispidus (hispid pocket mouse)				x	
Perognathus sp. (pocket mouse)				x	
Dipodomys elator (Texas kangaroo rat)			x		
Dipodomys sp. (kangaroo rat)		x			
Lepus californicus (jackrabbit)		x	x		x
Sylvilagus sp. (cottontail)	x	x	x		

* connotes extinct taxa

The oldest assemblage is from Laubach 3, dated at 23,230±490 years before present. It contains remains of several species not found in other localities in the cave (Table 1). These are spectacled bear (Tremarctos floridanus) (Figure 6), glyptodont (Glyptotherium floridanum) (Figure 7), large armadillo (Dasypus bellus), dire wolf (Canis dirus) (Figure 8), an extinct species of pronghorn, Jefferson's ground sloth (Megalonyx jeffersonii), and Brazilian free-tailed bat (Tadarida braziliensis) (Figure 9), and Texas kangaroo rat (Dipodomys elator). It also has remains of species found in some of the other Laubach localities: flat headed peccary (Platygonus compressus), black tailed prairie dog (Cynomys ludovicianus) (Figure 10), jaguar (Panthera onca) (Figure 11), and an extinct species of horse (Equus sp.). Toomey (1994) in a brief summary of the fauna pointed out the difference in the fauna from Laubach 3 and mentioned that it contained many species with tropical or subtropical living relatives.

All of these animals are known from other localities of late Pleistocene age in Texas with the exception of the Brazilian free-tailed bat. Its presence in this fauna is significant. It is the common cave bat in central Texas today. Toomey (1993, 1994) pointed out that this bat, living in Texas caves today, is totally absent in later Pleistocene and early Holocene deposits of all other caves for which we have faunas. It appears in the sequence in Hall's Cave in Kerr County at about 2,000 years before present. The date of its appearance in Laubach 3 at 23,000 years before present coincides with the end of the last interstadial (the warm period, dating approximately 23,000 to 58,000 years before present) preceding the last glacial maximum of the Wisconsinan glaciation (Musgrove and others, 2001). These data strongly suggest that this bat was unable to tolerate the climate in central Texas during the last glacial maximum. The reason for its seemingly late return to Texas as recorded in Halls Cave is not known.

The disappearance of the Brazilian free-tailed bat with the onset of the last glacial maximum raises the possibility that the ranges of some of the other species found only in Laubach 3 might also have been restricted at that time. However, these species are known from other localities in Texas that date within the last glacial maximum. The Texas kangaroo rat may be another species that suffered a range constriction at the end of the last interstadial. It currently lives only in a limited area in north central Texas. The record in Laubach 3 indicates a subsequent restriction in its range sometime in the last 23,000 years.

Two species, Tremarctos floridanus and the glyptodont, are known from late Pleistocene faunas from the eastern part of the United States, including the Gulf Coastal Plain and Mexico (Kurtén and Anderson, 1980; Gillette and Ray, 1981). They are not known from the Edwards Plateau. Their presence in Laubach Cave, located at the eastern edge of the Edwards Plateau, marks the western limit of their known distribution during the late Pleistocene and suggests environmental differences at that time between the Gulf Coastal Plain and the Edwards Plateau.

The faunas of Laubach 1, 2, and 5 will be discussed together as they are very similar in species composition. In addition, the radiocarbon dates of Laubach 1 and Laubach 2 are close (15,850±500 years before present and 13,970±319 years before present, respectively) although they do not overlap. They both fall in the last glacial maximum.

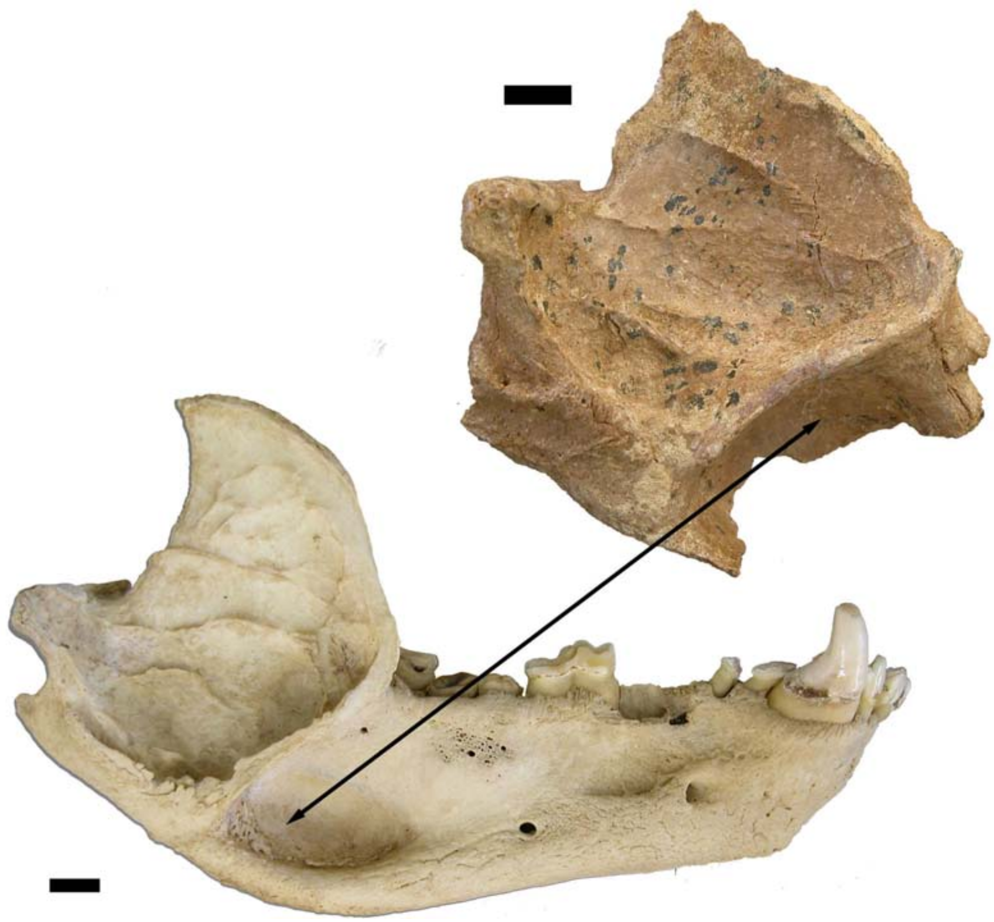

Figure 6. Tremarctos floridanus (TMM 41343-153). Posterior part of right lower jaw with reconstruction of main part of the ramus compared with the lower jaw of modern Tremarctos ornatus, below. Note the characteristic depression ahead of the masseteric fossa. Scale bars are 1 cm.

Figure 7. Glyptotherium floridanum (TMM 42343-2). Scute. Scale bar is 1 cm.

Figure 8. **Canis dirus (TMM 41343-67). Left upper premolar, lingual view. Scale bar is 1 cm.**

Figure 9. **Tadarida brasiliensis (TMM 41343-765). Skull, ventral view (A) and dorsal view (B). Scale bar is 1 cm.**

Figure 10. **Cynomys ludovicianus (TMM 40673). Palate. Scale bar is 1 cm.**

Figure 11. **Panthera onca (TMM 40673-49). Anterior end of right lower jaw with canine and fourth premolar. Scale bar is 1 cm.**

The fauna of Laubach 1 was described by Slaughter (1966). It contains a large sample of the large extinct peccary (Platygonus compressus), jaguar (Panthera onca), bob cat (Lynx rufus), camel (Camelops sp.), and mammoth (Mammuthus columbi). The sample of the peccary conforms to other samples of Platygonus compressus from other areas very well. The jaguar is within the size range of Pleistocene jaguars from North America, which were somewhat larger than their modern counterparts. The fauna from Laubach 2 is similar in that it has the camel, cottontail (Sylvilagus sp.), and packrat (Neotoma sp.) and also has horse, skunk, and several small rodents.

The trench in the basin north of Laubach 2 was relatively unproductive. A deciduous canine of the saber tooth cat, (Homotherium serum) (Figure 12), was found here. This animal is widespread in North America but is abundant only at Friesenhahn Cave in Bexar County. This locality has produced a large sample of this animal including a substantial number of juveniles of all ages that suggests that Homotherium used Friesenhahn Cave as a den for the young (Graham, 1976; Rawn-Schatzinger 1983, 1992). A cave in Cannon County, Tennessee, has also produced a juvenile specimen of Homotherium (Rawn-Schatzinger and Collins, 1981). The deciduous canine from Laubach Cave indicates that this cave was also used as a den for juveniles.

The most common animal is the large extinct peccary, Platygonus compressus. Slaughter's study of the sample from Laubach 1 demonstrated no differences from samples of comparable age from other parts of the United States. This species had a very wide distribution in North America during the late Pleistocene. Kurtén and Anderson (1980) pointed out that cave faunas very commonly contain Platygonus bones indicating that they probably used caves for shelter at times, as do modern peccaries. Many of the specimens are from immature animals.

Several extant species represented in the fauna of Laubach Cave are no longer found in central Texas and suggest that climatic and environmental changes may have constricted their ranges. One is a vole (Microtus sp.). Members of this group of rodents are generally found today to the north and east of central Texas in more mesic areas, although one relict population was found in Kerr County in the 1930s (Bryant, 1941). Voles are present in all Pleistocene faunas of Texas and indicate a climate more mesic than present. Another such species is the southern short tailed shrew (Blarina carolinensis) now found from east Texas eastward. The interpretation of more rainfall and/or a lower evaporation rate is supported by the growth rates of speleothems from the cave (Musgrove and others, 2001). They record faster growth of speleothems during the last glacial maximum than in the Holocene which is attributed to an increased availability of water.

The prairie dog (Cynomys ludovicianus) is present in Laubach 1 and 3. This animal is no longer present in central Texas, but there are historic records near Mason and in Bexar County (Hall and Kelson, 1959; Davis, 1974). They occur in a number of Pleistocene faunas in Texas but are rare in Holocene faunas. Prairie dogs are burrowers that need soil at least one meter thick. Their disappearance indicates that the areas with sufficiently thick soils for their burrowing activities have disappeared over most of central Texas.

Another characteristic of Pleistocene faunas that is not well represented in the Laubach Cave assemblages is the co-occurrence of species that are now allopatric (that is, species whose geographical distributions do not now overlap). These faunas have been termed non-analog

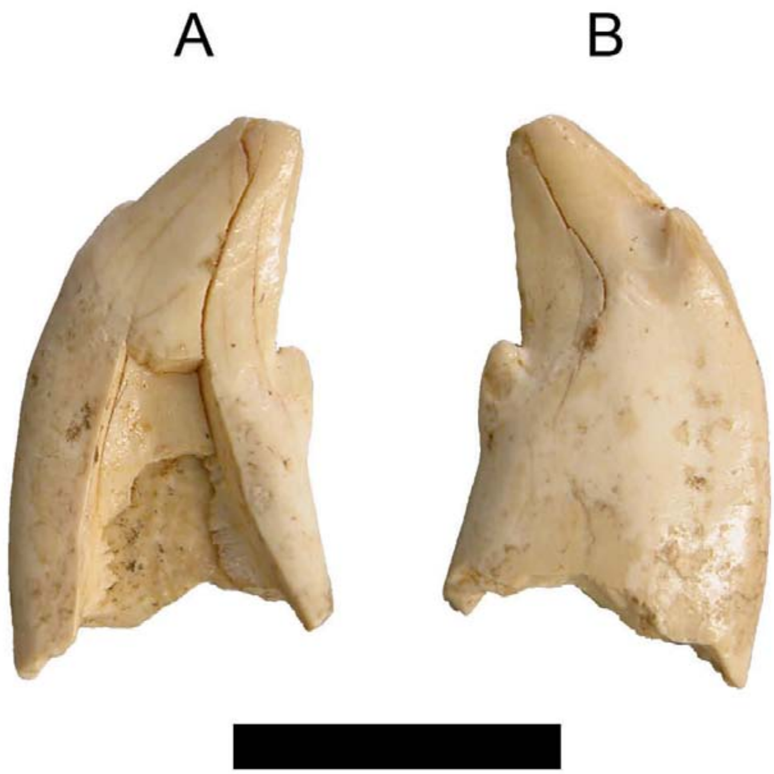

Figure 12. **Homotherium serum (TMM 40722-56). Deciduous left lower canine, labial view, (A) and lingual view (B). Scale bar is 1 cm.**

because they have no modern distributional analogs. Only two pairs of such species are currently known to occur in the Laubach Cave deposits, both involving the Texas kangaroo rat (Dipodomys elator). The vole (Microtus sp.) and the southern short tailed shrew (Blarina carolinensis) are both known from Laubach 3 along with the Texas kangaroo rat, but neither is found today in the same area as the Texas kangaroo rat. These assemblages have been interpreted as an indication that Pleistocene climates were less seasonal than the present (Hibbard, 1960; Lundelius, 1974). This is based on the observation that the species involved in such associations that are primarily northern in their distributions appear to have southern limits controlled by the summer aridity and temperature maxima while the species that are primarily southern in their distribution appear to have their northern limits controlled primarily by the winter temperature minima. The reason for the scarcity of non-analog associations in the Laubach Cave deposits is almost certainly the poor samples of the small animals currently available.

Conclusions

Inner Space Caverns (Laubach Cave) located in the Balcones Fault Zone in Williamson County is a complex system of passages whose orientations indicate strong fault and joint control. Vertebrate fossils are found at five locations in the cave marked by debris cones that mark former entrances. The faunas from three localities have radiocarbon dates of 23,230; 15,850; and 13,970 years before present. The faunas are not exactly the same and may indicate changes in the regional fauna during the late Pleistocene. The faunal assemblages indicate more mesic conditions during the last glacial maximum, and the presence of now allopatric species indicate a more equitable climate at that time.

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technical paper

Dye tracing recharge features under high-flow conditions, Onion Creek, Barton Springs Segment of the Edwards aquifer, Hays County, Texas

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Abstract

The Barton Springs/Edwards Aquifer Conservation District, in cooperation with the City of Austin, injected non-toxic organic dyes into two caves within the Barton Springs segment of the Edwards aquifer to trace groundwater flow paths and determine groundwater-flow velocities. Antioch and Cripple Crawfish Caves are located about 14.0 and 17.5 miles south, respectively, of Barton Springs, the primary discharge point from the aquifer. Twenty-five pounds of sodium fluorescein were injected into Antioch Cave on August 2, 2002 and arrived at Barton Springs between 7 to 8 days after the injection. Thirty-five pounds of eosine were injected into Cripple Crawfish Cave on August 6, 2002 and arrived at Barton Springs in less than 3.5 days after the injection. Under high spring flow conditions, groundwater-flow velocities from Antioch Cave and Cripple Crawfish Cave to Barton Springs are estimated to be 2.0 and 5.0 miles per day, respectively. Detections of dye at water-supply wells indicate a karst system composed of multiple diverging flow paths from these caves that, while recharging surface water, create mounds in the potentiometric surface. Groundwater flow then re-converges as it flows northeast, before discharging at Barton Springs. Interpreted flow paths generally coincide with troughs in the potentiometric surface in the hydraulically unconfined zone and ridges in the potentiometric surface in the hydraulically confined zone of the aquifer. Most interpreted flow paths are oriented normal to potentiometric surface contours. However, some interpreted flow paths are oriented parallel to potentiometric surface contours, indicating a highly anisotropic flow system. Groundwater flow was traced in wells along paths that are parallel to the N40E (dominant) and N45W (secondary) fault and fracture trends presented on geologic maps. Rapid groundwater flow velocities to springs and detections at wells indicate that conduits are an important component of flow, and the bimodal structural grain has influenced the development of conduits in the Edwards aquifer.

