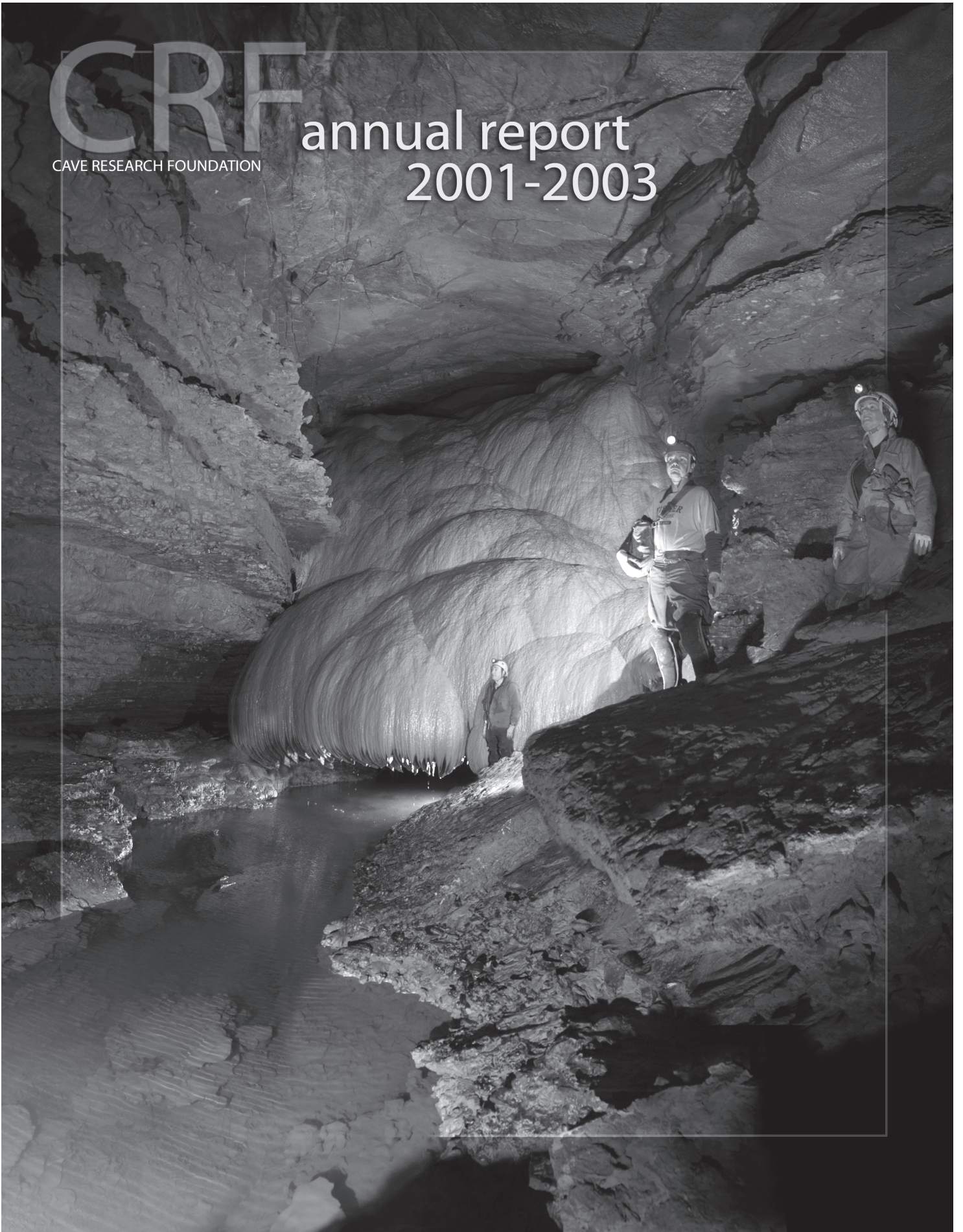



CRF

CAVE RESEARCH FOUNDATION

annual report 2001-2003





Annual Reports

2001-2003

Cave Research Foundation
177 Hamilton Valley Road
Cave City, Kentucky 42127

The Cave Research Foundation (CRF) is a private non-profit organization incorporated in 1957 under the laws of the Commonwealth of Kentucky. Its purpose is to:

Facilitate research, management, and interpretation of caves and karst resources

Form partnerships to study, protect and preserve cave resources and karst areas

Promote the long-term conservation of caves and karst resources

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Hawkins River at the Amos Hawkins Formation, Mammoth Cave
Cover layout and photo: Gary Berdeaux

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Cave Research Foundation Activities 2001

Cave Research Foundation Directors

2001

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Lava Beds Area: Janet Sowers

Ozark Operation Area: Scott House

Southwest Operation Area: Barbe Barker

Sequoia and Kings Canyon/Mineral King Operation
Area: John C. Tinsley

Hamilton Valley Director: Elizabeth Winkler
Newsletter editor: Paul Nelson

*Mapping near Edna's Dome area of Mammoth Cave, Kentucky
Photo: Pat Kambesis*

2001 Highlights

Annual Meeting

The 67th Meeting of the Cave Research Foundation Board was held after the National Cave Management Symposium in Tuscon, Arizon.

Joel Despain was elected as a new director on the Board
Rick Toomey was elected to serve as the next President.

The following CRF members were elected to become Fellows of the foundation: George Crothers, Daniel Gregor, Paul Nelson, David McKenzie and Matt Mezdilo

CRF Fellowships and grants program. A total of eleven applications were received for the program five were selected to receive awards. The individuals and research abstracts are summarized below:

Carbon chemistry of an alpine karst stream, Sequoia and Kings Canyon National Parks

Joel Despain . Western Kentucky University - MS Karst Research Fellowship: \$3500

Caves and karst provide many benefits to both people and wildlife including water supplies, habitat, and recreational opportunities. Karst also provides another unseen benefit to the biosphere. Karst naturally sequesters atmospheric carbon. Atmospheric carbon concentrations (in the form of carbon dioxide) have been steadily increasing since the initiation of industrial production more than 200 years ago. The amount of carbon dioxide released into the atmosphere has grown even more rapidly in the 20th century due to increased car, plane, power generation and industrial reliance on fossil fuels. In recent decades increasing atmospheric carbon concentrations has been closely linked to climate change, particularly rising average planetary temperatures.

It has been generally assumed that carbonate chemistry in all natural waters and karst areas led to the retention of 50 % geologically derived carbon and 50 % atmospherically derived carbon (e.g. Berner et al., 1983; Meybeck, 1987; Berner and Lasaga, 1989; Probst et al., 1994; Amiotte Suchet, P. and J.L. Probst, 1993, and 1995; Liu et al., 1998). However, recent work by Groves and Meiman in the temperate Mammoth Cave karst, Kentucky (Groves and Meiman, 2000) and previous chemical analysis by Plummer, et al. (Plummer, Wigley and Parkhurst, 1978) has produced results that vary from the assumed 50%/50% ratio.

Alpine karst systems operate under the chemical constraints of low water temperature and generally weak ionic solutions. However, carbon dioxide is more soluble in cold, natural waters, leading to lower pH values in alpine systems (due to the carbonic acid formed by the carbon dioxide dissolved in water). This contrasts sharply with the chemistry of temperate karst systems where warm water leads to stronger ionic concentrations, but sometimes lower carbonic acid concentrations. Thus, this study seeks to determine the actual amount of sequestered carbon in the discharge of the alpine Tufa Falls Spring over the course of one year.

Tufa Falls Spring drains two karst basins and adjoining lands covering some 7 square kilometers (as shown by previous dye tracing). The basins reach elevations of more than 3,600 meters, while the spring lies at an elevation of approximately 2,400 meters. Instrumentation to monitor the spring's chemistry lies some 150 meters downstream from the resurgence. Recorded parameters include stage (calibrated with salt slug discharge tests), pH, conductivity, and temperature. Grab samples for cation and anion analysis are also made on a regular basis to determine various ion concentrations relative to conductivity.

With the help of the Cave Research Foundation, in a year this project will have gained an understanding of the actual annual chemistry of an alpine karst stream. It is hoped that this information will have broader implications for the role that karst systems play in sequestering atmospheric carbon and moderating potential climate change.

Comparative systematics of subterranean amphipod crustaceans in the families Hadziidae and Melitidae

Thomas R. Sawicki, Old Dominion University — Ph.D.

Project Summary: Due to their morphological similarities, the taxonomic status of the amphipod families Hadziidae and Melitidae is uncertain. These similarities may be due to a shared common ancestor, indicating the two families should be synonymized, or due to convergent evolution which would suggest that the current taxonomic separation of the families is warranted. In order to help solve this problem, I am currently working on a molecular analysis of the two families using the mitochondrial gene cytochrome Oxidase III. Concurrent with the molecular work is a significant amount of alpha taxonomy, as there are many undescribed species within the Hadziidae.