Introduction

The Barton Springs segment of the Edwards aquifer (Barton Springs aquifer) is an important groundwater resource for municipal, industrial, domestic, recreational, and ecological needs. Approximately 50,000 people depend upon water from the Barton Springs aquifer as their sole source of drinking water, and the various spring outlets at Barton Springs are the only known habitats for the endangered Barton Springs Salamander. The Barton Springs aquifer is located south of the Colorado River, extending south to the City of Kyle, and generally between Interstate 35 and FM 1826 (Figure 1).

For this study dyes were injected in two caves and traced to numerous wells and to Barton Springs. This document summarizes groundwater dye tracing studies that have led to a better understanding of groundwater flow paths and velocities in the Barton Springs aquifer.

Purpose and scope

The Barton Springs/Edwards Aquifer Conservation District (District), in cooperation with the City of Austin, injected non-toxic organic dyes into two caves within the Barton Springs aquifer in August 2002. The objectives of this groundwater tracing study were to determine the time-of-travel, direction, and destination of groundwater flow and to better delineate the groundwater divide between the Barton Springs and San Antonio segments of the Edwards aquifer south of Onion Creek.

Previous tracing investigations

The Edwards Aquifer Research and Data Center successfully detected groundwater tracers several miles from their injection points within the San Marcos Springs area of the adjacent San Antonio segment of the Edwards aquifer (Ogden and others, 1986).

A small amount of tracer was injected by the U.S. Geological Survey in a well about 200 feet southwest of the main Barton Springs outlet in the pool. The tracer initially appeared about 10 minutes after injection and peaked about one hour after injection (Slade and others, 1986).

Between 1996 and 2001 the District, in cooperation with the City of Austin, performed 20 injections of dye into 17 different features, including features on Onion Creek (Hauwert and others, 2002). Those traces delineated several groundwater basins and rapid groundwater flow velocities of 0.5 to 7.0 miles per day depending on spring flow conditions in the aquifer (Hauwert and others, 2002; BSEACD, 2003).

Hydrogeologic setting

The Edwards aquifer is composed of the Cretaceous-age Edwards Group (Kainer and Person formations) and the Georgetown Formation, which consist primarily of limestone and dolomite about 500 feet thick (Rose, 1972; Small and others, 1986). The Edwards aquifer of central Texas is a dissolution-modified, faulted, karst aquifer composed of three hydrologically distinct segments: the southern (San Antonio) segment, the Barton Springs segment (Barton Springs aquifer), and the northern segment.

Geologic studies in central Texas have delineated faults (Small and others, 1996) and several informal stratigraphic members of the Kainer and Person formations of the Edwards Group (Rose, 1972), each having distinctive hydrogeologic characteristics. Faulting is related to the Balcones Fault system with bimodal trends of N40E (dominant) and N45W (secondary), with total offset of about 1,100 feet across the Barton Springs aquifer (Alexander, 1990).

The areal extent of the Barton Springs aquifer is about 155 square miles (Figure 1). The primary discharge for the Barton Springs aquifer occurs at Barton Springs, located within Barton Creek near the confluence with the Colorado River, near the center of Austin. Barton Springs is a complex of springs that are a major recreational attraction for the city and sustain base-flow to Town Lake (Colorado River). The long-term average spring flow of Barton Springs was 53 cubic feet per second (cfs) (City of Austin analysis of U.S. Geological Survey water resources data from 1917 to 1995). The lowest flow measurement recorded for Barton Springs was 9.6 cfs in 1956 (Brune, 2002).

The eastern boundary of the aquifer is known as the saline-water zone, characterized by a sharp increase in dissolved constituents (greater than 1,000 mg/l total dissolved solids) and a decrease in permeability (Flores, 1990). The western boundary of the aquifer is poorly defined and is delimited by Balcones Faulting and saturated thickness. The southern hydrologic divide between the Barton Springs and the San Antonio segments is estimated to occur between Onion Creek and the Blanco River based on potentiometric-surface elevations and recent dye tracing information (LBG-Guyton, 1994; Hauwert and others, 2004). The injection sites are located close to the approximated location of the groundwater flow boundary separating the Barton Springs and San Antonio segments.

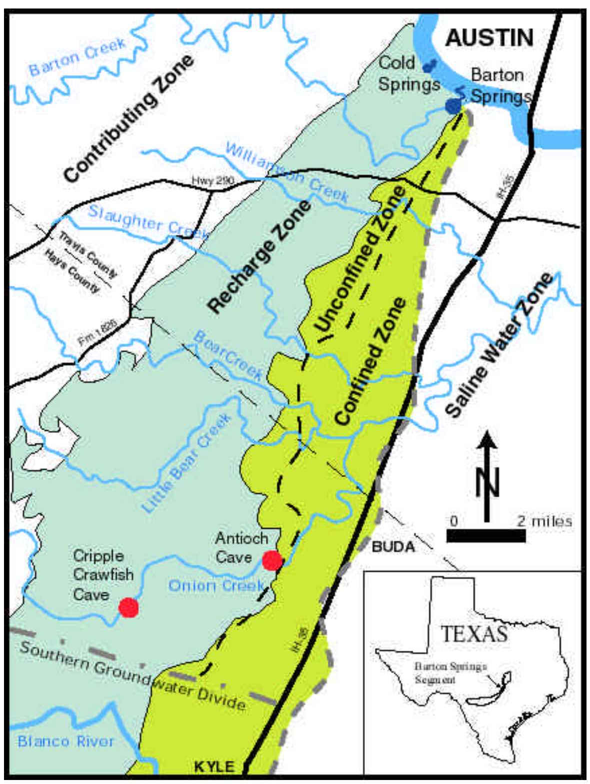

Figure 1. Location map of the study area.

The San Antonio segment is the largest and most prolific water-producing segment of the Edwards aquifer. The segment extends south and southwest from the City of Kyle in Hays County to Brackettville in Kinney County, a distance of greater than 180 miles. The two largest springs in this segment are Comal and San Marcos springs with mean flows reported by the U.S. Geological Survey of 264 cfs and 159 cfs, respectively. San Marcos Springs is located in the City of San Marcos, Hays County. The springs are a complex of several large and numerous small springs that discharge into Spring Lake, forming the headwaters of the San Marcos River. Previous investigators have divided the springs into a northern and southern group, each displaying unique flow patterns and chemistry. From groundwater tracing studies, the northern cluster of springs in Spring Lake is known to discharge groundwater that is recharged north of San Marcos Springs (Ogden and others, 1986). Antioch and Cripple Crawfish caves are located 13.4 and 11.4 miles north of San Marcos Springs, respectively.

Groundwater tracing in the Barton Springs aquifer has defined two groundwater basins with flow toward Barton Springs and a third smaller groundwater basin with flow toward Cold Springs. No dyes injected in Onion Creek or further north have been traced to San Marcos Springs (Hauwert and others, 2002). Groundwater generally flows west to east across the recharge zone and then converges with northeast-trending preferential groundwater flow paths parallel to major faulting, and then flows toward Barton Springs. Preferential flow paths were traced along troughs in the potentiometric surface, indicating zones of high permeability. Rates of groundwater flow determined from dye tracing were very rapid under high flow conditions (4 to 7 miles per day) and less rapid (up to 1 mile per day) under low spring flow conditions (Hauwert and others, 2002; Hauwert and others, 2004). Spring flow conditions are considered high if discharge exceeds 70 cfs and low if below 35 cfs.

Most of the water that recharges the Barton Springs aquifer infiltrates via discrete features such as caves, sinkholes, fractures, and solution cavities within the primary stream channels that cross the recharge zone. Onion Creek is the largest contributor of recharge to the aquifer. The remaining recharge enters the upland areas and the tributary channels within the recharge zone (Slade and others, 1986; BSEACD and COA, 2001).

Two large-capacity recharge features, Antioch and Crippled Crawfish caves, were injected with dyes as part of this study. Both caves are located near the lowest portion of the stream cross section of Onion Creek. Antioch Cave is the largest-capacity recharge feature documented in the Barton Springs aquifer and is located at the eastern edge of the recharge zone, near the City of Buda. Antioch Cave is a shaft developed in the Georgetown Formation that penetrates into the Edwards Group (Person Formation). The District constructed and maintains a water-quality structure consisting of a large concrete vault with a 36-inch pneumatic valve controlling the entry of water from Onion Creek (Figure 2). During one period of high stream flow, flow into the structure was reported to have averaged about 46 cfs with a peak of 94 cfs. Cripple Crawfish Cave is developed within the Kirschberg member of the Kainer Formation of the Edwards Group. Recharge from the upper two-mile stretch of Onion Creek on the recharge zone, which includes Cripple Crawfish Cave, accounts for one-third of the total flow loss (recharge) from Onion Creek on the basis on several flow surveys (BSEACD and COA, 2001).

Figure 2. **Concrete vault and valve system above Antioch Cave within Onion Creek (left). Sodium fluorescein dye being poured into the top of the vault (right).**

Methods of study

Groundwater tracing techniques are recognized as the only direct method of locating groundwater flow paths and determining travel times in karst aquifers. Groundwater dye tracing involves the introduction of non-toxic, organic dyes into the subsurface via injection points, such as caves, sinkholes, and wells, and analyzing charcoal receptors and water samples taken from discharge points such as wells and springs. Alexander and Quinlan (1992) discuss the methodology of groundwater tracing with dyes in karst terrains.

Groundwater tracers (dyes) and injection sites

Two traditional, well-documented, and distinct organic dyes were injected into the two natural recharge features within Onion Creek using creek water that was naturally recharging the aquifer. The dyes used in this study were sodium fluorescein (Acid Yellow 73, D&C Red, 45350) and eosine (Acid Red 87, D&C Red No. 22, 45380). Eosine and sodium fluorescein mixtures containing approximately 75 percent dye equivalent and 25 percent diluent were purchased as a powder. These dyes have been evaluated to be suitable for this and other studies due to their physical characteristics, safety for drinking water supplies and aquatic habitats, and low background concentrations (Smart, 1984; Field and others, 1996).

Twenty-five pounds of sodium fluorescein were injected into Antioch Cave on August 2, 2002. Dye was injected by pouring the dye mixture directly into the top of the vault while the side valve was open, allowing recharge into the structure and cave (Figure 2). Thirty-five pounds of eosine were injected into Cripple Crawfish Cave on August 6, 2002. The District and the City of Austin injected dye into Cripple Crawfish Cave through a PVC pipe inserted into the feature from the bank (Figure 3).

Sample collection

To monitor the movement of the dyes, charcoal receptors were placed in springs and many accessible wells. Receptor sites were monitored using a combination of charcoal receptors, which contain adsorbent activated charcoal in mesh packets, and water samples. Grab samples provide information on the instantaneous dye concentrations in the water. Charcoal receptors adsorb dye from the water and allow detection of dyes over extended periods of time. Charcoal receptors were placed at springs (Figure 4) and wells and collected periodically to determine a positive or negative result.

Figure 3. Vortex formed above Cripple Crawfish Cave (top). Nico Hauwert pouring eosine into a pipe inserted into Cripple Crawfish Cave on Onion Creek (bottom).

Figure 4. Brian Hunt retrieving receptors at San Marcos Springs (diversion outlet).

Spring sampling locations include Barton Springs (Main, Eliza, Upper, and Old Mill spring outlets) and San Marcos Springs (Crater Bottom, Salt and Pepper, Weismueller, Diversion, and Deep Hole spring outlets and the spillway of the dam forming Spring Lake). Spring sites were monitored for nine days with charcoal receptors before dye injection to detect background presence of dyes for Barton Springs. Spring receptors and grab samples were analyzed at the Ozark Underground Laboratory in Missouri. Sampling supplies were provided by the laboratory, and sampling procedures outlined by the laboratory were followed. After injection of the dye, charcoal receptors were collected daily along with grab samples at Barton Springs. Daily receptors were collected beginning August 9, 2002 and stopped September 19, 2002 and weekly receptors began thereafter at Barton Springs until November 4, 2002. Water samples were taken from an ISCO 3700 Automatic Compact Sampler at 4-hour intervals at Barton Springs from August 13, 2002 to October 8, 2002. Receptors and grab samples were collected at San Marcos Springs every three to four weeks starting August 1, 2002 until August 14, 2003.

Fifty-three wells were monitored for the presence or absence of dyes in groundwater. These wells had charcoal receptors within a perforated PVC pipe attached to a spigot allowing untreated groundwater to pass through the receptor each time the well pump cycled on. Charcoal receptors were collected about every three weeks starting July 16, 2002 until January 22, 2003. Charcoal receptors placed at wells were assembled by the District with supplies provided by the Edwards Aquifer Authority.

Preparation and analyses of samples

Charcoal and grab samples from San Marcos and Barton Springs were sent to Ozark Underground Laboratory for quantitative analyses on a spectrofluorophotometer. The laboratory's instrumentation analyses, protocols, and procedures are outlined in Aley (1999, 2000). The laboratory's detection limits for sodium fluorescein and eosine are 10 and 35 parts per trillion (ppt) for receptors and 5 and 8 ppt for water samples.

Charcoal receptors from wells were analyzed for qualitative results at the Edwards Aquifer Authority following procedures outlined by Geary Schindel and Steve Johnson (personal communication) and are only generally described here. Charcoal receptors were eluted in a solution containing 95 percent of a 70 percent solution of isopropyl alcohol in water and 5 percent of ammonium hydroxide or sodium hydroxide. The elutant was then placed in a glass vial for analysis. These samples were analyzed using a Perkin Elmer Model LS50B scanning spectrofluorophotometer. The spectrofluorophotometer performs a series of scans (ranging from 460 to 560 nanometers[nm]) exposing the samples to a known wavelength of light and monitors for emissions of light from the dye. Each of the dyes fluoresces at a known wavelength. Sodium fluorescein and eosine fluoresce around 490 nm and 520 nm, respectively (Figure 5). The detection limit for the receptors is approximately 12 parts per trillion (Geary Schindel and Steve Johnson, personal communication).

Positive dye recovery interpretation

The procedures and criteria for a quantitative analysis and positive detection of spring grab and charcoal samples are described in detail by Aley (1999, 2000). A certificate of analysis for each group of samples analyzed by Ozark Underground Laboratory contain analytical results from the laboratory's spectrofluorophotometer and laboratory interpretation of the results.

Criteria for determining a qualitative positive detection from charcoal samples from wells were generally as follows:

1) the fluorescence peak lies within the normal emission wavelength for the specific tracer;
2) the shape of the fluorescence peak is typical of the specific tracer;
3) the fluorescence amplitude (intensity) is greater than background intensity; and
4) other factors do not overwhelmingly suggest that the fluorescence did not result from the injected dye.

Analytical results were evaluated with the four criteria above to interpret the recovery of dye (Table 1).

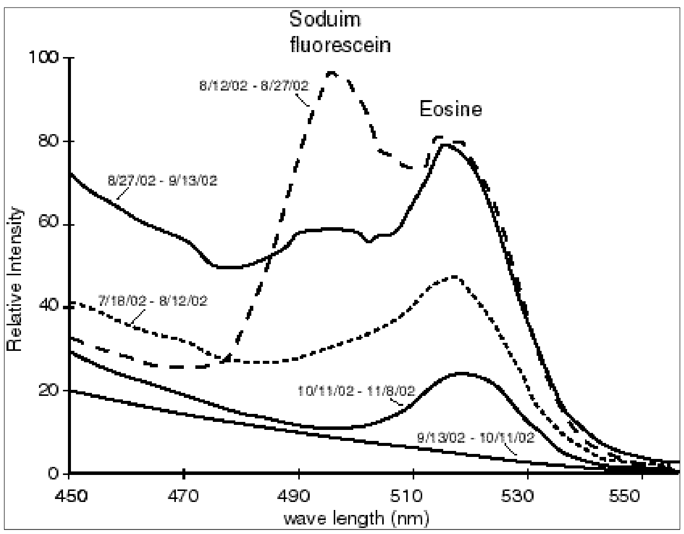

Figure 5. Example of charcoal sample analysis from well 5850511 (Johnson domestic well). Sodium fluorescein and eosine fluoresce around 490 nm and 520 nm, respectively.

Table 1. Interpretation of dye (EAA) results.

Abbreviation	Interpretation	Criteria
ND	Below Quantitation Limit	Fluorescence is below the quantitation limit and none of the criteria are met.
B	Background	Criteria #1 and #2 only.
+	Positive	Aspects of all four criteria are partially met, and as a whole indicate a positive dye recovery.
++	Very Positive	All four criteria are met.
+++	Extremely Positive	All four criteria are met with dye amplitude (concentration) greater than 10 times above background.

Mass recovery

Recovery of the injected tracer mass is calculated by using measured spring concentrations and spring discharge outlined in Field (2002). The percent recovery of dye is the ratio of recovered tracer mass to the mass of tracer injected. Tracer mass described in this report refers to pure dye mass and not dye mixture amounts. Breakthrough curves from the tracer tests were evaluated with spreadsheets and the numerical program Q-Tracer (Field, 2002) to determine mass recovered and some hydraulic parameters. Spring flow for each Barton Springs orifice was assumed to be 81 percent, 9 percent, and 10 percent for Main, Eliza, and Old Mill springs, respectively, of the total spring flow reported by the U.S. Geological Survey (David Johns, personal communication).

Quality control

Each dye receptor was handled following standard chain-of-custody protocols. Trip blanks, consisting of charcoal packets handled by field personnel during the course of sampling, were analyzed. These samples test for cross contamination between sites or contamination from other materials, to which field personnel might have been exposed.

Eluent and charcoal blanks were analyzed for quality control measures. Sodium fluorescein, eosine dye standards, and tap water were also analyzed on the Edward Aquifer Authority's spectrofluorophotometer to confirm operation and consistency of the instrument.

Results

Groundwater dye tracing results from samples collected at Barton Springs are presented in Table 2. No positive recoveries attributed to these injections were made at San Marcos Springs. Groundwater dye tracing results from samples collected at wells are summarized in Tables 3 and 4. Estimated and inferred groundwater flow paths between dye injection and recovery sites were created using potentiometric surface (water level) maps and structures from geologic maps (Figure 6). Detections of dye at water-supply wells indicate a karst system composed of multiple diverging flow paths from these caves, which re-converge as groundwater flows to the northeast, discharging at Barton Springs. Flow paths were observed within the unconfined zone and within the hydraulically confined portion of the aquifer.

Breakthrough curves and mass recovery

Breakthrough curves were prepared from the laboratory results, from which the initial travel time, duration, and peak concentrations were calculated. Breakthrough curves, which are graphs displaying dye concentrations over time, were evaluated to characterize the dye response at the springs (Figure 7).

Recovery of the dye mass was calculated using spreadsheets and the program Q-Tracer (Field, 2002). Both methods resulted in nearly identical mass recovery estimations for sodium fluorescein (Table 2). Eosine dye mass recovery is a minimum value, because the initial arrival was not sampled.

Recovery of dye mass at Barton Springs represents a minimum of mass recovered. Potentially more dye mass could have discharged to the Barton Springs complex below the detection limit or through other springs (such as upper Barton Springs). Adsorption of the dye on sediment could also account for the low mass recovered.

Background florescence and potential contamination

Low levels of background eosine were detected at Upper Barton Springs prior to injection and throughout the duration of the study. Accordingly, no positive dye trace recovery at Upper Barton Springs was noted from this study. No background eosine was detected at the remaining spring orifices. Sodium fluorescein was not detected at background levels at any of the spring orifices.

Table 2. Barton Springs dye recovery data.

Injection site	**Antioch Cave**	**Cripple Crawfish Cave**
Trace ID	M"	S
Dye	Sodium fluorescein 25 lbs	Eosine 35 lbs
Injection Date	8/2/2002	8/6/2002
Spring Flow (cfs) at time of injection	99	98
Minimum Distance from injection to springs	14.0 mi 22.6 km	17.5 mi 28.2 km
Distance corrected for sinuosity (1.3x)**	18.3 mi 29.4 km	22.8 mi 36.6 km
Dye First Arrival (hrs)**		
Main	170	<84.2
Eliza	169	<83.5
Old Mill	168	<83.2
Time to peak tracer concentration (hrs)**		
Main	311	
Eliza	286	
Old Mill	339	N/A
Mean tracer transit time (hrs)**		
Main	413	
Eliza	261	
Old Mill	373	N/A
Mean Tracer Velocity (km/d)**		
Main	1.7	
Eliza	2.7	
Old Mill	1.9	N/A
Maximum tracer velocity (km/d)**		
Main	4.2	
Eliza	4.2	
Old Mill	4.2	> 10.8
Maximum tracer velocity (mi/d)	2.0	5.0
Dye Mass Recovered (grams):		
Main	77.7	157.4
Eliza	1.90	4.80
Old Mill	7.00	40.4
Minimum Dye Mass Recovery	0.8 %	1.3%*

*First arrival of the dye was not sampled; therefore, time and mass parameters represent minimum values.
**Result using the program Q-Tracer (Fields, 2002).

Table 3. Eosine recovery at wells.

Map No.	SWN*	DD lat	DD long	Site name	Result	Qualitative recovery	No. days for first detection
1	5850511	30.17159	-97.82578	Johnson	Eos	++	up to 6
2	5850703	30.13813	-97.85522	Marbridge	Eos	++	up to 6
3	5857606	30.04773	-97.88367	Cindy Barton	Eos	+++	22 to 45
4	5857913	30.03389	-97.89111	Hays HS	Eos	+++	111 to 118
5	58507DF	30.14830	-97.84378	Figueroa	Eos	+	6 to 21
6	58575T4	30.05853	-97.92112	Ruby #4	Eos	+++	6 to 24
7	58576RH	30.04560	-97.89873	Ray Holt	Eos	+++	up to 1

*State Well Number

Table 4. Sodium fluorescein recovery at wells.

Map No.	SWN*	DD lat	DD long	Site name	Result	Qualitative recovery	No. days for first detection
1	5850511	30.17159	-97.82578	Johnson	Fl	++	10 to 25
8	5850845	30.12383	-97.82638	Arroyo Double	Fl	++	10 to 26
9	5857307	30.09986	-97.88229	Dahlstrom	Fl	+	98 to 129
10	5857903	30.03850	-97.88617	Negley	Fl	++	5 to 12
11	5858111	30.12319	-97.87226	City of Hays	Fl	++	10 to 25
12	5858121	30.10503	-97.86236	Leisurewoods #5	Fl	+++	up to 12
13	5858128	30.08725	-97.85361	Wright	Fl	+++	up to 12
5	58507DF	30.14830	-97.84378	Figueroa	Fl	+	42 to 70
14	58507PL	30.14581	-97.84589	Guajado	Fl	++	10 to 25
15	5850835	30.14671	-97.81308	Onion Creek C.C.	Fl	+	98 to 129
16	58573ES	30.11153	-97.88165	Swanson	Fl	++	10 to 25
17	58581DL	30.08587	-97.85644	Levin	Fl	+++	up to 12
18	58581JK	30.08645	-97.85426	Kortan	Fl	++	up to 12
19	58581KM	30.09347	-97.84483	Marks	Fl	+++	25 to 45
20	5858209	30.11934	-97.81612	Onion Creek Meadows	Fl	+	76 to 115
21	58584DD	30.07717	-97.86132	Dement	Fl	+++	up to 12
22	58584L	30.07083	-97.87473	Shackelford	Fl	++	up to 12

*State Well Number

No background concentrations of eosine were detected in any of the well samples collected prior to the injection. In addition, no false positive detections of eosine were encountered in well samples. Several well samples did have false positive detections of sodium fluorescein that appear to have been the result of contamination or sampling error. Additionally, several trip blanks (control samples) beginning on August 12, 2002 had false positive sodium fluorescein detections. These control samples appear to have been exposed to sodium fluorescein during the washing procedure intended to remove the black charcoal dust from the dry charcoal control samples. Control samples that were not washed did not have any false positive results.

Discussion

Injection of dyes into Antioch and Cripple Crawfish caves occurred during high spring flow conditions of 98 and 99 cfs at Barton Springs, respectively. Maximum groundwater flow velocities were calculated by the first arrival of the dye. Since the first arrival of eosine arrived before the first sampling event, the flow velocity reported in Table 2 is a minimum value. Additionally, dye travel times and recoveries may underestimate the actual groundwater flow rates and character of groundwater flow due to adsorption of the dye underground, the complexity of the actual flow paths (tortuosity), saturated and unsaturated flow paths, frequency of sampling, and the amount of dye used.

Breakthrough concentrations peak soon after initial arrival, suggesting an aquifer system strongly influenced by conduit (rapid, pipe-like) flow rather than diffuse (slow) flow. Several sodium fluorescein breakthrough peaks on Figure 7 suggest arrival of dye via different (conduit) pathways.

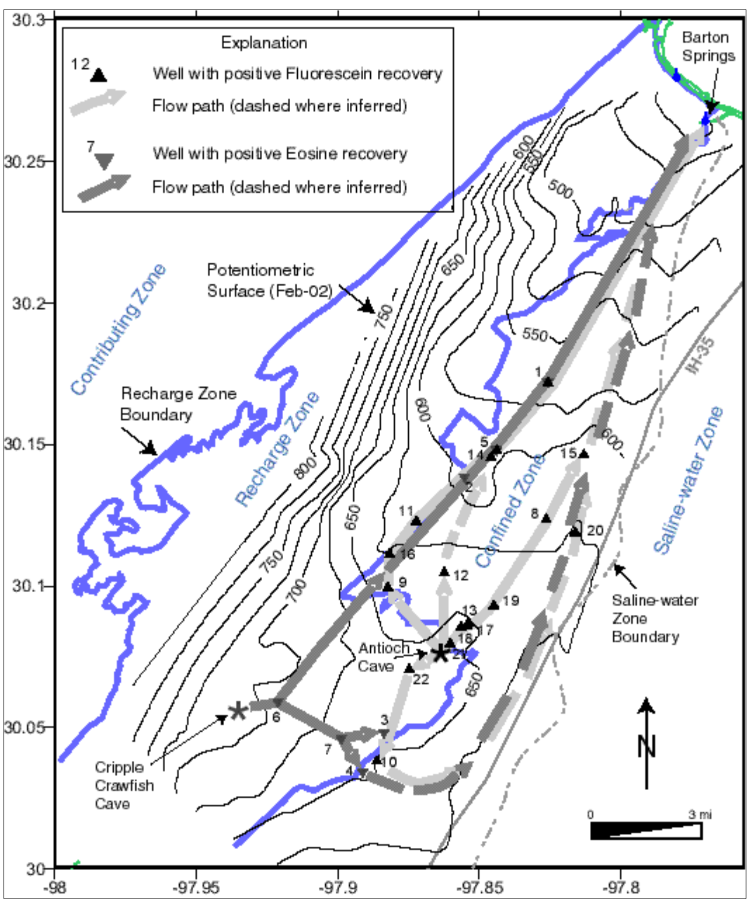

Figure 6. **Map of groundwater flow paths and potentiometric surface lines from a period of similar high-flow conditions (February 2002). The potentiometric surface was created using 175 groundwater elevation measurements throughout the study area.**

A potentiometric surface map constructed from water-level measurements in about 175 wells during February 2002 represents high flow aquifer conditions, similar to flow conditions of this study (shown on Figure 6). A mound in the potentiometric surface around Antioch Cave and Onion Creek is apparent on the potentiometric surface under these conditions. Dye was injected into the two caves as recharge was occurring. Under these conditions the dyes diverged from the caves and flowed in multiple directions away from the injection points. Flow from Antioch Cave generally followed the mound in the potentiometric surface in the confined zone and the trough in the potentiometric surface in the unconfined zone. Flow is interpreted to re-converge at some point or points up-gradient from Barton Springs (Figure 6). These flow paths are interpreted to be parallel to potentiometric lines in some areas, reflecting anisotropic flow in the aquifer or perhaps a lack of water-level control data.

Dyes from each injection site were detected in the same two wells (5850511 and 58507DF), indicating that groundwater flow converges into preferential flow paths (Hauwert and others, 2002). These wells are generally located within a broad potentiometric-surface trough in the unconfined zone (Figure 6).