**Cave organisms and the evolution of visual pigments:
mysid shrimp as model organisms**

Megan Porter
Brigham Young University - PhD

Project Summary: While biospeleologists have long speculated on the regressive evolution of eye loss in highly adapted cave organisms, only recently have cavernicoles played a prominent role in the investigation of visual pigment evolution. Visual pigments consist of the protein and associated receptors responsible for the detection of light, making vision possible. Additionally, the wavelength of light that visual pigments can detect differs between species. In this study, the wavelength of absorption and evolution of the visual pigment gene (opsin) will be investigated in three genera of mysid shrimp containing cave-adapted species: *Antromysis*, *Mysidium*, and *Troglomysis*. Because the cave-adapted species in each genus are from independent cave invasions, these genera provide independent replicates of the evolutionary experiment of eye loss. In terms of visual pigments, these cave-adapted species offer the opportunity to investigate the effect of the loss of functional constraint (i.e., no light) on the evolution of a gene. Because these genera also contain species found in surface environments, direct comparisons of the visual pigment gene between ancestral (eyed) and derived (cave-adapted eye loss) states can be made.

The objectives of this research include establishing the evolutionary relationships between the cave and surface species being investigated and evaluating the relationship among environment (light or lack thereof), the evolution of the opsin gene, and the wavelengths of light each species is capable of detecting. Visual pigments are proteins that belong to a large family of receptors that have been identified as critical in cellular communication systems, including the detection of hormones, neurotransmitters, odorants, and photons. Due to the exaggeration of non-light requiring modes of perception in cave organisms, this class of receptors has the potential to be a profitable area of research for biospeleologists. However, very little is understood about these cellular communication systems in cave organisms, particularly subterranean invertebrates. This study will elucidate the evolutionary processes of visual pigments in a group of cave invertebrates and their surface relatives. By elucidating the mechanisms controlling the tuning of visual pigments to different wavelengths in mysid shrimp, this study will provide a framework for testing opsin evolution in other organisms.

Stable carbon isotope values from bat guano in the examination of precipitation and vegetation changes in arid Mexico

Christopher M. Wurster
Syracuse University - PhD

The use of stable carbon isotope values from bat guano in the examination of precipitation and vegetation changes in arid Mexico his study aims to test the hypothesis that carbon isotope values of guano from 2 species of bats, the lesser long-nosed bat and the Mexican free-tailed bat, preserve a record of dietary intake, which reflects surrounding vegetation. In the arid regions of western Mexico, an increase in terrestrial vegetation biomass utilizing the Calvin cycle for photosynthesis (C3 vegetation) over plants utilizing Crassulacean Acid Metabolism (CAM vegetation) is highly correlative with precipitation anomalies associated with El Niño events. This is significant because C3 vegetation has a distinctive carbon isotopic signature compared to CAM plants, which may be recorded in guano deposits. Because the diet of the lesser long-nosed bat and the Mexican free-tailed bat strongly reflects available vegetation, an experiment is designed to test whether quantitative estimations of precipitation and C3/CAM vegetation ratio can be discerned from guano isotope values of carbon. This study will serve as a calibration for Holocene guano deposits that could yield long-term information on the strength and frequency of El Niño as well as climate change from a region where traditional paleoclimate methods cannot be applied.

Paleoclimate records in water extracted from speleothem calcite

Feride Serefiddin
McMaster University - PhD

This research seeks to further refine existing improvements to the extraction of fluid inclusions and find additional proxies for climate change using new techniques. Speleothems from Reed's Cave (South Dakota), Rat's Nest Cave (Alberta), Vancouver Island and California are being used to develop a paleoclimate history for western North America. Fluid inclusion analysis will complement existing isotope data from speleothems which have been dated using uranium-series dating. Hydrogen isotope variations will be measured by extracting fluid inclusion water from the speleothem calcite. The objective is to extract fluid inclusion water to measure the composition of paleoprecipitation and to calculate temperature changes from key periods in the Quaternary period. Paleotemperature reconstruction is a significant advance in the use of speleothems for quaternary research. The oxygen isotope paleothermometer provides important data, but a complementary technique to confirm these results is not yet

available. This research proposes to develop a paleothermometer from the hydrogen isotope record in fluid inclusions and possibly the hydrogen present in the calcite lattice. Besides the water present in inclusions, additional water is obtained by heating the speleothem calcite to over

800°C; this suggests that water strongly bound to the calcite, a type of lattice water. The isotopic fractionation between this water and that of fluid inclusions may provide an additional paleothermometer. This could provide an additional proxy record for climate model calibrations.



Main bulding at Hamilton Valley Research Station Photo: Pat Kambesis

Hamilton Valley Research Station Update

Elizabeth Winkler

At this writing, the CRF national headquarters and research station at Hamilton Valley have been in operation just shy of 20 months. The good news is that, so far, nothing has exploded, erupted, caved in or completely failed on us (well ... except a temporary problem with the water system), and thus far, the bills have been paid.

We have been able to rent the facility to a variety of groups and individual scientists, so our income base has expanded beyond CRF expeditions, though CRF Eastern Operation continues to be our primary and most significant tenant. We have also rented the facility a number of times to the Central Kentucky Karst Coalition, a CRF affiliate for their project work in Roppel Cave. Summer of 2001, a group of CRF members raised money for the facility by running an informal post-NSS Convention camp at HV raising over \$300. Finally, although we hope never to repeat this usage, HV served as a staging area during the rescue from Sides Cave of CRF member Chris Groves.

CRF has been able to support the work of other caving, karst, and environmental groups through rental of the facility. Our first tenants were many of the attendees of the Mammoth Cave Science Conference (2000). In addition, the National Speleological Society (NSS) Mammoth Cave Restoration Field Camp filled both bunkhouses for two days

in October 2000, and later in the same month, the Hoffman Institute (headed by CRF BOD member Chris Groves) sponsored three Chinese researchers from the Guanxi Karst Tourism group from The People's Republic of China. In August of 2001, the Ohio Coleopterist Society, (CRF member Dick Maxey) stayed at the facility and studied the beetles of the area.

We have also become a resource for university geology classes from many states as well. In March 2001, Dr. John Mylroie, Mississippi State University, brought his graduate level Karst Processes class, 18 students, to the facility for a 3-day course. He wrote after the trip that they thoroughly enjoyed using the facility. He came back for a week in July with nine high school earth science teachers. In March 2001, Dr. Jonathan Martin of the Department of Geological Sciences at the University of Florida brought his graduate Hydrologic Processes class to look at karst hydrogeologic features around the Mammoth cave area for three days. Two university geology classes from Eastern Kentucky University and Memphis State University spent the weekend in October of 2001 - the same weekend as the Leonid Meteor shower. I was there that weekend as well working on the building. Many of us took sleeping bags out into the grassy area in front of the main building and watched the glorious meteor shower all night. In November, Dr. Daryl

Granger brought his geomorphology class from Indiana on his annual field trip to Mammoth Cave.

We have been able to support the work of individual researchers and students as well, both CRF and non-affiliated people. For instance Rick Toomey and Mona Colburn (CRF) stayed at the facility in January, March and May (2001) while working on a CRF/Mammoth Cave National Park/Illinois State Museum joint research project. Six members of CRF stayed at the facility while attending the Western Kentucky Karst workshop last summer as well. The facility also hosted CRF member Mike Yocum and several members of his crew while he was completing his Safety Video Project for Mammoth Cave National Park. Finally, one of Patty Jo Watson's Master's students, Angela Gordon, has been studying, under the direction of CRF member George Crowthers, a stand of plants found in Hamilton Valley called "rattlesnake master". They have been working with HV Land Management Manager Roger McClure to ensure the protection of this stand (see Dr. Watson's article this volume for more information).

As part of Red Watson and Roger McClure's original vision, we have also made HV available for rental to individual CRF members and their families as a beautiful get-away place. Many members have taken us up on this opportunity including Jeff Middleton and his family, Don Coons, Pat Kambesis, George Crowther, Naoko Yokohama and many others including myself. It is a glorious view from the balcony into the valley below, especially at sunset and dawn when deer and wild turkey can be seen cavorting about.

We are not as yet completely self sufficient, but we are getting much closer to that goal. At present, our most costly expenditures are our insurance and paying off the last \$40,000 of the construction debt. Our insurance runs in the neighborhood of \$10,000 a year. We have explored many options and other companies, but have been unable to find any way or reducing that expenditure, and in future years, this cost is likely to keep increasing. There are two basic reasons why this cost is so high: 1) our distance from the nearest fire station (which is unlikely to change unless Cave City finds the need to build one west of the city); and 2) the fact that we are on well water which insurance companies do not consider reliable nor provide sufficient pressure. That is also unlikely to change. One local resident tried to get a petition passed to bring city water out Park Ridge Road but was unable to get enough support for the project.

Other expenditures: gas, electricity, phone, and supplies are all quite reasonable. We are fortunate that we have three HV supply officers who work to get us good deals on things we need: Alan Welhausen (kitchen supplies), Bob Osburn (of-

fice supplies and equipment) and Dick Maxey (cleaning supplies). We are also looking at ways to reduce utility expenses. For example, Roger McClure, Land Management, has been planting trees up close to the buildings to provide shade and lessen the need for electricity. Sue Hagan has been promoting ecologically sound living habits, like encouraging people to open windows and enjoy fresh air rather than depending on noisy air conditioners. Furthermore, many of our needed supplies, furniture, and equipment have come from the generous donations of our members, (too numerous to mention them all here) but I will mention a few who have given a great deal of time and effort: Joyce Hoffmaster, Erik and Courtney Sikora, Matt Mezydlo, Sue Hagan, Gary Berdeaux, Janice Tucker, Daniel Gregor, Roger and Shannon Smith, Dick Maxey, Roger McClure, Fred Schumann, Charles Fox, Bonnie and John DeLong, Elizabeth and Ed Klausner, and Tom Brucker.