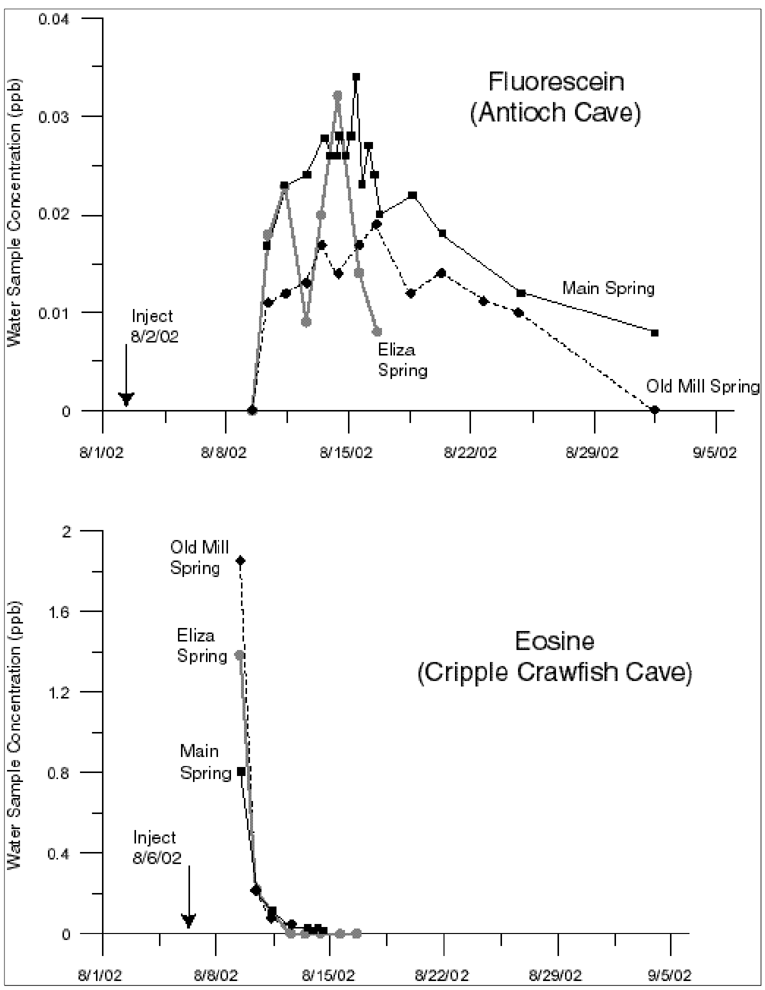

Figure 7. **Breakthrough curves of sodium fluorescein and eosine at Barton Springs.**

These data demonstrate the dynamic nature of this karst aquifer system with some aspects of flow reversing under different hydrologic conditions when compared to previous dye trace studies (Hauwert and others, 2002). Under average flow conditions, groundwater flow is predominantly from west to east and then northeast. This study also shows that under active recharge conditions some additional components of flow from these large recharge features can be to the northwest, southeast, and to the south.

Dye was recovered from wells south of Onion Creek in Mountain City, although no dye was recovered from San Marcos Springs during the year of monitoring associated with this study. Hauwert and others (2004) proposed a saline-water flow route along the eastern boundary of the aquifer to Barton Springs, which could be the flow path for water mounding during recharge and initially flowing to the south (shown as dashed or inferred flow paths in Figure 6). Positive recovery of sodium fluorescein in wells 5858209 and 5850835 near the saline-water zone many weeks after injection (Table 4) could support such a path, although these results should be verified in future traces due to the relatively low qualitative recovery of dye at these wells.

Rapid groundwater flow was traced in wells along paths that are parallel to the dominant and secondary fault and fracture trend presented on geologic maps (Small and others, 1996) and lineament studies (Alexander, 1990). Therefore, conduit flow within the aquifer appears to be strongly influenced by the bimodal fault and fracture system with trends of N40E (dominant) and N45W (secondary) (Figure 8).

Conclusions

- Groundwater flow velocities from Antioch and Cripple Crawfish caves to Barton Springs under high spring flow conditions are 2.0 and 5.0 miles per day, respectively. These rapid velocities indicate that conduits are an important component of groundwater flow.
- Tracer testing of Antioch and Cripple Crawfish caves reveals a groundwater flow system composed of multiple diverging flow paths from the caves as they recharge surface water. Flow then appears to re-converge as it flows northeast before discharging at Barton Springs.
- Flow paths appear to coincide with troughs in the potentiometric surface in the hydraulically unconfined zone and with ridges in the potentiometric surface in the hydraulically confined portion of the aquifer.
- Conduit flow within the aquifer appears to be strongly influenced by the bimodal fault and fracture system.

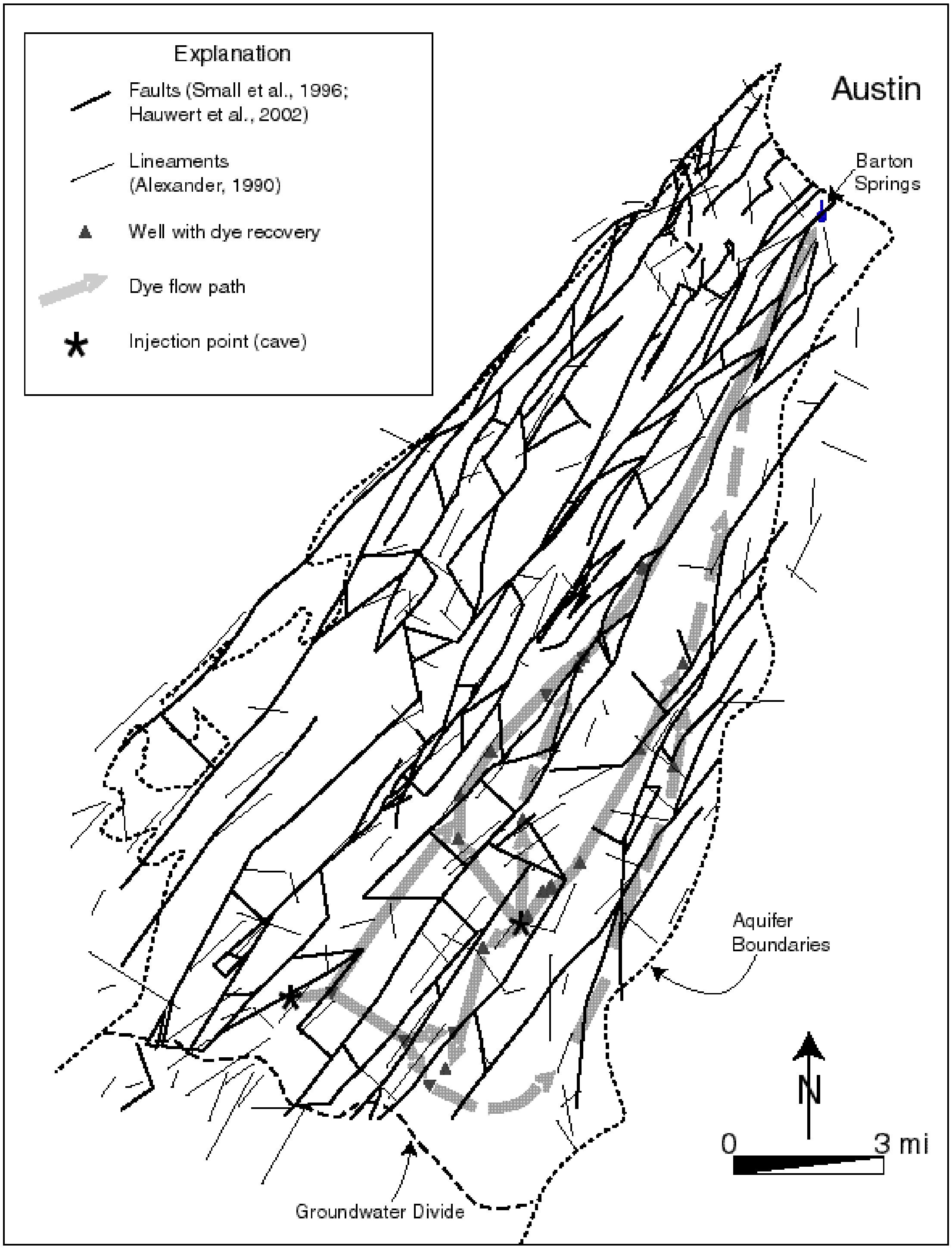

Figure 8. **Map showing faults and lineaments with flow paths drawn from the potentiometric map (figure 6) superimposed. Note the flow paths generally follow structural trends.**

Acknowledgments

This work was done in close collaboration between the District and the City of Austin and is an extension of dye tracing work performed from 1996 to 2001. Results of this study were initially presented at the Geological Society of America: South-Central Meeting in San Antonio, April 1, 2005. Nico Hauwert (City) injected eosine dye into Cripple Crawfish Cave. David Johns (City) retrieved samples from Barton Springs. Mark Mathis (District) injected sodium fluorescein dye into Antioch Cave; Joe Beery (District) collected receptors from wells; Brian Smith (District) and Brian Hunt (District) retrieved samples from San Marcos Springs; and Stefani Campbell (District) and Brian Hunt extracted and analyzed receptors at the Edwards Aquifer Authority.

Thanks goes to Geary Schindel and Steve Johnson of the Edwards Aquifer Authority for support of this effort with supplies, analytical equipment, training, and advise. Scott Wood, Bridget Clark, and Ron Coley of San Marcos Springs Aquarena Center supported our monitoring efforts. Tom Aley and Ozark Underground Laboratory staff provided advice and guidance. The District would like to extend its gratitude to all well and landowners and other participants in this study.

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technical paper

The spatial distribution of radiological contaminants in the Hickory aquifer and other aquifers overlying the Llano Uplift, Central Texas

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Abstract

The Llano Uplift is a Precambrian granite intrusion located in central Texas. Overlying this granite intrusion is a sequence of aquifers ranging from Precambrian fractured granites to Pennsylvanian limestones supplying groundwater for thirteen counties. Within this sequence are three locally important aquifers: the Cambrian-aged Hickory aquifer (sandstones and shales), the Ordovician-aged Ellenburger-San Saba aquifer (limestones), and the Pennsylvanian-aged Marble Falls Aquifer (limestone). Minor local aquifers include the Precambrian fracture granites, and the Cambrian-aged Cap Mountain Member (limestone), Lion Mountain Member (limestone), and the Welge Member (sandstone). Pennsylvanian-aged faulting has locally compartmentalized these aquifers.

The Hickory aquifer is comprised of up to a 550-foot-thick sequence of interbedded artesian sandstones and shales that are naturally radioactive. The dominant radiological contaminants with concentrations exceeding U.S. Environmental Protection Agency drinking water standards in the groundwater are radium and radon, which are natural radioactive decay products of uranium and thorium. The source of the uranium and thorium was the geochemical decomposition of the granites (feldspars) and accessory minerals (less than one percent of total) from the granite intrusives in the Llano Uplift. The radioactivity has been redistributed to phosphatic materials, interbedded shale laminae, and to a lesser extent hematitic cement within the Hickory aquifer. Locally, the overlying Ellenburger-San Saba and Marble Falls aquifers (not known as sources of radiological groundwater) may have been contaminated along faults by the artesian waters from the underlying Hickory aquifer.

Daniel B. Stephens & Associates, Inc. was hired by the City of San Angelo to investigate the spatial distribution of the radiological contaminants within the Hickory and the overlying aquifers. Radiological analyses have been conducted for a total of 257 wells completed in the Hickory aquifer. The spatial geographic distribution of these radiological analyses was investigated using a geographic information system. Review of the geographic distribution of the radiological concentrations in groundwater indicates that both the higher and lower concentrations appear to be somewhat clustered, suggesting that either chemical, physical,

temporal, or a combination of these variables may be influencing the geographic distribution. Scatter plots were created to investigate geochemical relationships. No statistically significant chemical correlations were identified with the available Texas Water Development Board water well chemistry data. However, a few geochemical or environmental variables were identified that seem to influence the geographic distribution of higher radium concentrations. These variables include well depth, sulfate and bicarbonate concentrations, and pH.

In addition, a Schlumberger Natural Gamma Ray Spectroscopy was used as part of a geophysical log suite to investigate the vertical zoning of radioactive sources within three Hickory aquifer municipal water supply wells in McCulloch and Menard counties. This high efficiency gamma spectroscopy tool measures unique spectral signatures of uranium, thorium, and potassium and calculates the respective concentrations of these elements within the formation. Clayey zones had the highest concentrations of thorium and uranium; thorium concentrations were generally three times that of uranium with maximum thorium peaks up to 35 parts per million; and uranium peaks up to 12 parts per million in the clayey horizons. Thorium and uranium concentrations in these sands were generally half to one-third that of the clays. Effective porosities of the sands/sandstones of the Hickory aquifer range from 10.7 to 23.8 percent with a mean of 16.1 percent.

Introduction

The Hickory aquifer is the major groundwater supply for four counties (Llano, Mason, McCulloch, and San Saba) and a minor supply for nine other counties in central Texas. The subsurface extent of the Hickory aquifer illustrated in Figure 1 is based on an isochem of 3,000 milligrams per liter total dissolved solids (that is, regions where total dissolved solids exceed 3,000 milligrams per liter are not shown).

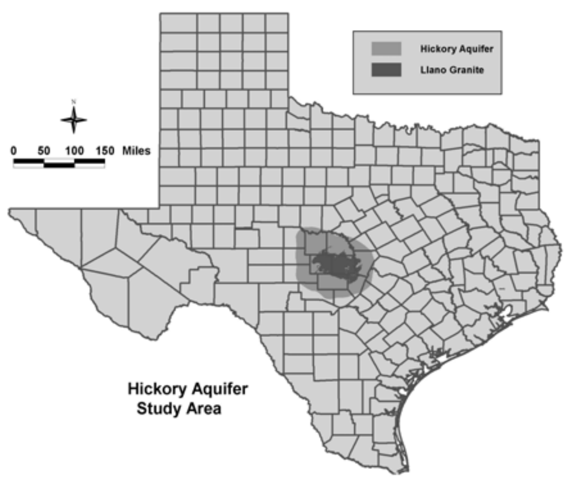

Figure 1. Hickory aquifer study area.

A number of local cities and towns, such as San Angelo, Brady, Mason, Eden, and Llano, use or plan to use the Hickory aquifer as their long-term water supply and have limited alternatives for other supply sources. However, federally imposed regulations concerning radiological concentrations for public drinking water may severely limit the usage of this groundwater supply in the future. In an effort to evaluate the feasibility of using the Hickory aquifer as a public water supply, Danial B. Stephens & Associates was hired to investigate the spatial and geographic distribution of the radiological contaminants. This analysis of the spatial distribution of radiological contaminants within the Hickory aquifer is still in progress.

General geology, stratigraphy, and hydrology

Hickory Sandstone (or aquifer) is late Cambrian in age and is the lowest member of the Riley Formation (Moore Hollow Group) that lies unconformably on a complex of Precambrian metamorphic rocks into which postmetamorphic (Llano Granite) rocks were intruded approximately 1.1 billion years ago.

The Precambrian surface on which the Hickory Sandstone was deposited had a relief of 600 to 750 feet, and islands of Precambrian basement rock stood above the topmost beds of Hickory. Therefore, the thickness of the Hickory aquifer varies locally because of these irregular topographic Precambrian surfaces. Differential erosion of the Precambrian basement rocks left northwest-trending ridges that influenced the distribution of the different sedimentary facies of the Hickory aquifer (McBride and others, 2002).

Depositionally, the Hickory Sandstone has been interpreted as a marine transgressive sequence from fluvial to shallow marine. The Hickory Sandstone has been subdivided into three facies. The lower facies is a braided stream quartz sandstone sequence; is characterized by weakly cemented, medium to very coarse, poorly sorted sandstones; and has an average thickness of approximately 200 feet or more. The lower facies has excellent reservoir qualities with permeabilities up to several darcys (Zhurina, 2003; Figure 2).