Finally, we have saved an incredible amount of money from the labor of individual members whose expertise in electrical work, carpentry, painting, building, plumbing, trail building etc. have been generously donated at expedition weekends and special work weekends. Several people have gone well beyond the normal call of duty in this area and must be thanked here: the group who paid for and built the utility building (Dick Maxey, Richard Zopf, Cheryl Early, Joyce Hoffmaster, Daniel Gregor, Dave Hanson, and Shiela Sands). Roger McClure (assisted by Rick Nelson, John Feil, Stan Sides and Jack Freeman) has been taking care of the land itself. When we can keep him and the tractor out of the sinkholes, Roger keeps the land bushhogged and wisely manages all of the federal and state programs with which we are involved. These programs generate a significant amount of funding for HV. Last year they brought in about \$3500.



Bunkhouses at Hamilton Valley Photo: Pat Kambesis

A number of projects and plans have been put into effect that are working towards that goal. For example, CRF BOD member Dr. Chris Groves of Western Kentucky University has instituted a campaign to university geology departments across the United States to promote the facility as a research station and conference center. One of goals as laid out in the original HV Plan is "to provide a means for the CRF to further its established goals of support for research, education, and conservation of caves, karst areas, and karst resources. The availability and use of the HVRC will facilitate these goals". Chris's efforts for us are certainly in line with this objective. At the end of 2001, I initiated a Capital Campaign to eliminate the remaining debt of \$41,000 on the HV buildings. Since then, almost 40 members have donated \$15,000 towards that goal. I have written an additional request published in the April CRF Newsletter. At the beginning of the summer, a follow up request will go out to members who have not as yet donated. We have received donations both large and small - all of which are important as we get closer to eliminating this debt. Without the obligation of this debt, which accounts for almost 35% of our major monthly costs (rough monthly costs: electricity \$300, insurance \$850, loan payment \$625), we would

be in good shape financially with the increase in rental occupancy.

Blessedly, a maintenance fund of \$15,000 has been established through the ongoing generosity of Roger McClure, Cave Books, and Red Watson to cover the replacement of major equipment and/or damage to the building. I expect the first major replacement that will need to be done is an overhaul of our water system which went down for a couple of days this last month. Fortunately, Richard Zopf was on the property at the time and knew what to do to keep the system from further breaking destruction until it could be repaired.

So, we have a great deal to feel good about with this venture. It has taken many years of discussions, planning, fund raising, and implementation, carried out by what I have described to others as a large group of folk with "well defined personalities", to get us this lovely and useful research center. We have not always agreed on the the little things, or even the big things, but we have been able to put aside our differences to achieve a wonderful testament to our perseverance and commitment to our passion and our work.

Operation Area Reports

Eastern Operations Accomplishments

Dave West, Eastern Operation Manager

Cave Research Foundation, Eastern Operations
Accomplishments August 1 2000-August 31, 2001

During this period Eastern Operations fielded Seventy-six (76) parties into various objectives within Mammoth Cave National Park. This effort accounted for Three Thousand, One Hundred Eighty Seven person hours of labor in support of projects in Cartography (2483), Lesser Cave Inventory (392), Paleontology (168), Photo Documentation (82), Narrative Description (39), and Hydrology (23). Eastern Operations has also assisted the CKKC with its continued work in Roppel Cave with logistical support.

Data support has been provided, through the Cartography Program, to Stephen Thomas for development of elevation maps, a project for a class paper in Dr. Art Palmer's "Karst Geology" course at WKU. Data support has also been provided through the Cartography and GIS programs to Mr. Scott Recker for his project to identify and map existing boreholes into the cave, as well as information to Mr. Michael Adams, NPS, for inclusion in a park handbook.

All operations have moved from the Park's facility at Maple Springs to the Foundation's new facility at Hamilton Valley. This has significantly reduced the necessity of late operating hours for use of the Green River Ferry by expedition participants and freed the park's facility for use by other groups.

In August of 2001, our annual meeting with the representatives of the Mammoth Cave National Park was held and future goals were discussed and agreed upon. An effort will be made to assist the park with providing radio-location data to tie the in-cave surveys to the surface features more definitively. This will allow the park's GIS database to tie together better as well. The park will provide Eastern Operations with some funding as part of this work. Funding is also being provided to the Cartography program to upgrade its computer hardware to help improve the digital output of its cartographers, and allow easier integration of the map sheets into the GIS database.

Lava Beds National Monument Report

William C. Devereaux
Co-Operations Manager

Our project year begins October 1 and ends September 30 of each year. This allows us to make our annual report to the Lava Beds, New Mexico (LBE) staff for the Thanksgiving weekend annual meeting. The period also coincides with the weather patterns that dictate our research rhythms.

This report will detail the projects that I am responsible for, as well as detailed numbers from a spreadsheet that I use to

keep track of people, projects, and expeditions. This coming year, I hope to expand the sheet back into previous years to quantify our work since 1990.

The year we call 2001 saw 35 people work on 10 different projects over 27 expeditions while contributing 1502 hours of work in the Monument. Those hours do not include the hours those people spend getting to and from LBE, drafting

maps, working on COMPASS files, building or repairing equipment, writing reports, composing and responding to e-mails from each other or the LABE staff. Those hours also do not reflect the hours that Park staff (both permanent and seasonal), Seasonal Conservation Associates (SCAs), and volunteers who went on trips with us to support our work. There were also local National Speleological Society (NSS) cavers who gave us materials and assistance. The success of this project belongs to people who care about this Monument and the caves herein.

The projects that I worked on this last year were a Comprehensive File Review, Ice Level Monitoring, GPS Location and Monument Installation, and Cave Reconnaissance Inventory.

In January 2001, The Resource Division Chief, Chuck Barat, asked me to go through the file folders and give him an assessment of their completeness. It sounded simple, so I said "Of course." I spent the next six months, on seven trips to review 459 files and give him a report. Each cave file is supposed to have four key documents in it, and the recon card has 12 critical pieces of information that are supposed to be written

three for the cave name. Later, the three files are compared with the base station to get a differential location. The software makes a scatter plot, and a printout is viewed to see if the diagram is tight enough to make the location within a one cm circle. If the answer is yes, then we declare it good. If not, we go back and start over. When the UTM coordinates of the three sessions are accepted, then the Monument staff put the location into the GIS system. One of the new wrinkles in both GIS data gathering and cave mapping here, is to tie the brass monument and the GPS location one meter above it to the published cave map. Many cave maps are dated from the 1930s to last year. They obviously do not have the monument or GPS location on them. We are trying to do that as we go. There is a separate project to work on that correction. This year we did 14 GPS fixes and installed 28 new monuments.

The last project I can report on for this report is Cave Reconnaissance Inventory. This project also started long before

CRF became a player at Lava Beds NM. What we did in 1988 was define the project, create standards and an inventory form/card, train our people how to use the form, and work with the Monument staff on how to apply it. Many of the other projects use the "card" as a starting point for their work. It is the most basic document that must be completed when a cave is found, recorded, studied, or marked. Mike Sims created the project, invented the form, and trained most of in its use. The form is a joint form called LABE, CRF 5/93. The card comes in two forms. The two-sided card is 5" x 7". The one-sided version is 8.5" x 11". We found that the card version often did not get the flip side filled out. So the single sheet with both card sides on the front meant that all the data got filled in the first time to the cave. The "short" inventory consists of 19 specific items in four categories that the field researcher looks for in the cave during their first visit. They can circle the "Yes" or "No" symbol and make remarks to the side of the entry. They look for bats, pictographs, access problems, formations, ice, etc. The card is a living document. It is filled out in pencil and is updated as new information comes to light. This year we made 43 new cards and fixed 40 older ones.

No report would be complete with credit given to some of the CRF JVs who make the projects happen. Dr. Janet Sowers is the overall Principle Investigator who makes the project stay on track. Fred Douglas and David Kuhnelt have been with me on many of the trips and made my progress possible. Dr. Bill Broekel and his family have stepped forward and taken on a lot of mapping and recon duties this year. Iris Heusler came onboard as a mapper, a team leader, and now a Co-PI for the mapping project. Veda DePape built the meter sticks and compass wands that we use in mapping and entrance photography. This year saw her move to Pennsylvania and join up with the Mammoth folks. Their gain, our loss. Amy Ponsetti took on the GIS project as it begins.

Lava Beds Personnel:

Janet Sowers, co-Project Manager, Technical Director; **William C. Devereaux** co-Project Manager, Field Director; **Mike Sims**: Principal Investigator - Cave gating projects; **Bruce Rogers**, Principal Investigator- Cave mapping; **Bill and Peri Franz**: Principal Investigators for virtual reality cave tour.

Ozarks Operation Area Cave Inventory, Mapping and Management

Scott House



Fieldwork in the Pioneer Forest photo by Scott House

Once again, Cave Research Foundation's (CRF) work in the Ozarks focused on the Lower Ozarks area, an area of southeast Missouri so unique and well-preserved that it has been named by The Nature Conservancy as one of the world's "Last Great Places". This area lies on the southeast flank of the Ozark Plateau and is characterized by clear, spring-fed rivers, as well as a large area of karst development in mostly Ordovician and Cambrian dolomites. This area includes the drainage basins of the Current, Jacks Fork, Eleven Point, and Black Rivers. Most of our active projects, at present, lie within this area.