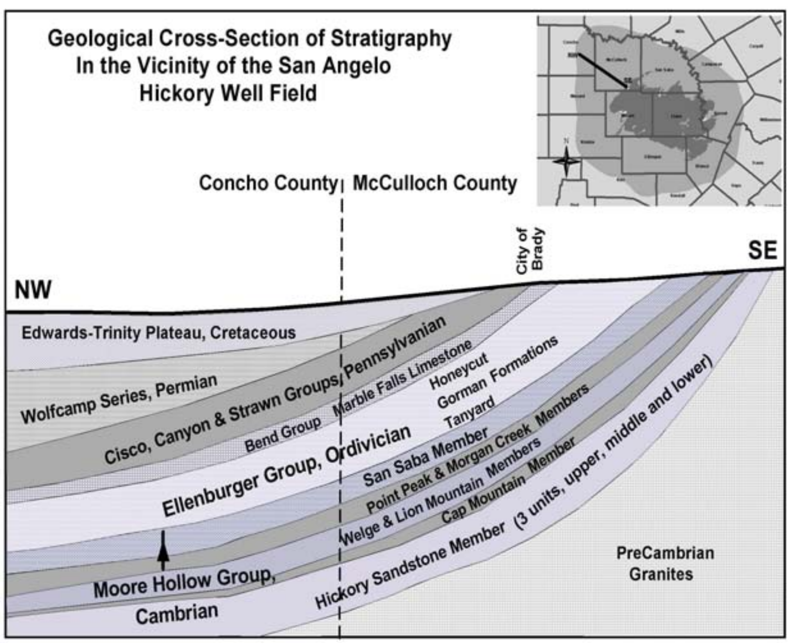

Figure 2. Geological cross section of San Angelo Hickory Well Field (not to scale).

The middle facies is a gradational fining upwards sequence consisting of interbedded fine- to coarse-grained quartzose sandstones with numerous laterally continuous mudstone laminae and interbeds. The middle facies is up to 200-feet thick and generally is a poorer aquifer interval locally acting as an aquitard between the lower and upper facies (Zhurina, 2003).

The upper facies, or ironstone facies, is up to 100-feet thick and consists of red to maroon, coarse-grained, moderately sorted, fossiliferous quartz sandstone interbedded with a few clay rich layers. The sandstone has been moderately to strongly cemented with iron oxide and calcite (Zhurina, 2003). Locally, the upper facies has been in the past considered as a potential iron ore deposit averaging 12 percent iron (McBride and others, 2002). Because of the pervasive iron oxide and calcite cement, this unit generally has poor aquifer characteristics.

The Hickory aquifer dips approximately 90 to 120 feet per mile (Carrell, 2000). Well depths range from less than 100 feet to almost 4,000 feet moving radially away from the Llano Uplift. Pumping tests and geological studies from the Texas Water Development Board water well database indicate that porosity ranges from 3 to 42 percent, the storage coefficient ranges from 0.0001 to 0.00004, and transmissivity ranges from 5,000 to 44,000 gallons per day per foot (Carrell, 2000; Bluntzer, 1992). Hickory aquifer wells can produce up to 1,000 gallons per minute, although the mean production capacity is 210 gallons per minute. The mean specific capacity is six gallons per minute per foot of drawdown. Aquifer thickness ranges from near 0 to 550 feet but averages 400 feet, and the groundwater is artesian in most confined areas (Bluntzer, 1992).

Faulting of the Hickory aquifer and overlying stratigraphic units through the middle Pennsylvanian occurred during the Ouachita Orogeny, resulting in numerous horsts and grabens (Johnson, 2004). These northeast-striking normal faults have up to 1,000 feet of throw, and trends range from N40E to N75W (Carrell, 2000). This faulting has resulted in the compartmentalization of the Hickory aquifer (Randolph, 1991; Johnson, 2004). Locally, the faults may serve as impermeable barriers or may have aligned the more productive lower facies of the Hickory aquifer with the less productive middle or upper Hickory facies (Zhurina, 2003; Carrell, 2000). Also locally, the overlying Ellenburger-San Saba and Marble Falls aquifers may have been contaminated along faults by the artesian waters from the underlying Hickory aquifer.

Overlying younger aquifers and aquitards

Cap Mountain Limestone Member, aquitard (Cambrian)

The Cap Mountain Limestone Member of the Riley Formation conformably overlies the Hickory Sandstone member, and the contact is transitional. The Cap Mountain Limestone consists chiefly of nearly pure granular limestone containing some beds of impure dark-brown limestone and calcareous sandstone, especially in the lower part of the unit. The observed thickness of the Cap Mountain Limestone ranges from 120 to 280 feet. The Cap Mountain Limestone is nearly impermeable except where it has been jointed or faulted and is not known to yield groundwater (Mason, 1961).

Lion Mountain Member, aquifer (Cambrian)

The Lion Mountain Sandstone Member, the uppermost member of the Riley Formation, conformably overlies the Cap Mountain Limestone. The Lion Mountain Sandstone consists largely of glauconitic sandstone containing fossiliferous limestone lenses in the lower portion of the member. The observed thickness of the Lion Mountain Sandstone ranges from 20 to 50 feet. The Lion Mountain Sandstone and the overlying Welge Sandstone Member form one single groundwater reservoir (Mason, 1961).

Welge Sandstone Member (Wilberns Formation), aquifer (Cambrian)

The Welge Sandstone Member consists of brown, poorly cemented, mostly nonglauconitic, quartzose sandstone. The contact with the Welge Sandstone with the underlying Lion Mountain Sandstone is fairly sharp. The Welge Member ranges in thickness from 20 to 50 feet. The Lion Mountain and the Welge Sandstone Member form one single groundwater reservoir (Mason, 1961). The wells completed in these formations can produce up to approximately 150 gallons per minute of potable water and have specific capacities ranging from 1 to 10 gallons per minute per foot of drawdown.

Morgan Creek Limestone and Point Peak Shale Members (Wilberns Formation, aquitard [Cambrian])

The Morgan Creek Limestone conformably overlies the Welge Sandstone and consists of medium- to coarse-grained glauconitic well-bedded limestone. The thickness of the Morgan Creek ranges from 70 to 140 feet. The Point Peak Shale Member consists of well-bedded soft-greenish shale containing beds of fine-grained dolomite, glauconitic limestone, and limestone pebble conglomerate. The Point Peak Shale averages about 160 feet thick. Neither formation yields significant amounts of water (Mason, 1961).

San Saba Limestone (Wilberns Formation), aquifer (Cambrian)

The San Saba Limestone Member of the Wilberns Formation conformably overlies the Point Peak Shale Member. The San Saba consists largely of beds of glauconitic limestone and dolomite replacing stromatolic reef. The San Saba Limestone averages approximately 280 feet in thickness (Mason, 1961; Barnes and Bell, 1977). The wells completed in the San Saba Limestone can produce up to approximately 100 gallons per minute of potable water and have specific capacities ranging from 1 to 10 gallons per minute per foot of drawdown.

Ellenburger Group, aquifer (Ordovician)

The Ellenburger Group is a thick sequence of fine- to coarse-grained limestones and dolomites consisting of three formations: Honeycut, Gorman, and Tanyard. Much of the Ellenburger Group is fossiliferous, and chert is common in the upper part. The observed thickness ranges from 0 foot (eroded sections) to more than 600 feet but averages about 450 feet. Locally, areas of the Ellenburger have been karstified, resulting in higher well yields. Ellenburger wells can produce up to 1,000 gallons per minute (mean is 80 gallons per minute) and have specific capacities up to 70 gallons per minute per foot of drawdown (mean is 16 gallons per minute per foot of drawdown). Pumping tests and geological studies indicate that porosity ranges from 1 to 17 percent, the storage coefficient is about 0.0022, and transmissivity ranges from 56,000 to 96,000 gallons per day per foot (Bluntzer, 1992).

The Hickory aquifer and overlying stratigraphic units (Cambrian through Ordovician) through the middle Pennsylvanian (Marble Falls Formation) were faulted during the Ouachita Orogeny (Johnson, 2004). Late Pennsylvanian and younger formations were deposited on top of this faulted sequence.

Overlying younger Paleozoic and Mesozoic rocks (Silurian through Cretaceous)

Overlying the formations discussed above is a thick sequence of shales, limestones, and sandstones. Silurian, Devonian, and Mississippian formations are usually missing throughout the study area and have been eroded away.

The lower Pennsylvanian includes the Marble Falls Formation of the Bend Group. This limestone formation can be up to 600-feet thick and locally has undergone karstification. Marble Falls wells can produce up to 400 gallons per minute (mean yield is 90 gallons per minute) and have specific capacities up to 30 gallons per minute per foot of drawdown (TWDB well database). Locally, the Marble Falls and the underlying Ellenburger and San Saba aquifers may be hydrologically connected (Ashworth and Hopkins, 1995; TWDB well database).

On the surface, the Cretaceous Edwards-Trinity (Plateau) aquifer lies west and south of the study area. This major Texas aquifer does not have significant hydraulic connection with the Hickory aquifer and the other overlying Cambrian, Ordovician, and lower Pennsylvanian aquifers and will not be discussed further in this paper.

Chemical data for the study area

Borehole exploration in the Hickory aquifer for public drinking water with low concentrations of radiological contamination is problematic. Because radiological analyses of water generally require two or more weeks, this time delay could create costly logistical problems for field equipment and personnel while waiting on the laboratory results. The authors investigated available Texas Water Development Board borehole chemistry data with the hope of identifying other chemical variables indicative of low or high radium concentrations.

The Texas Water Development Board database includes 2,710 wells that are completed in the Precambrian (pre-Hickory) through the lower Pennsylvanian (Marble Falls Formation) aquifers in the thirteen-county area of interest. This sequence of formations was investigated because of the possibility of artesian Hickory aquifer waters leaking into overlying formations along faults. Geochemical analyses are available for a total of 930 of these wells, including some combination of cations (selective trace metals), anions, well depth, pH, oxidation reduction potential, and radiological data. Radium or its daughter decay product radon has been identified as the major source of radiological contamination in the Hickory aquifer. The U.S. Environmental Protection Agency (EPA) and Texas drinking water standard for radium (Ra^{226} + Ra^{228}) is five picocuries per liter (pCi/L).

Radiological analyses are available for a total of 257 of these wells, including alpha and/or beta and/or Ra^{226} or Ra^{228} (very few uranium detections) and some combination of other chemical analyses. Of these 257 wells with radiological analyses, a total of 105 (70 from the Hickory aquifer and 35 from overlying aquifers) detected one or more radiological concentrations that equaled or exceeded the EPA radiological drinking water standards (red stars in Figure 3). The geographic distribution of 152 wells that had radiological concentrations less than EPA standards (non-Hickory, 101 wells [green circles] and Hickory, 51 wells [yellow circles]) in Figure3).

The geographic distribution of both the high and low radiological concentrations in Figure 3 are somewhat clustered, suggesting that either chemical, physical, or temporal influences, or a combination of these factors, may be influencing the geographic distribution.

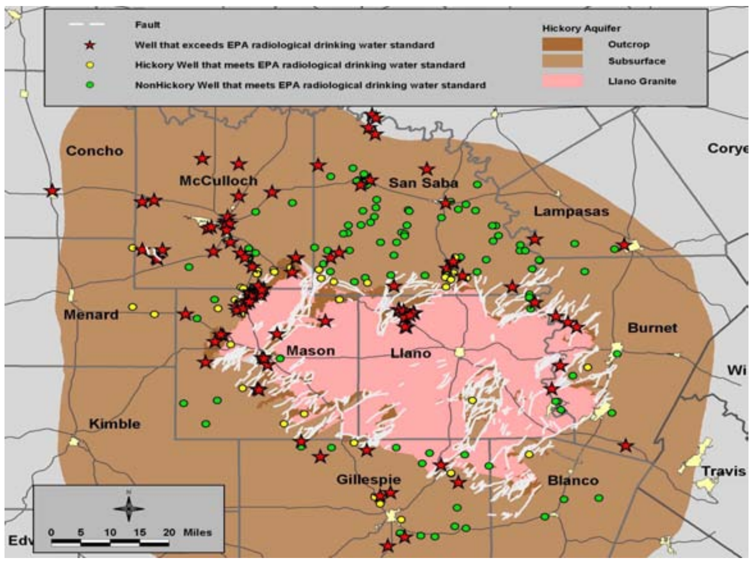

Figure 3. TWDB wells with radiological geochemistry.

A series of scatter plots of various combinations of chemical constituents were investigated using the geochemical data from 121 Hickory aquifer wells for which radiological analyses have been conducted. The following references were used to guide the selection of what chemical variables may cause the mobilization of radiological constituents:

- Upchurch and others (1991): pH, oxidation reduction potential, sulfate, strontium, barium, fracture traces, and water table fluctuations.
- CRCPDa (1994): oxidation reduction potential and temperature.
- Tuckfield and others (2004): pH.
- USGS (1998): pH and well depth.
- Landa (1999): pH, barium, and sulfate.

Well depths in the Hickory aquifer range from less than 100 feet at the outcrop to almost 3,500 feet deep downdip. A scatter plot of total dissolved solids concentrations versus well depth is shown in Figure 4. Data are shown for a total of 96 wells; however, this dataset may be somewhat biased because there are only four wells representing well geochemistry between 1,000 and 2,000 feet. The data distribution can probably be explained by demographics (population distribution and economics). A number of cities (that is, San Angelo, Brady, and Eden) in Texas have Hickory aquifer wells deeper than 2,000 feet, while irrigation wells near the outcrop area are generally less than 500 feet deep. A possible interpretation of Figure 4 may be

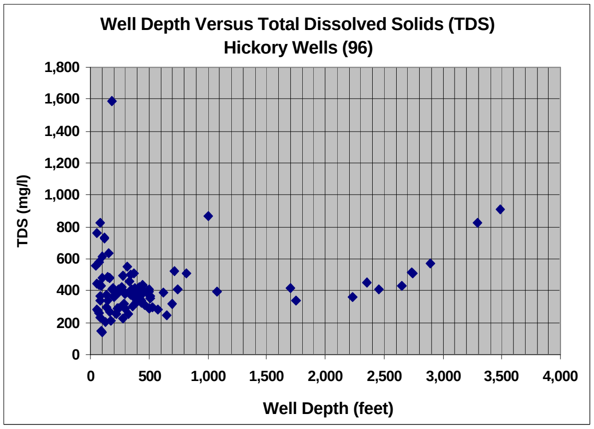

Figure 4. TDS concentration versus well depth.

that water quality (total dissolved solids) begins to rapidly deteriorate at approximately 2,700 feet but still may meet the Texas drinking water standards (1,000 mg/L) as deep as 3,500 feet.

The natural radioactive decay process of uranium and thorium produces radium. U^{238} decays by emitting alpha particles to produce Ra^{226}, and Th^{232} decays by emitting a beta particle (electron) to produce Ra^{228}. The radioactive isotopes Ra^{226} and Ra^{228} are equally soluble (USGS, 1998). Total alpha radiochemical analyses would include isotopes from all the alpha emitters: radium, radon, polonium, thorium, and bismuth. A total beta analysis would include isotopes from all the beta emitters: radium, lead, bismuth, and actinium (Argonne National Laboratory, 2001). Using the available geochemical information from the Texas Water Development Board database, the coefficient of determination (R^2) for total alpha versus $Ra^{226} + Ra^{228}$ is $R^2 = 0.720$; for total beta versus $Ra^{226} + Ra^{228}$, $R^2 = 0.824$. Total alpha analyses are the most common radiological analysis in the Texas Water Development Board database.