In 1999, the CRF Foundation's Board of Directors approved the merging of the Missouri and Fitton Cave (Arkansas) projects together into a new Ozarks Operation Area. This will help the Foundation by merging two areas that frequently share personnel and will aid both project areas by adding personnel and expertise to our portfolio.

Buffalo National River

CRF began coordinating an effort in Fitton Cave back in the early 1980s. A map was produced in 1990 showing much of the surveyed cave. Our major goal at Fitton Cave is to create a new map series which will include all the presently surveyed passages. Protocols and standards for this new series have been worked out in conjunction with Bureau of Natural Resources (BNR) cave specialist Chuck Bitting, and work is now focusing on completing and analyzing the data set. We expect drafting work to proceed as soon as this data phase is finished. Pete Lindsley and Terry Holsinger are working on the data. In the meantime, we intend to focus on smaller caves within Buffalo National River. There are a large number of smaller caves that need inventory and survey, and we expect

to work on this in the coming year. In addition, we are cooperating with BNR in the creation of improved databases for their cave management program. A cartography and planning meeting was held in May of 1999, and meetings with BNR took place in October and November as well. An action plan for getting the Fitton maps updated has been drafted.

A number of trips were taken in 1998 and 1999 to tie up surveys in the cave, establish entrance and radio point locations, and fix survey problems. In addition, one small cave, Cave X, was surveyed.

Mark Twain National Forest

The Mark Twain National Forest (MTNF) consists of 1.7 million acres of land, mostly in southern Missouri. Work by the Foundation on the Forest has been ongoing since 1986. There are approximately 380 known caves on MTNF land.

Eleven Point District

Most of the Foundation's work has been on an area known as the Eleven Point - Doniphan District. The Eleven Point River, a National Wild and Scenic River, flows through the area which is only some 25 miles west of the Current River. The work within this area has been mostly biological inventory (covered in a separate article within this annual report, see Sutton) that was initiated in response to proposed lead mining activities. Numerous caves within this project area have been surveyed and inventoried.

The Phase One report this work was published by the Missouri Speleological Survey as Volume 33 of *Missouri Speleology*. The work on Phase Two has been completed by Mick Sutton and his completed report has been delivered to

the MTNF and is slated for an upcoming issue of *Missouri Speleology*. Phase Three has since been begun and is continuing.

Other Districts

Survey work, under the leadership of Steve Irvine, continues on Crocker Cave, a mile-long muddy cave in south-central Missouri; several trips were taken there in 1998 and 1999. One new priority of the Forest Service is for us to do assessments of caves in high-ATV-traffic areas of the Forest. This work is getting underway.

CRF was awarded a United States Forest Service Certificate of Achievement for our work in Missouri. The Forest Service estimates that our cooperative and volunteer work in Missouri has saved the government \$300,000.

Database work for the MTNF was funded in 1998. This is an ongoing cooperative effort with the Missouri Speleological Survey and MTNF. We have purchased and distributed copies of the FileMaker Pro program and template. Updates of data are being forwarded to the Forest Service.

We are enjoying working with the Forest's new cave specialist, Neil Babik, who has accompanied crews on several trips.

Ozark National Scenic Riverways

The Ozark National Scenic Riverways consists of approximately 80,000 acres along the Current and Jacks Fork Rivers in southeast Missouri. A long term CRF project here has increased the number of known caves from 80 in 1980 to over 300 in 2001, over 200 of which have also been surveyed. Survey and inventory continue on Riverways lands when time permits: several small caves were surveyed in 1998 and 1999 while a number of other locations were checked. A number of cave maps from previous years were completed.

A two year-long biologic study of Round Spring Cave by Mick Sutton was completed. One of the most interesting findings was the identification of life cycles of the cave salamander (*E. lucifuga*) and how it interacts with the grotto salamander (*T. spelaeus*).

Mick Sutton and Scott House continue to participate in the OZAR Cave Management Team. We had four meetings in 1998 and 1999; this team works out particulars of cave management, including monitoring, research permits, and other activities.

We continue to map caves and assemble all data for the Riverways. The data is in FileMaker Pro format and is being integrated into the state files. An ongoing major effort is the successful integration of data from a five-year NPS archaeological survey of certain caves within the Riverways. New cave locations and improved locations for others have re-

sulted from this effort. This process is not yet finished and will still require additional field trips to verify cave locations.

We created and modified a database for monitoring caves in the Riverways. As part of this, procedures and protocols were also identified and standardized. Mick Sutton and Scott House held a workshop for NPS personnel at the Powder Mill facility in 1998. This workshop included classroom discussions and a field experience. During the two seasons since, the rangers took monitoring trips to 80 priority caves using the forms and database that we created in cooperation with the NPS.

The Foundation completed a bio-inventory project involving stream censuses in wet caves along the lower Current River. As part of this project, we also mapped these caves. The census work has been completed and all but one survey were finished as well. The remaining cave has not been finished due to a bat colony that we first identified three years ago.

From time to time, CRF cooperates with the NPS Interpretive Division by providing guide service for specialized tours in Round Spring Cave. An ArcView extension to allow the easy import and display of cave locational data was created by Eric Compas. A nice feature of this extension is the automatic retrieval of digital topographic maps as the scale or location of the base view changes. The Riverways continues to financially support our work in the Lower Ozarks area by allowing us year-round the use of a field facility at Powder Mill (Owls Bend).

Pioneer Forest

Pioneer Forest is a privately-held forest of approximately 180,000 acres in the Lower Ozarks. CRF has been involved in survey and inventory of caves (of which there are about 100) located on these lands. In addition, we have been providing services to the forest in the form of data and cave management. Specifically, we have integrated additional data into the database and provided that information to Pioneer Forest. Field trips in the past two years have confirmed the presence of a fairly large winter colony of endangered bats in one of the larger caves in Pioneer Forest. Since this cave receives ever-increasing visitation, we have suggested management strategies that are scheduled to be implemented.

Missouri Department of Conservation

CRF continues to map and help inventory caves owned by the Missouri Department of Conservation, an agency that manages state forest lands and wildlife. We also continue to provide services to the Department in the form of cooperative data management and consultation.

Powder Mill Creek Cave

Powder Mill Creek Cave is a large, transitional cave (phreatic passages currently being modified by ground water movement) located in the Lower Ozarks area less than a mile from the Current River. Although within the legislated boundaries of the Ozark Riverways, it is actually owned and managed by the Department of Conservation. The cave is closed except for research and harbors an increasing number of Indiana bats in the winter. CRF has been surveying the cave for the past twelve years, and it is now nearly eight miles in length. Draft copies of the map were provided to a researcher in the Missouri Department of Natural Resources - Geological Survey for the purpose of creating an ArcView base map for a sedimentation study. In addition, the electronic data was used to create an ArcView overlay which was provided to the Department of Conservation. Doug Baker has led the survey effort here, ably assisted by George Bilbrey and others.

We continued several other projects on Department land:

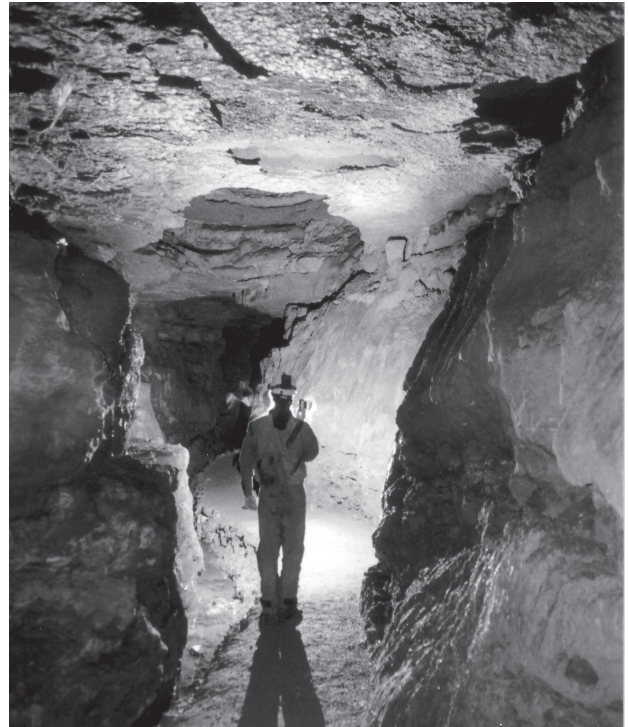
- Several smaller caves on Department land have been or are in the process of being surveyed and inventoried. These include Shop Hollow Cave, Spring Hollow Cave, Forester Cave, and others, mostly in Shannon County near the Current River. These are all new discoveries, mostly in remote areas. Forester and Shop Hollow are still being surveyed.

- Mick Sutton, Sue Hagan, and Scott House participated in the Department's Cave Policy Advisory Committee.

- Scott House wrote a natural areas nomination for the Department on the Sunklands. The Sunklands is a large (6,000 acres) area of giant sinkholes, forests, losing streams, big springs, caves, and at least one natural arch. All of this is owned by two agencies and one private landowner. CRF has been instrumental in the survey and inventory of caves in this area.

- A new major gray bat colony was found by CRF in the Lower Ozarks area.