A scatter plot of total alpha versus well depth was initially investigated (Figure 5). Again, this dataset is limited due to the lack of available geochemical analyses between 1,000 and 2,200 feet. However, according to the available data, increasing well depth does not necessarily result in increasing total alpha concentrations.

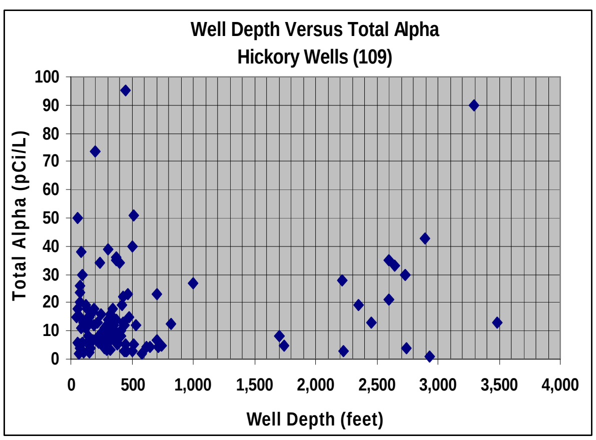

Figure 5. Total alpha versus well depth

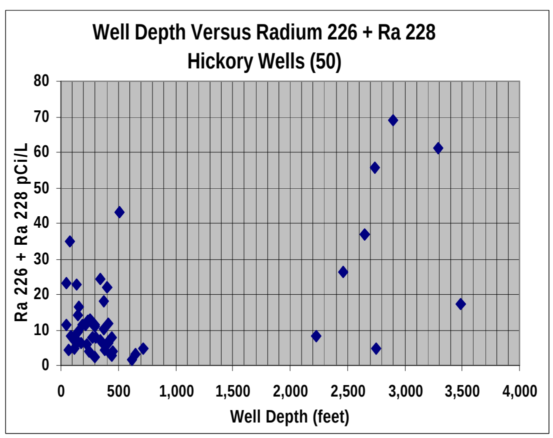

Figure 6. $Ra^{226} + Ra^{228}$ versus well depth

A scatter plot of $Ra^{226} + Ra^{228}$ versus well depth yields a more definitive result (Figure 6). Again, although there is no geochemical information available between 750 and 2,250 feet, the available information in this plot suggests that radium concentrations increase with increasing depth. The reason that these two plots were not more similar was not investigated. One probable explanation, however, is that the dominant radium isotope, Ra^{228}, is the result of beta decay from Th^{232} and therefore would not be detected in a total alpha analysis. Other possibilities for the observed variance may be the use of different laboratories, different detection limits, different laboratory analysis techniques, and other factors. Future analysis of new geochemical data and available water well data may help to resolve this problem.

A number of publications (for example, Llanda, 1999; Upchurch and others, 1991) state that radium can be mobilized as a sulfate complex. Once in the groundwater, radium is subject to adsorption in groundwater and adsorption onto aquifer mineral surfaces. Upchurch and others (1991) states that "Radium forms strong bonds with sulfate and carbonate." The solubility of radium sulfate is quite low and limits radium mobility in most systems. Figure 7 is the scatter plot of sulfate concentration versus $Ra^{226} + Ra^{228}$. The coefficient of determination is very weak ($R^2 = 0.47$). Obviously, other variables are also influencing radium concentrations besides the availability of sulfate. However, sulfate had the highest R^2 along with radium. Scatter plots for 11 other chemical combinations with radium were created and analyzed (Ca, HCO_3, Ba, Mg, Na, NO_3, Sr, Ba, Cl, Fe, and B), none of which had statistically significant correlations.

Another possibility investigated was the potential for chemical concentration or chemical environmental ranges (pH, ORP, temperature, and others) to influence concentrations of Ra^{226} and Ra^{228} in the groundwater. Figure 8 is a scatter plot of bicarbonate concentration versus $Ra^{226} + Ra^{228}$. The highest radium concentrations (those greater than 20 pCi/L in Figure 8) generally seem to occur with bicarbonate concentrations between approximately 280 and 410 mg/L.

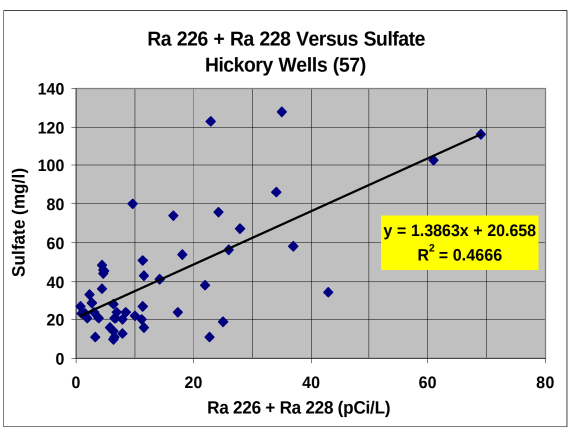

Figure 7. Sulfate concentration vs. $Ra^{226} + Ra^{228}$

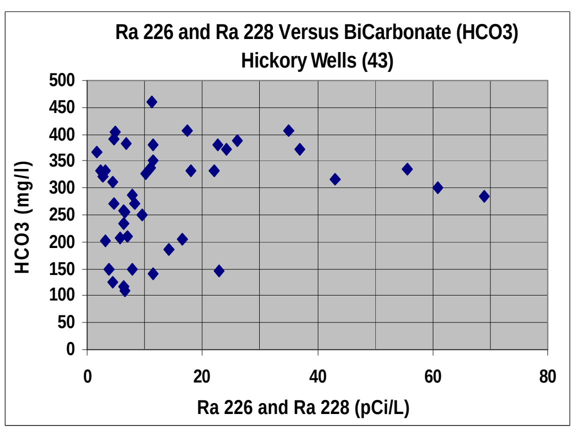

Figure 8. Bicarbonate Concentration vs. $Ra^{226} + Ra^{228}$

A similar pattern was also observed for pH versus $Ra^{226} + Ra^{228}$ (Figure 9). All 13 of the $Ra^{226} + Ra^{228}$ concentrations that were greater than 20 pCi/L fell between a pH range of 6.7 and 8.2. According to Upchurch and others (1991): "Adsorption/desorption is related to chemistry of the groundwater with adsorption being stronger with increasing pH. At the low (<5) pH range, an inverse correlation between radium level and pH, (i.e., increased radium mobility) is expected.

Radium is more mobile at acidic conditions because the solubility of minerals that contain radium (sulfates and carbonates) increases and adsorption of radium decreases. Thus, Ra^{226} and Ra^{228} concentrations should correlate with pH at pH values below 7." In Figure 9, the observed pattern for Ra^{226} + Ra^{228} concentrations versus pH suggests that other variables are more dominant in the geographic distribution of radium in the groundwater of the Hickory aquifer.

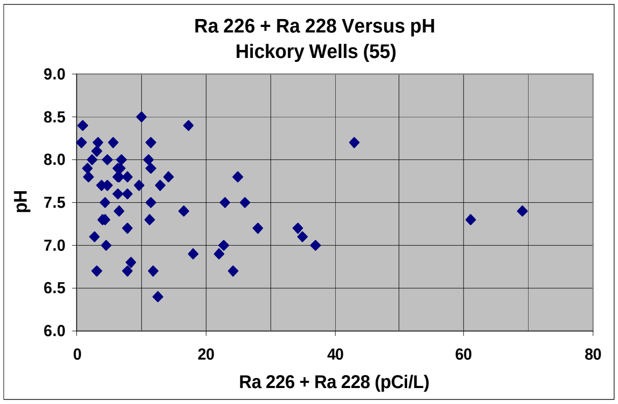

Figure 9. pH versus Ra^{226} + Ra^{228}

In summary, no statistically significant chemical correlations were identified with the available water well chemistry data. However, a few geochemical or environmental variables were identified that seem to somewhat influence the geographic distribution of higher radium concentrations. These variables include well depth, sulfate and bicarbonate concentrations, and pH. Hopefully, multivariable analyses of these and other geochemical variables in the future may identify a combination of chemical variables that can be used as exploration guides to estimate radium concentrations in Hickory aquifer groundwater.

Vertical radiological zoning within the Hickory aquifer

Lithology, stratigraphy, and structure may also influence the vertical distribution of radiological concentrations within the Hickory aquifer. Unfortunately, there are very few water, oil, or gas wells that penetrate the Hickory aquifer. Because the Ellenburger Formation was structurally faulted contemporaneously with the underlying Hickory during the Pennsylvanian, the Ellenburger and the Hickory have a similar structural history. Dr. Bob Loucks, considered a world authority on the Ellenburger Formation, was subcontracted and reviewed over 50 geophysical logs from Mason, McCulloch, Menard, and Concho counties. He constructed the regional stratigraphy from the Precambrian granites and Hickory aquifer through the Ellenburger and San Saba formations. The geophysical log suite used included nine San Angelo Hickory aquifer wells in southwestern McCulloch and northeastern Menard counties. Dr. Loucks compiled structural tops, bases, and isopach thicknesses for all known aquifers within the Cambrian to Ordovician stratigraphic sequence. All stratigraphic and structural picks used in this paper were based on Dr. Loucks work.

During the Fall of 2004, a Schlumberger Natural Gamma Ray Spectroscopy tool was used as part of a geophysical log suite for three San Angelo municipal water supply wells within the Hickory aquifer. This high-efficiency spectroscopy tool measured natural radioactivity and inferred the abundance of the naturally occurring radioactive concentrations of thorium, uranium, and potassium. These digital data were processed to evaluate the relationships between the lithology and/or stratigraphy and the vertical distribution of the radioactive horizons.

The Hickory aquifer section of the San Angelo Water Supply Well No. 3 is illustrated in Figure 10. The three characteristic facies of the Hickory aquifer are evident. The lower Hickory facies braided stream quartz sandstone sequence is relatively thin in this well (about 150 feet thick at depths from 2,240 to 2,390 feet below land surrface). The middle facies, consisting of interbedded fine to coarse grained quartzose sandstones with numerous laterally continuous mudstone laminae and interbeds, is from 2,060 to 2,240 feet deep. The upper facies is strongly cemented with authigenic iron oxide and calcite and is a coarse-grained, fossiliferous, quartz sandstone from 1,920 to 2,060 feet deep (Figure 10). Pumping tests of this well indicate a well yield of approximately 510 gallons per minute and a transmissivity of 19,500 gallons per day per foot.

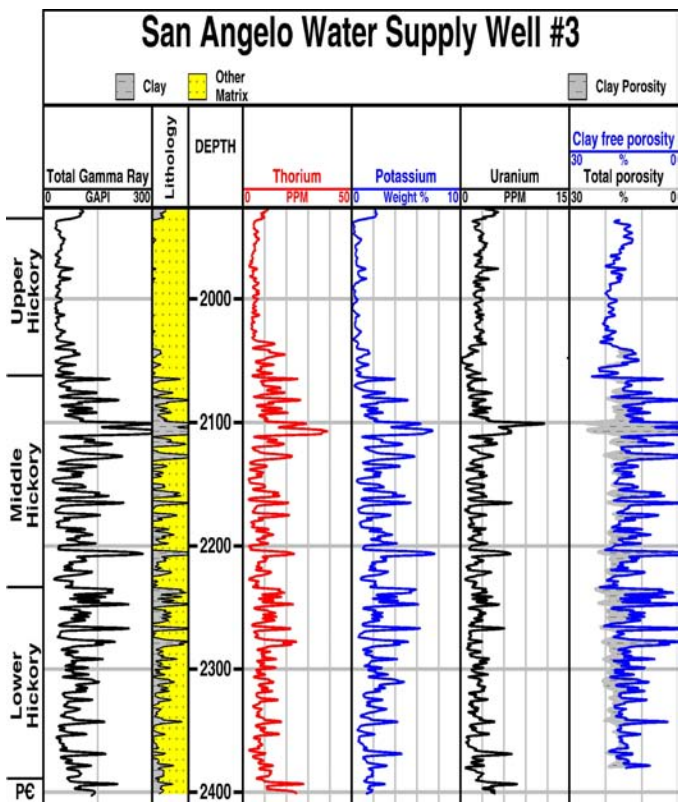

Figure 10. Natural gamma ray spectroscopy survey of San Angelo Well No. 3. Depth is in feet.

The mineralogical distribution of the natural uranium and thorium radioactivity was previously studied by Kim and others (1995). Precambrian and Hickory cores were used in this detailed petrographic study, which determined that the original local natural radioactivity was generated from the geochemical decomposition of the local granites (feldspars) and accessory minerals (less than one percent of total). The radioactive elements are redistributed to interbedded shale laminae, phosphatic materials and to a lesser extent hematitic cement within the Hickory aquifer. The aquifer rocks contain relatively high concentrations of thorium and uranium, with averages of 13.7 and 3.8 ppm, respectively (Kim and others, 1995).

A comparison of the spectral gamma peaks of thorium, potassium, and uranium with the corresponding "lithology" column in Figure 10 confirms that the clayey zones hold the highest concentrations of radiological contaminants. Thorium concentrations are generally three times that of uranium, with maximum thorium peaks up to 35 ppm and uranium peaks up to 12 ppm in the clayey horizons.

The iron-rich upper facies of the Hickory (1,920 to 1,920 feet deep) (Figure 10) seems to have relatively lower concentrations of thorium, potassium, and uranium. Kim and others (1995) observed a slight enrichment of uranium in the hematite cement of the upper facies. Hematite cement is up to 12 percent in this interval (McBride and others, 2002), and this iron concentration may possibly be masking the measured gamma spectra.

A plot of the geophysical digital effective (non-clay) porosity versus uranium concentrations for the sandy horizons within San Angelo Well No. 3 are illustrated in Figure 11. In addition, thorium concentrations are represented by the color scale along the x-axis. The thorium concentrations range from 2.6 to 19.3 ppm with a mean concentration of 6.9 ppm. The uranium concentrations range from 0.1 to 5 ppm with a mean concentration of 2.0 ppm. Thorium and uranium concentrations in the sands were generally half to one-third that of the clays.

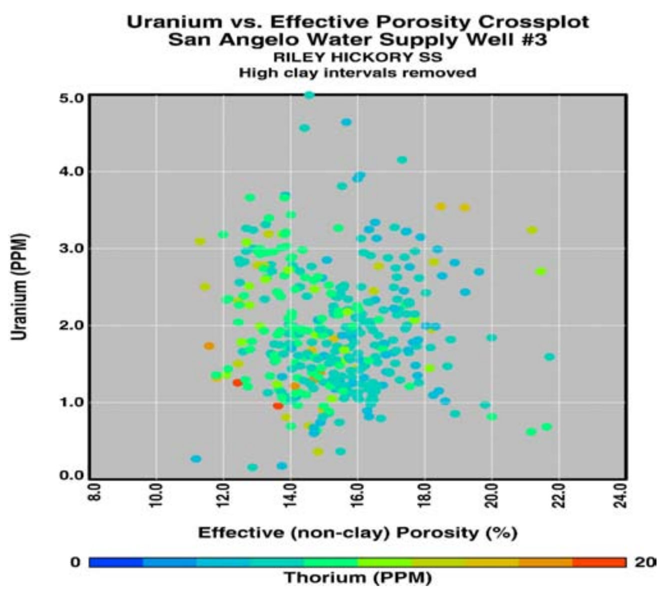

Figure 11. Uranium versus effective porosity cross plot with thorium, San Angelo Hickory Well No. 3.