- Scott House taught a three day speleology course for educators in 1998. He was assisted by Mick Sutton, Sue Hagan, and the Department's cave biologist, Bill Elliott. In 1999 the course was repeated and taught by Scott House and Bill Elliott. A speleology workshop for cavers was held in August of 1999: Scott House and Bob Osburn taught an introduction to cave mapping while Mick Sutton and Bill Elliott taught the basics of cave ecology. Approximately 25 people attended. Sue Hagan and Bill Elliott helped teach a 20-woman caving course



Round Spring Cave, Photo by Scott House and Richard Young

for the Department's *Becoming an Outdoors Woman* (BOW) program. All of these workshops were made possible and funded by the Missouri Department of Conservation. They were all held at the Department's Presley Conservation Center in Shannon County.

Missouri Department of Natural Resources

Division of Geology and Land Survey

CRF continues to work with the DNR/DGLS and the Missouri Speleological Survey on cooperative cave files. The DGLS and MSS maintain three sets of cave files covering the entire state; one set of these are repositied in St. Louis where CRF provides housing for them. CRF continues to work with the DGLS on updating its computer database of state caves. The eventual goal is to merge the agency databases with the rest of the Missouri files and enhance those files to provide additional querying capabilities.

Division of Parks

CRF has undertaken a new survey of Fisher Cave, a large show cave in Meramec State Park. Par-

tially surveyed several times previously, Fisher is a well-decorated, historic cave that is shown to visitors by lantern light. We began our survey in September 1999 and have already completed nearly 4000 feet. Nearby, Paul Hauck is surveying a smaller upland sink cave, also in Meramec State Park. Meramec State Park is a large park of several thousand acres located along the Meramec River 60 miles southwest of St. Louis.

Missouri Speleological Survey

The MSS works to collect all cave info in the state. We cooperate fully:

- Maps and reports are turned in to the MSS and are archived by the Missouri Department of Natural Resources.

- We help publish *Missouri Speleology*. We provided two manuscripts to MS in the past two years. One of these, *The Wild Caves of Benton County* written by Matt Beeson, was published this year. The other is the Phase 2 MTNF report by Mick Sutton.

- Scott House is currently serving as Vice-President of the MSS.

- We coordinated a Cave Resource Committee meeting involving most of the interested agencies as well as the MSS and Missouri Cave and Karst Conservancy.

- We are leading the way by facilitating the development of a new type of state cave database. At one time, the state cave database was maintained by the DNR/DGLS. Eventually, however, support for the program was withdrawn; at that point it became obvious that the material could not even be read. The code for that data was broken and integrated into two new databases: the Speleo Information Database (SID) and a FileMaker Pro version. SID was conceptualized by Joel Laws and programmed by Joe Ditto. These two also managed to get the data into the FileMaker format which was then imported into a database created by Scott House. The FileMaker version has the ability to be split up into manageable county units. We have "farmed out" these counties to individuals in the MSS to enter additional data (the original data only had locational information). As these counties get completed, they are re-integrated into the main database. In addition, protocols

were worked out with DNR/DGLS for the MSS to take over the verification of new cave information and assignment of cave identification numbers. Joel Laws and Scott House lead that effort, assisted by a number of other people. At present, the locational data additions and revisions are entered into both the SID and FileMaker versions. Although FileMaker is more flexible and easier to use, SID offers better security and

has relational features that FileMaker lacks. As this project progresses our aim is to integrate these two databases into one unit that has the best features of both.

- CRF members provided show and tell demonstrations at several MSS meetings. Scott House demonstrated simple databases, Joel Laws demonstrated SID, Jerry Wagner displayed USGS information, Bob Osburn's computer-generated maps were on display, Mick Sutton brought biological specimens and microscopes, and Eric Compas brought ArcView demonstrations.

United States Geological Survey

We have been cooperating with the USGS on projects involving geologic mapping of lands around the Ozark Riverways.

- Randy Orndorf of the USGS is heading this up and has been out in the field with us on several occasions.

- Bob Osburn and Scott House are developing models of cave and karst development in the Lower Ozarks.

- We are sharing our database information with this project.

- The USGS is supporting us financially with some expense money.

- We are mapping some privately-owned caves as part of this project, particularly Sutherland and Banker Caves. The survey of Sutherland has now been finished.

- Several caves near the old Midco mine site were surveyed.

Private Caves

- The survey of a large cave in Pulaski County is proceeding under the direction of Jim Kaufmann. The cave also has important paleontological remains which are being excavated with the cooperation of the Illinois State Museum.

- A survey of Banker Cave in Shannon County was begun and has not yet been completed.

- Other privately owned caves, such as Sutherland Cave, were surveyed in cooperation with the USGS project.

Personnel and Management

We continue to attract a select group of people. Folks usually start caving with us because they want to do more science-based caving. Ozark cavers are generally very pleased with the level of CRF interaction with agencies and caving groups. The merger of our two operations areas is

also proving to be beneficial to attracting quality help. Occasional government funding of our various projects and wise investment management by our CRF treasurer has given us the funding stability to perform work that we would otherwise not be able to do. Lastly, a new trip report database has been created which will enable us to better track our many various projects and report on them to our sponsors in a more efficient and accurate manner.

Ozarks Operation Area

Operations Manager - Scott House

Assistant Operations Manager - Pete Lindsley

Personnel - Danny Vann

Logkeeper and Ecologist - Mick Sutton

Geologist - Bob Osburn

Environmental Engineer - Doug Baker

ArcView Specialist - Eric Compas

Service

MDC Teachers Workshop 1998

MDC Teachers Workshop 1999

Speleology Workshop 1999

Topo Map Workshop 1998

Topo Map Workshop 1999

Cartography workshop at Buffalo

Cave Monitoring workshop at ONSR

Sequoia and Kings Canyon and Mineral King Operation Area

John C. Tinsley

The SEKI operation has seen a banner year in terms of cartography, with new discoveries mainly in the southern portion of Lilburn Cave that have a lot of folks excited, to the point that three additional expeditions have been conducted to date, in addition to the eight regularly scheduled expeditions.

Cartography: Chief Cartographer Peter Bosted reports that Lilburn Cave's surveyed length is about 29.5 kilometers (18.3 miles, if you're scoring). At least a half dozen new joint venturers have attended the expeditions this year, and have proven to be solid performers. Additional exploration and cartography operations have been conducted intermittently in Mays Cave, but small cavers are required.

Sedimentology: Tinsley reports that the mild winter and prolonged cool spring season limited peak runoff to low levels. Consequently, little in-cave sediment movement occurred. GPS locations are being obtained on the karst features of Redwood Canyon, including sinkholes and swallets and creeks, in order to check the surface karst map being prepared by Tinsley.

Cave Diving: Bill Farr conducted an exploratory dive of the Upstream Rise and discovered that his dive line was not buried by sand, confirming Tinsley's assertion that little sediment appeared to have moved last winter. Weather and balky SCUBA regulators permitting, Bill plans a push dive of the Upstream Rise during low clear water conditions that persist in the autumn months in Redwood Canyon. Bill also found an air-filled bell that had been overlooked during previous

dives. He may endeavor to explore that area further, although it isn't far from the entry point for the dive.

Exploratory Digs: Under Brad Hacker, leads have been pushed in Pebble Pile Creek, Redwood Creek, and at several points within Lilburn Cave. Air movement suggests promise, but the boulders are large and the bedrock cracks are too small for cavers.

Hydrology: The hydrology project is on hold while Jack Hess serves in his new capacity as anthrax experimental animal in Washington, D.C. Tinsley will re-establish the datalogger at Big Spring this November, to maintain the long-term monitoring study of the karst system.

Cave Restoration: Bill Frantz has continued cleaning of the Jefferson Memorial area, with other areas being temporarily deferred.

Mineral King: Jeff Cheraz and Roger Mortimer coordinated a major expedition on Labor Day weekend, to check the emerging map of White Chief Cave. Roger Mortimer returned to California for that weekend to help lead the effort. Roger will be returning to California from his year in Indiana, to his old job in the teaching program at Fresno State's medical program. We will welcome him and his bride Amanda with great relief, as they are an integral part of our effort, and small projects are intrinsically fragile entities. Bill Frantz led a trip to the caves of the Timber Gap area, and Jeff Cheraz led a trip to the Cascade Creek area for ridgewalking. These trips were run as day trips out of Cold Springs Campground, located near most of the trailheads that depart from Mineral King.

Southwest Operation Area

Barbe Barker

CRF Southwest members (51) worked a total of 1266 volunteer hours in the year 2001 in support of various ongoing projects at Carlsbad Caverns National Park. Because of

good communications and productive expeditions, our relationship with the Cave Resource Office continues to be very good

Survey and Re-survey continues. All expeditions are organized around the number of approved sketchers who have signed up for any given expedition. Sometimes we have as many as 6 and consequently, all of our expeditions objectives are survey. On those expeditions where we do not have sketchers, the emphasis is on restoration.

The number of skilled restoration people continues to grow. Individuals take charge of a project and attend each expedition to work that specific area. We really cultivate and express appreciation to these people as they are the backbone of each expedition. Ongoing restoration projects include: Lakes of the Clouds, Dome Room, Guadalupe Room, The Ranger Room, Texas Trail (which is now finished). Work in The Rookery is still on hold until bridges are installed over the water. This is tentatively scheduled for 2002.

We continue to do Scientific and Geologic inventory for Harvey DuChene. The Mystery Room needs inventory since it was not done concurrently with survey.

Training: We have several approved trainers for the Scientific And Geology Inventory and continually train new people to use the forms that DuChene has developed for use within the park. We are also teaching those involved with restoration, new techniques to expand their knowledge base for different types of impact to the cave.

CRF Southwest personnel continue to work at Fort Stanton Cave (volunteer hours 1576 total by 46 participants) and in the Lincoln National Forest (volunteer hours 2842 by 97 participants).

Archeology

CRF Archeological Project Update, 1995-2001

Patty Jo Watson

In the period since the last summaries were published (Crothers 2000; Watson 1996, 2000a, 2000b), CRF Archeological Project research has continued in a number of different directions.

(1) Three publications have appeared presenting results of the Paleofecal Research Project (Gremillion and Sobolik 1996; Kennedy and Watson 1997; Sobolik et al. 1996), which was begun in 1992 to date, sex, and analyze 12 paleofecal specimens (6 from Mammoth Cave and 6 from Salts Cave). All are about 2500 years old, and all but one were deposited by males. The exception may have been left by a woman, or by a pre-pubescent individual.

(2) Three other articles have been published concerning the Hourglass Cave research (Mosch and Watson 1996, 1997; Stone 1996), which focuses upon a 45-year old man who died in a high-altitude (over 3000 m) cave in the southern Rocky Mountains about 8000 years ago. Since publication of those articles, we have obtained six more radiocarbon dates as follows (all dates are conventional C14 ages, uncalibrated): two small charcoal fragments from the passage floor near the entrance (Beta-81201, 1960 b.p. +/- 80, and Beta-81202, 2310 b.p. +/- 50); two dates on charcoal smudges carefully removed from the cave wall between the entrance and the find spot of the human bones by rock art dating expert Alan Watchman, Australian National University-Canberra (CAMS 34506/UCR 3494, 1560 b.p. +/- 340, and CAMS 34507/UCR 3497, 3880 b.p. +/- 70); and two dates on charcoal fragments from locations between the entrance and the human bone (CAMS 34509/UCR 3495, 1690 b.p. +/- 60, and CAMS 34510/UCR 3496, 1530 b.p. +/- 40).

Hence, it is now clear that there were several prehistoric trips into Hourglass Cave, not just one.

(3) In 1999, Washington University graduate student Angela Gordon completed a Master's degree project centering on identification of the raw material used to make

the prehistoric footgear (vegetal fiber moccasins) found in Salts Cave and Mammoth Cave (Gordon 1999). During the course of her project, we were provided information by Rick Olson, Mammoth Cave National Park ecologist, about a stand of the crucial plant: *Eryngium yuccifolium*, "rattlesnake master," or "button snakeroot." Under the direction of George Crothers, the *Eryngium* patch (on CRF property in Hamilton Valley) was mapped. Joan Miller, who figured out how to replicate the ancient footgear (Miller 1988), has taught a number of us to make them, also. In collaboration with Roger McClure, we have all been keeping close watch on the *Eryngium* stand to learn what we can about the natural history of this important plant.

(4) Together with several other archaeologists who are carrying out cave archaeology in the Midsouth and Southeast, George Crothers and I have just completed a fairly comprehensive summary of results to date (Crothers et al. In Press).

(5) Shell Mound Archaeological Project research in Butler County, Kentucky, along the Green River 40 miles west of Mammoth Cave National Park was begun in the 1970s to obtain information on antecedents for the early agricultural complex so well represented in prehistoric botanical remains scattered throughout several miles of passages in Salts and Mammoth Caves (Carstens and Watson eds. 1996, Marquardt and Watson 1983, Marquardt et al. in preparation). In 1999, George Crothers completed his dissertation research at two Archaic shell mounds in the Big Bend of Green River (Crothers 1999). Subsequently, he and Darcy Morey, together with geoarchaeologist Julie Stein, began a long term investigation of geographic and geological relations between the ancient mounds and the river (Morey and Crothers 1998, Morey et al. In Press). Most recently, Crothers has undertaken conductivity and sediment-coring studies of the first mound to be excavated by the WPA back in the late 1930s (site 15Oh1, Chiggerville). This work is ongoing, with the goal of locating an undisturbed portion of the site that could yield radiocarbon dates as well as stratigraphic information on plant and animal remains.

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The Yalahau Archaeological Cave Survey

Dominique Rissolo

Between 1995 and 2000, I directed a series of cave investigations in a largely unstudied portion of the northeastern Yucatán Peninsula known as the Yalahau region (figure 1). My project, which was supported in part by the Cave Research Foundation and conducted under a permit from the National Institute of Anthropology and History (INAH) in Mexico, led the completion of a doctoral degree in anthropology from the University of California, Riverside in 2001. The ongoing Yalahau Archaeological Cave Survey is associated with the UCR Yalahau Regional Human Ecology Project — a long-term, interdisciplinary research program focusing on the relationship between the ancient Maya and their environment in northern Quintana Roo.

During my dissertation research, I recorded and investigated twenty caves of archaeological interest. Evidence of ancient Maya activity included deposits of pottery and other artifacts, shrines, stairways and terraces, stone basins, modification of the cave interior, mining, breakage and removal of speleothems, and rock art. It is important to note that the ancient Maya never lived in caves, and the results of my research highlight the ceremonial nature of cave use common throughout Mesoamerica. The caves of the Yalahau region were particularly intriguing given the apparent emphasis on water control and collection.

For the ancient Maya of the northwestern Yucatán Peninsula, caves and cenotes either functioned as the primary sources of drinking water or were seasonally used as “last resorts” when all other reserves were exhausted. These watery portals, which were imbued with sacred qualities, are as much a part of the cultural identity of the northern lowlands as they are integral components of the enigmatic karst landscape. Unlike the northwestern peninsula, a range of readily available freshwater sources including wetlands and numerous small cenotes characterizes an inland portion of northern Quintana Roo.

Given the relative abundance and accessibility of surface water in this area, an archaeological cave survey was designed to evaluate the nature and extent of cave use in the Yalahau region. My primary goal was to isolate the ritual function of the caves and identify evidence of their specialized appropriation. The secondary goal was to determine the extent to which the archaeology of the region’s caves could provide functional and chronological information regarding both regional settlement and the overall cultural organization

of the landscape. At the same time, the cave survey hoped to take advantage of ongoing investigations of surface sites by integrating their results into the analysis of cave function and chronology.

The most obvious question concerned the nature of cave use in a water rich environment. Given the accessibility of surface water in the region, were the caves reserved for ceremonial purposes? If so, what are the material correlates of ritualized water collection? Furthermore, what are the possible emic criteria for specialized cave selection or appropriation and how was it achieved? These were the fundamental questions that shaped the research design. If water can be easily procured at the surface via a range sources, one would expect evidence of water collection from caves to be characteristic of more ceremonial behavior. Moreover, if water from remote and relatively inaccessible cave pools (or from dripping speleothems) was especially valued, we should see its exploitation *even* in areas where alternative (that is, more accessible) water sources exist. Secondly, in caves that have been appropriated for ritual activities, we should be able to identify those natural speleological characteristics that contributed to its selection as well as influenced (or determined) the spatial manipulation and (re)organization of the cave en-

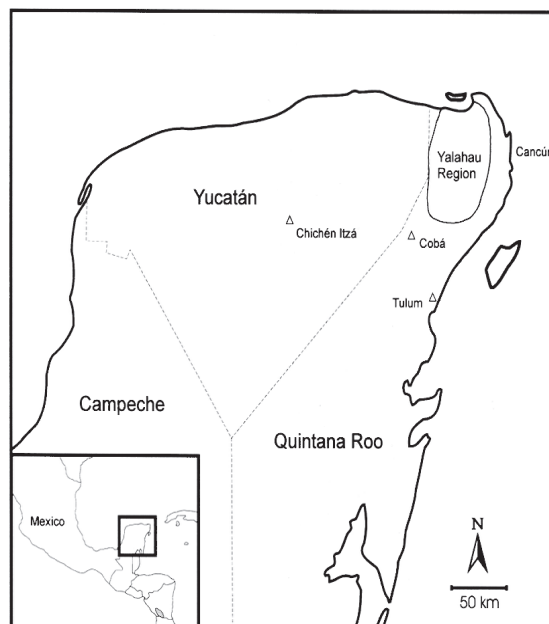


Figure 1: Location of the Yalahau region.

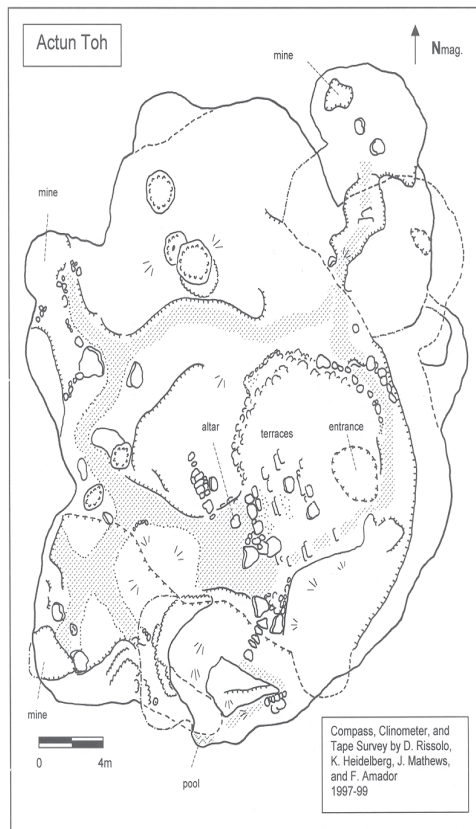


Figure 2: Map of Actun Toh.

vironment. The abundance of accessible water in the Yalahau region, combined with the relative inaccessibility of its watery caves, made the region ideally suited for such a study.