Effective (non-clay) porosity ranges from 10.7 to 23.8 percent, with a mean of 16.1 percent (Figure 11). In general, the highest thorium concentrations seem to be associated with the lower effective porosities (11 to 14 percent). The uranium concentrations appear to be randomly distributed relative to the effective porosity of the sands.

A number of potential fault zones (including two in the San Angelo Hickory well field) were identified by Dr. Loucks during his stratigraphic evaluation of the geophysical logs. Because Upchurch and others (1991) had observed higher total alpha concentrations up to 0.3 kilometers (approximately 1,000 feet) laterally away from fracture traces, the authors investigated the potential for higher or lower radiological concentrations in the vicinity of faulting. Unfortunately, the lack of strategically located water wells with radiological geochemistry combined with the relatively poor resolution for the fault locations resulted in inconclusive results. However, review of the existing data implies that faulting may influence radiological concentrations in the Hickory aquifer. Future refinement of fault locations and additional radiological well data may determine if there is a relationship between faulting and radiological concentrations.

It is presently unknown if the vertical variations in the distribution of thorium and uranium concentrations within the Hickory aquifer clays and sands actually result in vertical zoning of the radium. It is possible that sandy zones trapped between clays with the higher concentrations of uranium and thorium may act as sinks for radium. Review of the geophysical logs and data analyses of the three natural gamma ray spectroscopy geophysical surveys from the San Angelo Hickory well field (form a dip section dipping east to west, distance of dip section is approximately 5 miles) indicate that the clay/shale seams are relatively continuous downdip. In addition, the overall clay to sand ratio in the Hickory aquifer and the overall concentrations of thorium and uranium in the clay layers decrease downdip in this three well dip section.

Conclusions

Borehole exploration in the Hickory aquifer for public drinking water with low concentrations of radiological contamination is problematic. Because radiological analyses of water generally requires two or more weeks, this time delay could create costly logistical problems for field equipment and personnel while waiting on the radiological analyses results. The authors investigated available borehole chemistry data with the hope of identifying other chemical variables indicative of low or high radium concentrations.

The well geochemistry data was investigated to determine if there were any geochemical variables that influenced the geographic distribution of radium. In summary, no statistically significant chemical correlations were identified with the available water well chemistry data. However, a few geochemical or environmental variables were identified that seem to somewhat influence the geographic distribution of higher radium concentrations. These variables include well depth, sulfate and bicarbonate concentrations, and pH.

During the Fall of 2004, a Schlumberger natural gamma ray spectroscopy tool was used as part of a geophysical log suite for three San Angelo municipal water supply wells within the Hickory aquifer. This high-efficiency spectroscopy tool measured natural radioactivity and inferred the abundance of the naturally occurring radioactive concentrations of thorium, uranium, and potassium. Clayey zones had the highest concentrations of thorium and uranium. Thorium concentrations were generally three times that of uranium with maximum thorium peaks up to 35 ppm and uranium peaks up to 12 ppm in the clayey horizons.

Thorium and uranium concentrations in the sands were generally half to one-third that of the clays, and the effective (non-clay) porosity ranged from 10.7 to 23.8 percent with a mean of 16.1 percent. It is presently unknown if the vertical distribution of thorium and uranium concentrations within the Hickory aquifer clays and sands actually results in the vertical zoning of the radium.

The questions that will hopefully be answered in future studies include the following:

1. Do the higher radium concentrations (daughter decay products of thorium and uranium) occur in close proximity to the higher clayey zones?
2. Are the sandy zones trapped between these clayey zones sinks for higher radium concentrations?
3. What combination of chemical, physical, and/or temporal conditions control the distribution of radium?
4. Do the concentrations of uranium and thorium decrease with depth in the clays and how does that affect radium concentrations?

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note

Effects of urbanization and structural runoff controls on water quality of streams in the Austin, Texas area

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Introduction

For many years, much concern and speculation have been expressed regarding the effects of urbanization on the water quality of streams in the Austin area. Since about 1975, the U.S. Geological Survey (USGS), City of Austin, and other governmental agencies have been monitoring the water quality of many streams in the Austin area. Many dozens of streams have been sampled in Travis County and range in size, location, physical characteristics, and extent of development. In 1990, the USGS published a report summarizing its data and presenting findings regarding the effects of impervious cover on water quality (Veenhuis and Slade, 1990). In the same year, the City of Austin (1990) published findings from their water-quality monitoring programs.

Eighteen stream sites for large multiple land-use basins were included in the USGS study—the impervious cover of the basins ranged from less than 1 percent to 42 percent. The sites represent most major streams in the Austin area. The basin drainage areas range from 6.3 square miles on Williamson Creek to 166 square miles on Onion Creek. Filter ponds, grass-lined swells, and other runoff controls exist in many of the basins. The number of water-quality samples for each site ranged from 9 to 147, with at least 20 samples available for 13 of the sites.

Eight stream sites for small single land-use suburban basins ranging from 3 to 95 percent impervious cover were included for the City of Austin study. The sites, which include data from their Surface Water Monitoring Program and the National Urban Runoff Program (NURP) in Austin, range in size from 3 to 371 acres. Storm water-quality loads were calculated for each site—the number of storm loads for each site ranged from 12 to 26.

Effects of urbanization on water quality

For the USGS study, the water-quality data for each site were aggregated into one of three flow categories for purposes of interpretation—base flow, rising stages (before the peak stage), and falling stages (after the peak). Furthermore, each of the 18 sites was aggregated into one of four development classifications: rural (less than 1 percent impervious cover); mostly rural (2 to 7 percent impervious cover); partly urban (9 to 20 percent impervious cover); and urban (greater than 40 percent impervious cover).

The report concluded that water-quality concentrations for storm samples are greatly increased with increased impervious cover. For example, the median suspended-solids concentration for rural basins is 6 milligrams per liter (mg/L) for rising-stage samples. For urban basins the median concentration is 4,100 mg/L, an increase of 6,700 percent (Table 1). The median concentrations and percent changes in median concentrations from a rural basin to an urban basin for samples collected during rising stages for the eight major water-quality constituents investigated are presented in Table 1.

The City of Austin report presents findings similar to those from the USGS report: water-quality degradation due to full urbanization for the above and other water-quality constituents represents hundreds if not thousands percent increases. Such findings are comparable to those from NURP studies around the Nation.

Table 1. Median water-quality concentrations for rural and urban basins, for samples collected during rising stream stages.

Water-quality constituent	Median value for rural basins	Median value for urban basins	Percent change in median concentration from rural to urban basin
dissolved solids	245	130	47 % decrease
suspended solids	6.0	410	6700 % increase
biochemical oxygen demand	0.95	6.0	530 % increase
total organic carbon	4.0	18	350 % increase
total nitrogen	0.5	2.15	330 % increase
total phosphorus	0.02	0.45	2150 % increase
fecal coliform	1,000	42,000	4100 % increase
fecal streptococci	1,200	75,000	6150 % increase

Note: Values for all constituents are in mg/L except for fecal constituents, which are in colonies per 100 milliliters.

Best management practices

In an effort to mitigate the impacts of urbanization on the quality of storm water, the City of Austin and other agencies have required structural best management practices (BMPs) be designed and installed throughout the area. More than 1,000 BMPs exist in the area and more are being built. The BMPs generally represent public information programs, wetlands, wet ponds, dry ponds, filters, grass swells, irrigation, and street sweeping. In 1987, the USGS published a report presenting the data and effects of two different runoff controls on runoff quality in Austin

(Welborn and Veenhuis, 1987). The largest sand filter pond at Barton Creek Square Mall was monitored for the quantity and water quality of inflow and outflow from the pond. The inflow and outflow water-quality loads were determined for 22 storms. Also, the reduction in water-quality loads between the inflow and outflow was calculated for each storm—load reductions depict those removed by the filtering pond and thus represent the efficiency of the pond in removing water-quality loads. The average (mean) removal efficiency based on all 22 storms then was calculated for each of the analyzed water-quality constituents. The mean change in water-quality load (as a percent) from the inflow to the outflow is presented in Table 2 for the constituents.

The runoff control for the other site is a grass-lined swell at Alta Vista Planned Unit Development. Analyses of water-quality samples at the inflow and outflow from this site indicate that the swell had no measured effect on water quality. However, the swell was limited in size and contained steep slopes. Studies of other local sites indicate significant removal efficiencies of water-quality concentrations for vegetated areas. The effectiveness of such controls is dependent on site characteristics such as area size, type and extent of soils and vegetation, land slope, and the type, location, and extent of development.

Table 2. Mean percent removal by Barton Creek Square Mall BMP for analyzed water-quality constituents

Water-quality constituent	Mean change in water-quality load due to filtering pond
dissolved solids	13 % increase
suspended solids	78 % decrease
biochemical oxygen demand	76 % decrease
total organic carbon	60 % decrease
total nitrogen	27 % decrease
fecal coliform	81 % decrease
fecal streptococci	81 % decrease
biochemical oxygen demand	76 % decrease
chemical oxygen demand	62 % decrease
dissolved volitile solids	21 % decrease
dissolved lead	33 % decrease
dissolved iron	55 % decrease
dissolved zinc	60 % decrease

The City of Austin has conducted several studies evaluating the effectiveness of BMPs. A summary of those studies and presentation of related reports are presented online at http://www.ci.austin.tx.us/watershed/stormwater_treatment.htm. Also, many other agencies have conducted studies of the effects of BMPs on water quality of urban runoff. The National Urban Runoff Program sponsored by the U.S. Environmental Protection Agency and the USGS conducted many of the studies, many of which are presented on the Internet at http://www.bmpdatabase.org/. Based on these studies, Table 3 is a summary of the general removal efficiencies for different types of BMPs.

Some grassy swells and wet ponds are being used in the Austin area but sand filters probably represent the most prevalent BMP in the area. Removal efficiency of filters is dependent upon maintenance of the filter material. Field inspections and other evidence indicate that many of the filters are not being maintained or properly maintained, thus the efficiency of such filters might be lower than indicated in the table. Also, the efficiency of filters and ponds is substantially reduced if stormwater bypasses or overflows the filter.

A relatively new BMP being used, especially on the Edwards aquifer, involves impoundment and irrigation of urban-runoff. Information or data regarding removal efficiency for this type BMP could not be found. However, the removal effectiveness of such a BMP is highly dependent on local environmental conditions. For example, thin soils, lack of vegetation, steep slopes, or the presence of recharge features (such as sinkholes, caves, or faults) could reduce surface attenuation of contaminants thus allowing contaminants to recharge the aquifer or runoff from the area. Also, irrigation practices affect contaminant-removal efficiencies—irrigation of urban runoff during or immediately after storms, when soils are wet, would likely cause contaminants to runoff from the area. Additionally, large storms or multiple storms creating volumes of runoff exceeding the storage capacity of the impoundment would discharge the impoundment without filtration or be required to be irrigated during periods when soils are still saturated from rain.

Table 3. Typical removal efficiencies for various types of BMPs

Type of BMP	Removal efficiencies
Public information program	5-10% for most water-quality constituents
Wetlands	up to 90%; best for nutrients, some metals increased
Wet ponds	60-80%; best for sediment-related constituents
Dry ponds	30-70%; best for sediment-related constituents
Filters	30-70%; most are horizontal; best for sediment-related constituents; efficiency dependent upon maintenance
Grassy swells	10-20%; more efficient for specific sites
Street sweeping	0-10%; some evidence that sweepers can increase water-quality loads

A runoff-filtering system manufactured by AquaLogic Inc., in San Antonio, Texas (http://aqualogic-usa.com/frameset.html) is being used on the Edwards aquifer recharge zone in the San Antonio area. The system contains a sediment-settling basin and standpipes containing 10-micron filtering media, designed to filter all received runoff. AquaLogic Inc. provides frequent inspection and maintenance via contract with property owners, thus assuring that the system performs properly. Maintenance includes removal of all material from the sediment pond and replacement of filter media in the standpipes. Although the effectiveness of this system has not yet been tested for most urban-related contaminants, it is likely more effective than sand filters. Also, it might perform superior to other BMPs simply because it receives scheduled and mandated inspections and maintenance by the manufacturer.

Conclusions

As summarized in Table 1, degradation in water quality due to urbanization for 7 of the 8 constituents range from about 300 percent to about 6,700 percent in the Austin area.

For maintained BMPs, data summarized in Table 3 and from other local studies have verified national findings regarding the efficiency of BMPs: they generally reduce water-quality values by only 30 to 70 percent for most water-quality constituents. Best management practices mitigate water-quality loads but generally do not compensate for substantial water-quality degradation caused by urbanization. Therefore, many ordinances and other rules limiting the location, type, and density of urban development have been developed in order to minimize water-quality degradation.