Provided below are brief descriptions of three caves, which exhibit patterns characteristic of ceremonial or specialized use. Actun Toh is the largest and most intensively modified cave in the survey (figure 2). A large mound of collapse debris is located directly below the entrance shaft. This mound was transformed into a terraced pyramidal structure, the basal riser of which rests atop an artificial floor. A stone altar was erected in front of the structure and a circuit of stairways and paths lead from the floor to other portions of the cave. One such stairway descends into a room where a small pool is located. A panel of five carved faces marks the entrance to the room. The co-occurrence of clearly delineated and marked paths leading to cave water is common in the region. Controlled test excavations in Actun Toh (figure 3) produced ceramic deposits dating to the Early Classic period (approximately AD 350- AD 600). This chronological assessment is consistent with the Megalithic architectural style of the terraced mound.

A series of stairways and landings also leads to a small pool in Pak Ch'en. The most sophisticated and diagnostic panel of rock art yet reported in the Yalahau region accompanies the route through this small and otherwise unimpressive cave. Among the carved images are Codex-style depictions of Postclassic deities related to rain and the concept sacredness (figure 4) as well as vulva motifs, which are thought to be associated with water and fertility.

Access into many of the watery caves in the region is difficult — often requiring the negotiation of vertical drops and long crawlways. These water-bearing caves were neither the only nor the easiest means of water collection in the region, yet evidence of their use as sites for specialized water procurement is clear. This is best observed in the relationship between Actun Pech and its nearby wells. At the bottom of a pit, a small entrance (figure 5) provides access to a long, narrow, horizontal tunnel. This passage leads to a small intermittent pool, 67 m into the cave. The section of tunnel leading to the pool is littered with pottery, and debris was piled along the walls to facilitate movement through the crawlway. The tiny ephemeral pool appears to have been the final destination of this arduous crawlway as no evidence of cultural activity exists in the 55m of tunnel beyond the pool.

Approximately 600 m from Actun Pech, is an ancient well that provides perennial access to the water table. Near this well, a cluster of residential mounds and an additional well were identified. It seems unlikely that the ancient Maya would have ventured into Actun Pech in search of drinking water when it could have been more easily and regularly procured from local wells. Rather, the water collected from Actun Pech and other caves was likely valued for its remote and sacred origin.



Figure 4: A carved image of the deity known to Mayanists as God C, adorns the walls of Pak Ch'en (photo by D. Rissolo).

In all the water-bearing caves in the survey, the pools appear to have structured the nature of human activity between the entrance and the pool itself. Furthermore, the natural layout or morphology of the caves directed or channeled human interaction with cave space, which was then reinforced by cultural modifications to the cave environment. Even in caves without pools, dripwater was often collected from stalactites. Once again, the proximity of such caves to primary water sources rules out their utilitarian role. It should also be noted that simply the presence of water in caves was important, in addition to the process of its extraction. Watery areas in caves were imbued with sacred qualities and often served as sites for offertory practices. Water collected from caves by the ancient Maya was no doubt valued for its symbolic purity and the use of this *zuhuy ha'* (virgin water) in rain rituals remains a strong part of modern Yucatec Maya religious tradition.

The study of caves within their regional context, which include other archaeological sites and topographic features, facilitates the identification and increased understanding of such cultural patterning. The Yalahau Archaeological Cave Survey will continue to in its efforts to better articulate the relationships between caves and surface sites and reveal how the ancient Maya conceptualized, transformed, an interacted with caves in the region.

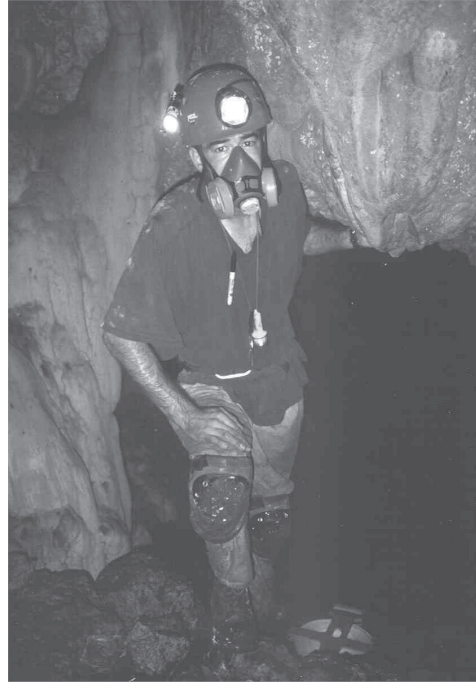


Figure 5: Dominique Rissolo at the entrance to Actun Pech. Respirators protect against histoplasmosis, which is present in some of the caves in the region (photo by K.R. Heidelberg).

Biology

Biological Inventory in the Missouri Ozarks

by Mick Sutton

This report briefly summarizes CRF's (Cave Research Foundation) biological inventories in caves of the Missouri Ozarks from 1998 through 2001. Within this time frame, CRF inventory crews visited a total of 55 caves and one mine. A total of 640 records were added to CRF's Missouri cave fauna database, representing 130 taxa (not all of them identified to species level). Most of the field work took place in caves on the Mark Twain National Forest (MTNF), with substantial additional contributions from caves owned by the Ozark National Scenic Riverways (ONSR), Missouri Department of Conservation (MDC), and a few privately owned caves.

Mark Twain National Forest

The caves visited ranged from tiny (20 ft.) to about a mile in length. Much of the work was concentrated, as in previous years, on caves of the Eleven Point District of the Lower Ozarks physiographic division. This is the most cavernous district on the MTNF, but by the end of the period, a large majority of its caves had been mapped and inventoried. A report was completed outlining work on 60 caves within the Eleven Point District (Sutton, 1998), and a modified and updated version of this will be published in Missouri Speleology (in press). A dozen or so smaller and widely scattered caves remain to be visited on the District.

A rare undescribed springtail, *Arrhopalites* new sp., had been previously collected from Saltpeter Hollow Cave, but further specimens were requested by taxonomist Ken Christiansen. By setting a dung bait station, we were eventually able to collect several additional specimens.

One biologically interesting area was around Fremont in Carter County, where there are some moderately long stream caves. Camp Yarn Cave housed, in addition to a routine assemblage of terrestrial invertebrates, some unusual troglobitic millipedes. Chordeumatid cave millipedes are common in the Ozarks, the species being *Tingupa pallida* more than 95% of the time, with occasional appearances by several rarer species, but the Camp Yarn millipedes were undescribed species of *Chaetaspis*, a polydesmid. *Chaetaspis* had been collected from only one other Missouri cave, Tumbling Creek (Ozark Underground Laboratory) in Taney County, more than 100 miles from Camp Yarn. The Tumbling Creek specimen is be-

ing described by Julian Lewis, who also examined the Camp Yarn specimens. Unfortunately, the only male specimen from Camp Yarn was one molt short of maturity, so the millipede is at a taxonomic impasse for now. The millipedes in nearby Turley Cave were the common *Tingupa pallida*, but a rare terrestrial isopod, *Amerigoniscus* sp., had been previously reported from Turley and neighboring Mosquito Caves. During the present inventory, several visits to both of these caves failed to reveal the rare isopod.

No major new bat colonies were recorded on the MTNF, but we continued to document the exceptionally prolific populations of pipistrelles in certain caves, with very high population densities in Slave Cave, a small cave in the Little Hurricane Creek (Eleven Point) drainage.

While coverage of Eleven Point District caves approached saturation, two projects in southwestern Missouri were instigated. Both arose from concerns over the effect of increasing levels of off-road vehicle traffic on the MTNF. In the Chadwick area of Christian County there is a network of developed ORV trails, together with an unofficial network of illicit trails. CRF crews inventoried (and mapped where needed) the ten known caves plus one previously unknown. The few accessible cave streams showed a depauperate stream fauna, perhaps not unrelated to the colder than normal water temperature during this cold-weather inventory - i.e., the underground water sources appear to be very local.

In the Cassville District, Barry County, there is another area where legitimate heavy use of forest roads by ORV enthusiasts is leading to a proliferation of unauthorized trails. The area contains several dozen caves, and CRF crews are still in the process of visiting these for biological inventory and mapping where necessary. The typical species make-up is a bit different from what we have been used to seeing in the Lower Ozarks, though with a good deal of overlap. One rarity that showed up was the troglobitic isopod *Caecidotea stilodactyla*, taking the place of the familiar *C. antricola* or *salemensis* in one cave. A rarity that did not show up, perhaps fortunately, was a recorded den of copperheads in Currey Cave. The late March visit was perhaps early enough that the snakes were still in inaccessible winter quarters. One interesting cave receiving casual caver traffic is Radium Cave, where a complex network of often wet passages have been

opened up by extensive sediment excavation; in addition, two artificial shafts have been bored into the cave, all in a futile effort to discover and mine “radioactive minerals” that have long been rumored to exist there. A lot of debris from the mining efforts remains preserved in the cave.

The Rolla-Houston MTNF district was briefly visited to inventory a couple of caves in the area of a planned burn, and a long stream cave in the Salem-Potosi District, Cave Hollow Cave, was mapped and inventoried.