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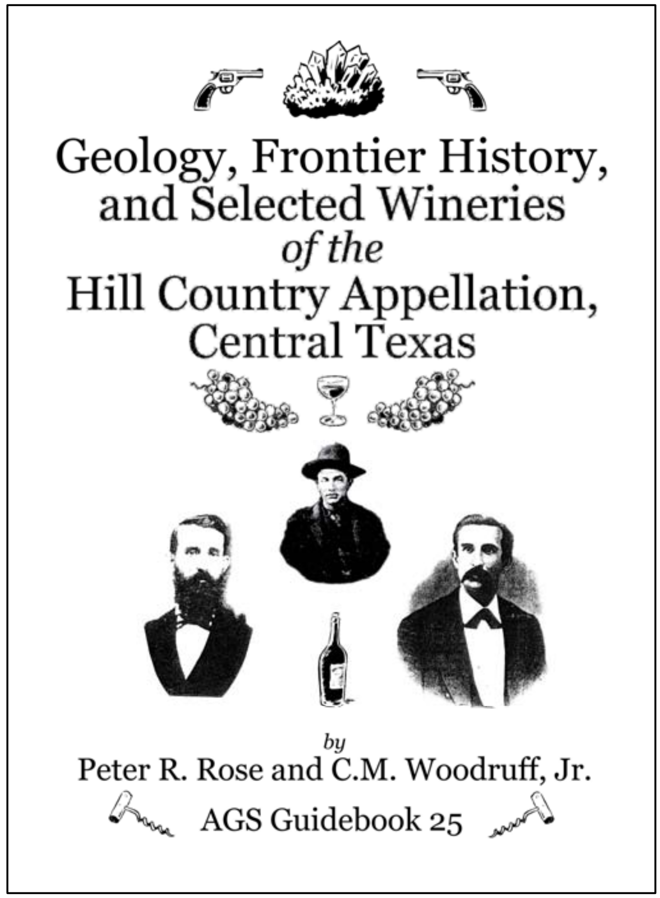
Geology, Frontier History, and Selected Wineries of the Hill Country Appellation, Central Texas by P. R. Rose and C. M. Woodruff, Jr. Guidebook 25, 2005, 109 p. **AGS GB 25, $15.00**



members

Margaret Allen
Melissa K. Allen
Mary Ambrose
Danielle M. Bailey
Alan R. Batcheller
Heather Beatty
Jeffrey Scott Beckage
Robert H. Blodgett
Robert L. Bluntzer
Pat Bobeck
Robert E. Boyer
Craig Caldwell
Alan Cherepon
Eddie Collins
Sarah Davidson
Boyd Dreyer
Shirley Dutton
Rizer Everett
Lynne Fahlquist
Bruce E. Fink
William L. Fisher
Louis Fleischhauer
Gary Franklin
Jennifer J. Garcia
Chris G. Goss
Andrew G. Grubbs
Edgar H. Guevara
Jack Holt
Jack M. Howard
Kathleen Howard
Brian Hunt
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Katie Kier
Robert S. Kier
Paul Knox
Conrad Kuharic
J. Richard Kyle
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Ann Hoadley Leist
Ada Lichaa
Christian M. Llull
Marilyn Czimer Long
Ted Longgood
Ernest Lundelius
Robert Mace
Roy Marvin
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John K. Mikels
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John Pickens
Cindy Ridgeway
Chris Riley
Michael Robbins
Jimmie Norton Russell
James W. Sansom
Jim Scaief
Wayne A. Schild
K Scott
Rainer Senger
Scott Settemeyer
Raymond M. Slade
Rebecca C. Smyth
Allan Standen
Mary M. Talley
Peter Trabant
Ramon H. Trevino
Dennis Trombatore
Shirley C. Wade
Timothy G. Walter
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Leslie P. White
Randy Williams
Clark R. Wilson
Charles M. Woodruff
Constance McDaniel Wyman
Rosemary M. Wyman
Doug Zarker

Austin Geological Society Membership Application:

Please enroll me in the Austin Geological Society as (check one): *Date:* ____________________

- O Renewal Active Member ($20 dues/year)
- O Renewal Student Member ($5 dues/year)
- O New Active Member ($20 prior to November, $15 Nov.-Jan., $10 Feb.-April, $5 May-July)
- O New Student Member ($5 prior to November, $3.75 Nov.-Jan., $2.50 Feb.-April, $1.25 May-July)

• *Name*: ____

Renewing Members:

- O Check here if your previous year membership information in AGS files is current. If your information is current, you do not need to fill out the rest of the form.

New Members or Renewing Members With Changes:

• *Telephone*: (Office)______________________(Home)______________________

• *Mailing Address*:

Street or box: ____

City:______________________ Zip: ______________________

• *Email Address*: ____

- O Check here if you would prefer having the AGS Newsletter emailed to your email account.
- O Check here if you do not want meeting notices emailed to your email account.
- O Check here if you do not want your email or mailing address releases to other geological entities.

• *Background:*

Employer: ____

College Education (degree and field, year, school):______________________

____

Present Focus*:* ____

Disciplines of Interest: ____

Mail this form and payment to:
Treasurer, Austin Geological Society, P.O. Box 1302, Austin, TX 78767-1302

We invite you to become a member of the Austin Geological Society and share in our programs. Your membership will bring you:

- notice of AGS meetings with speakers.
- notice of AGS field trips to sites of geological interest.
- social gatherings of geological professionals in the Austin area.
- a monthly newsletter to keep you informed of Society and regional news of interest to geologists.
- the opportunity to become acquainted with other geologists in the Austin area.

The requirements for membership are:

- To be eligible for Active Membership, an applicant shall have a degree in geology from a recognized college or university, or the equivalent experience, or have been actively engaged in the application of geology or related scientific or professional work for a minimum of two years.
- Consideration of Honorary Membership shall be based on continued dedication and service to the Austin Geological Society. Honorary members shall be selected by the Executive Board. Any Active Member may submit the name of an individual to the Executive Board for consideration as an Honorary Member.
- Any person who is a student in good standing, studying for a degree in geology or related science, is eligible for Student Membership. Student Members shall not be eligible to vote or hold elective office.

AUSTIN GEOLOGICAL SOCIETY

CONSTITUTION

Approved October 7, 1965
Revised December 21, 1990
Revised August 14, 1995
Revised May 1, 2000

ARTICLE I

Name and Objectives

Section 1. This organization shall be named "Austin Geological Society."

Section 2. The objectives of the Society are:

(1) to stimulate interest in and promote advancement of geology;
(2) to facilitate discussion and dissemination of geologic information;
(3) to encourage social and professional cooperation among geologists and associated scientists;
(4) to maintain a high professional standing among the members; and
(5) to enhance public understanding of the professional activities of the members.

ARTICLE II

Membership

Section 1. The members of the Society shall consist of persons concerned with the science and practice of geology.

Section 2. Various classifications of memberships and qualifications thereof shall be established by the Bylaws of the Society.

ARTICLE III

Government

The government of the Society shall be vested in five (5) elected officers and an Executive Board. The composition of this government, the manner of selection, the terms of office, the specific duties, responsibilities, and other matters relevant to such bodies and officers shall be as provided in the Bylaws of the Society. Any responsibility and authority of government of the Society not otherwise specified in these governing documents shall be reserved for the Executive Board.

ARTICLE IV

Amendments

Amendments to this Constitution may be proposed at any time by petition signed by at least 20 percent of the Active Members or by the Executive Board. Adoption of such amendments shall be by ballot in which approval is given by at least three-fourth of the total number of Active Members. There shall be an intervening Regular Meeting before the balloting and subsequent to the submission of the amendment.

ARTICLE V

Dissolution of Society

In the event it should be deemed advisable to dissolve the Society, all assets at the time of dissolution shall be donated to a worthy geologic cause, as selected by the Executive Board.

ARTICLE VI

Bylaws

The Bylaws, consisting of six (6) articles as appended hereto, are adopted and may be amended, enlarged, or reduced as provided in the Bylaws.

bylaws

AUSTIN GEOLOGICAL SOCIETY

BYLAWS

ARTICLE I

Membership

Section 1. The membership of this organization shall be made up of Active, Honorary, and Student Members.

(1) To be eligible for Active Membership, an applicant shall have a degree in geology from a recognized college or university, or the equivalent experience, or have been actively engaged in the application of geology or related scientific or professional work for a minimum of two (2) years.
(2) Consideration for Honorary Membership shall be based on continued dedication and service to the Austin Geological Society. Honorary members shall be selected by the Executive Board. Any Active Member may submit the name of an individual to the Executive Board for consideration as an Honorary Member.
(3) Any person who is a student in good standing, studying for a degree in geology or related science, is eligible for Student Membership. Student Members shall not be eligible to vote or hold elective office.

Section 2. Any member who is in arrears of dues or legally incurred indebtedness to the Society shall be suspended from the Society. The Executive Board shall restore former membership status to any such suspended member when the indebtedness has been liquidated.

Section 3. All Active, Honorary, and Student Members shall be guided by the highest standards of business ethics, personal honor, and professional conduct. Any member who, after proper investigation by the Executive Board, is found guilty of violating any of these standards of conduct may be admonished, suspended, allowed to resign, or expelled from membership at the discretion of the Executive Board.

Section 4. Applicants for membership shall submit an application and dues to the Treasurer. Membership applications shall include the following information:

(1) Professional affiliation,
(2) Education, and
(3) A statement of how the prospective member qualifies for membership.

New members shall be announced in the next newsletter and introduced to the Society at the next meeting.

ARTICLE II

Dues and Special Assessments

Section 1. The annual dues for Active Members and Student Members of the Society shall be established at the beginning of each administrative year by the Executive Board. Dues shall be payable on or before November 1 each year. No dues shall be required of Honorary Members.

Section 2. Dues for new members who join the Society after the beginning of the administrative year shall be prorated according to the quarter of the administrative year.

Section 3. Members who are in arrears for dues and/or special assessments for a period of three (3) months shall be deemed suspended and may be dropped from the rolls at the discretion of the Executive Board. Such former members may be reinstated by the Executive Board upon payment of dues and/or special assessments in arrears plus a reinstatement fee of 25 percent of the amount owed.

ARTICLE III

Officers

Section 1. The officers of this organization shall be the President, President-Elect, Vice-President, Secretary, and Treasurer. The tenure of these officers shall be one (1) administrative year.

Section 2. The duties of the President shall be to preside at all meetings, call Special Meetings, appoint such committees as are not provided for in the Bylaws, and, jointly with the Secretary and Treasurer, sign all written contracts and other obligations of the Society. The President shall assume the duties of Chairperson of the Executive Board and supervise the business of the Society. The President shall also be responsible for making arrangements for a meeting place for Regular Meetings and providing for an annual audit of financial records.

Section 3. The duties of the President-Elect shall be to participate in Executive Board meetings and serve as understudy to the President. The President-Elect will assume the office of the President the following year. The President-Elect shall also serve as Chairperson of the Election Committee.

Section 4. The duties of the Vice-President shall be to assume the office of president when a vacancy for any cause occurs and assume the duties of the President during the absence or disability of the President. In addition, the Vice-President shall serve as Chairperson of the Technical Program Committee.

Section 5. The duties of the Secretary shall be to keep the Minutes of all meetings, to attend to all correspondence and press notices, to receive and be custodian of all documents and papers of the Society, and to notify all Executive Board members of each Executive Board Meeting. The Secretary shall also serve as Chairperson of the Newsletter Committee. The Secretary, jointly with the President and Treasurer, shall sign all written contracts and other obligations of the Society and shall assume the duties of the President in the absence of the President and Vice-President.

Section 6. The duties of the Treasurer shall be to receive and disburse all funds as authorized by the Society, to keep accurate accounts thereof, and to submit annually a report of the

Treasurer's records for auditing. The Treasurer shall be present or delegate a substitute to be present at each Regular Meeting to collect monies and membership applications. The Treasurer, jointly with the President and Secretary, shall sign all written contracts and other obligations of the Society, and shall assume the duties of the President in the absence of the President, Vice-President, and Secretary.

Section 7. The Executive Board shall consist of the President, President-Elect, Vice-President, Treasurer, and the last available past President. The Executive Board's duties shall be to appoint officers to fill vacancies occurring during the administrative year, except the office of President to which the Vice-President shall succeed; and to have general supervision of the organization.

Section 8. The election of officers shall be held at the Annual Meeting. Nominations shall be made by the Election Committee consisting of the President-Elect and at least two members appointed by the President-Elect. This Committee shall nominate two or more candidates for each elective office to be announced in the Society Newsletter prior to the Annual Meeting. At the Annual Meeting, additional nominations may be made from the floor following the report of the Election Committee. The Election Committee shall be responsible for preparation, distribution, and collection of the ballots at the Annual Meeting, and the tabulation of the results of said balloting. The committee shall present the results of the balloting to the President of the Society during the Annual Meeting so that the newly elected officers may be presented to the Society. Voting shall be by secret ballot. Ballots shall be distributed during registration at the Annual Meeting and shall be returned to the Election Committee upon completion. If none of the candidates for a particular office obtains a majority of the votes cast, the candidate with the least number of votes shall be eliminated and a second ballot taken. If there is a tie between two candidates, a second ballot shall be taken at the Annual Meeting. If, after the second ballot, there is still a tie, the winner shall be decided by the flip of a coin.

ARTICLE IV

Standing Committees

Section 1. There shall be the following Standing Committees within the Society:

- Publications Committee,
- Technical Program Committee,
- Newsletter Committee,
- Field Trip Committee,
- Membership Committee,
- Web Committee,
- Election Committee, and
- Awards Committee.

The President shall appoint a Chairperson to those committees not already chaired by an officer. These appointments shall be for one administrative year. The Chairperson of a Standing Committee may, in turn, appoint any additional members in good standing with the Society to his or her committee.

In addition to the aforesaid standing committees, there is the Nominating Committee, as previously set forth in Article III, Section 8, of the Bylaws. The President may appoint any special committees as the Executive Board may authorize.

Any Committee Chairperson or member may be removed and replaced by a new appointee upon majority action of the Executive Board.

Section 2. The purpose of the Publications Committee is to oversee the sale of Society publications and assist in the publication of any other manuscripts or documents the Executive Board may authorize.

Section 3. The function of the Technical Program Committee is to provide a program for the Regular Meetings of the Society and to make necessary arrangements for that program.

Section 4. The function of the Newsletter Committee shall be to prepare and mail a newsletter to serve as an announcement of Society Meetings.

Section 5. The purpose of the Field Trip Committee shall be to organize the Society field trips on a suggested schedule of one in the fall and one in the spring.

Section 6. The Membership Committee shall encourage membership, assist the Treasurer and Newsletter Chairperson, maintain a list of active members, and prepare the Society Directory.

Section 7 The Web Committee shall be responsible for the design and upkeep of the Society Web page.

Section 8. The Awards/Scholarship Committee shall nominate and recommend award and scholarship candidates to the Executive Board.

ARTICLE V

Meetings

Section 1. The meetings of the Society shall be of three classes: Regular, Executive Board, and Annual.

Section 2. The Society shall hold at least one Regular Meeting each month from August through April except that, by vote of the Executive Board, additional Regular Meetings may be held or Regular Meetings may be discontinued for a period not to exceed three months. The appropriate time and place for Regular Meetings shall be selected by the President or a delegated Committee.

Section 3. Executive Board Meetings shall be held at such times and places and for such purposes as the Executive Board deems necessary and as announced by the President.

Section 4. The Annual Meeting shall be held during the month of May at a place and time designated by the Executive Board. The purpose of this meeting will be to complete the business of the administrative year and shall include the following order of business:

(1) Report of the Executive Board, the President, the Treasurer, and the Standing Committees. Standing Committees may be considered with the report from the President.
(2) Old or unfinished business.
(3) New business.
(4) Election of new officers.

(5) Program.
(6) Presentation of new officers.

Section 5. The administrative year shall be from August 1 of one year to July 31 of the following year.

ARTICLE VI

Awards

Section 1. The Awards Committee shall submit recommendations to the Executive Board for the Public Service Award, the Distinguished Service Award, and for scholarships to be awarded by the Society.

Section 2. The Public Service Award shall be given to recognize contribution of members to the Society to public affairs and to encourage geologists to take a more active part in such affairs. The recipient shall be a member of the Society, but may be in any class of membership. This award may be given without regard to previous awards. Granting the award in any year shall be discretionary.

Section 3. The Distinguished Service Award shall be given to members who have distinguished themselves in singular and beneficial long-term service to the Society. The emphasis shall be on long-term and, at the same time, meaningful service to the Society. The term singular does not necessarily mean without precedence, but rather that the activity be specific as distinguished from general service. More than one member of the Society may be considered in any one year for the award, but Honorary Members should generally be excluded.

Section 4. Scholarships shall be awarded from an endowed scholarship fund. The Executive Board shall select scholarship recipients from candidates recommended by the Awards Committee. Granting scholarships in any year shall be discretionary.

ARTICLE VII

Amendment to Bylaws

Amendments to the Bylaws shall be made by vote of three-fourths of the Active Members present at any Regular Meeting, provided that due notice of the proposed amendment has been submitted to the members of the Society at least two weeks in advance of the date on which the ballot is taken, and provided a quorum (twenty-five percent of the Active Membership) is present at said meeting.