Ozark National Scenic Riverways

The bioinventory program outlined in the 1997 CRF Annual Report was completed. Like the MTNF bioinventory, this program arose from concern over the potential long-term effects of mineral exploration within the watersheds of the Current and Eleven Point Rivers. A group of stream caves, most of them already mapped, were visited to obtain baseline data on their biological community make-ups. Although the main focus was on aquatic ecology, terrestrial communities were also examined. One item of interest was the presence of troglobitic crayfish (*Cambarus hubrichti*) in Big Spring, the largest spring in the Ozarks. A small talus cave behind the huge vauculian rising gives access to a fragment of the spring feeder channel; baiting here was successful in attracting a single crayfish.

The most biologically interesting and diverse caves were two caves with summer colonies of gray bats. Coalbank Cave was already mapped and its bat colony fairly well documented. Shop Hollow Cave, in a wild and remote woodland setting on MDC land within the ONSR boundary, on the other hand, had only scanty information. The cave, still incompletely mapped and explored, contained a large, previously unrecorded, gray bat colony, numbering at least 10,000. As in the case of several other summer gray bat caves in the Lower Ozarks, significant numbers (100s) of gray bats also overwinter in the summer colony cave.

Since caves on this project received multiple inventory visits over several seasons, we were able to document in both Shop Hollow and Panther Spring Caves large population fluctuations in the common troglomorphic snail *Fontigens aldrichi*. Among the more unusual faunal records was one for river otter (*Lutria canadensis*) in Coalbank Cave, attested by distinct prints and scat near the downstream siphon leading to the Current River. We have one other record of otters using a Current River cave.

The multi-season study of the ecology of ONSR’s large show cave, Round Spring Cavern, was wrapped up, and remaining bait stations removed. Seasonal and successional fluctuations in terrestrial cavernicole populations were recorded (pa-

per in preparation). An unsolved question arising from the project is the nature of the marked population fluctuations of cave and grotto salamanders. The cave is a cave salamander breeding site, and our results seem to suggest that egg-laying takes place in an “unorthodox” setting—broad, shallow pools with deep silt substrates.

Unrelated to this inventory project, half a dozen other caves and shelters within ONSR, some of them not previously recorded, were inventoried in concert with mapping trips. The largest and most significant biologically was Mose Prather Cave, which contains a summer gray bat colony and hibernating Indiana bats. The pit entrance also provided some biological excitement in the form of two live if lethargic copperheads. Paleontologists Rick Toomey and Mona Colburn carried out a parallel paleo-inventory; their most unusual find was a small collection of human bones in stream gravel.

Missouri Department of Conservation

In addition to the MDC caves visited as part of the NSR inventory, a fairly large “new” cave, Forester Cave, turned up. It is still not completely mapped, but its biology has been recorded in collaboration with MDC cave specialist Bill Elliott. There was a biological inventory trip in Powder Mill Creek Cave to introduce Bill to the biology of this very long stream cave, which is still being mapped by CRF crews.

As part of an educational project, Susan Cave, a mile-long stream cave in Washington County, was inventoried. CRF is assisting MDC in guiding tours of the cave for both the general public and for outdoor education professionals, with an emphasis on cave biology and conservation. One interesting find was a small, previously overlooked hibernating colony of Indiana bats.

CRF members have been assisting MDC and US Fish and Wildlife Service personnel in inventorying Missouri’s largest colony of Indiana bats (*Myotis sodalis*) in Pilot Knob Mine, an abandoned and somewhat unstable iron mine in Iron County. The site of the hibernaculum itself has proved elusive and inaccessible, but extensive bat use of the mine is documented by harp-trap sampling at the entrance every fall, at a period when the bats are swarming prior to hibernation. In addition to the Indianas, significant numbers of little brown and long-eared bats also use the mine. In October 2001, the main mine entrance was gated to supplement the oft-breached fence around the site, which is a National Wildlife Refuge.

CRF has also been cooperating with MDC by adding published and unpublished inventory records to a statewide cave biology database developed by MDC’s Bill Elliott. As a separate part of this small-grant project, a number of voucher

specimens of cave invertebrates were archived at the Enns Entomology Museum at the University of Missouri.

Pioneer Forest and other private caves

A CRF geology party entering Cookstove (aka Squaredance) Cave on the privately-owned Pioneer Forest in Shannon County came across what appeared to be a twilight-zone colony of Indiana bats. Follow-up visits, with CRF assisting MDC bat specialist Rick Clawson, confirmed that the cave is a significant *M. sodalis* hibernaculum, with about 1000 bats using both the twilight zone and a dark zone site. Some spill-over from this colony also occurs in nearby Holmes Hollow Cave, where ORV traffic (within the cave!) is causing concern. Cookstove Cave itself is very heavily visited by casual cavers and cave-for-pay groups, and Pioneer staff are trying to gain some control over unauthorized ORV use throughout the area.

CRF cavers and others led by Jim Kaufmann carried out an archeological project in a large privately owned cave along the Gasconade River in Pulaski County (the cave remains anonymous owing to delicate land-owner relations). An almost entire skeleton of a short-faced bear was removed from a remote setting, with individual bones and bone groups encased in plaster for safe passage out of the cave and for study and storage at the Illinois State Museum. We also documented that the cave contains a major gray bat summer

colony, a small number of hibernating Indiana bats, and by far the largest population we have seen of the troglomorphic spider *Cicurina cavernicola*, associated with the bat guano piles.

Biological inventory took place in Banker Cave, a stream cave in Shannon County owned by a member of the MTNF staff. The most significant find here was a specimen of the tiny troglobitic spider *Islandiana* new sp. We have documented this undescribed species in five previous Lower Ozark caves, but this was the first mature male we had collected, making it far more useful taxonomically. The specimen supplements the only other male *Islandiana* new sp. ever collected, from Taney County's Tumbling Creek Cave (again!). The spiders are being examined by taxonomist Don Buckle.

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Cartography/GIS

Cartography at Lilburn Cave, CA 1998-2001

Peter Bosted

Overview

The Cave Research Foundation (CRF) began a project to improve the cartography of Lilburn Cave in 1980. The original goal was to re-sketch the major passages in this three-dimensional maze cave, located in a band of marble in Redwood Canyon, in Kings Canyon National Park, California. It soon became apparent that the previous survey of 7.8 miles had overlooked numerous side passages, and by the end of 1997 the length stood at about 16.5 miles.

Understanding the cave has been greatly improved since the early 1990's by using a quadrangle map system, where vertical elevation is used to divide each area into as many as five layers. Approximately two miles of new survey was added in 1998-2001, with most of the new leads found by carefully checking recently complete maps. About 1000 new stations were used, for an average shot length of approximately 10 feet. We also re-surveyed about 3000 feet, mostly to improve loop closures and improve sketches, but sometimes by mistake. There were 73 survey trips into Lilburn over this four-year period, spread over five to ten expeditions per year. Almost half of the trips occurred in 2001. The official length of Lilburn is now 18.47 miles (29.72 km), and the vertical extent remains unchanged at 500 feet (152 m).

A major effort was made to get caught up on the quadrangle maps over the past four years. We now have a working version of all of the approximately 83 quadrangles (including three new ones due to new discoveries), and 80% of these are completely up to date. Less than one mile remains to be drafted onto the remaining 20%.

The following sections give more detail, one a year-by-year basis.

1998

This was a slow year, with the CRF fielding only four expeditions involving cartography: May 27-28, July 3-4, October 31, and November 7. The unusually wet winter precluded access to the cave before Memorial Day, and even on that weekend we tramped through snow for a 6.5-mile-long hike rather than the usual 5 miles to the research cabin. There

were a total of eight survey trips into Lilburn Cave, with a total of 1215 feet of new passage being surveyed using 111 stations. In addition, about six stations were re-surveyed by mistake on the November trip. Several question marks were checked and found to be too short or tight to survey.

Three of the July survey trips were to the new area in the very southern end of the cave, discovered late last year. Even in July, it was a very wet trip to get through the Yellow Floored Domes and past the Mousetrack turnoff to climb up to this muddy breakdown and phreatic tube area. Two pits (each about 40' deep) were dropped and a waterfall could be heard ahead through boulders. A return trip in October found much dryer conditions. No way on could be found through the boulders at the base of the second 40' pit, but following the main canyon southwards from the room between the two pits led to a series of good sized rooms, and several other deep pits with quite strong breezes blowing out of them. Careful rigging will be needed to descend these safely, due to large quantities of unstable breakdown. We called this new area Southern Comfort because it is cold, tight, and muddy, and a bottle of the so-named liquor sounded very good at the time.

Another July trip found new passage at the end of the Pandora Complex, which came within a few feet of connecting to a new section of the Underworld surveyed on the sole May trip. Some new passage was found in the Clay Palace beyond a tight squeeze. It connected to a larger passage which later study of the map revealed to be un-surveyed, so more potential remains here as well. Finally, some mop-up survey was done in the Attic, and one team spent a day checking the complicated Schreiber Complex, but did no surveying.

1999

There were nine survey expeditions to Redwood Canyon between October 1998 and October 1999. There were 22 survey trips into Lilburn Cave, netting a total of about 3400 feet of new passage in 340 stations, and 800 feet of resurvey in 80 stations.

The largest portion of new survey (1400 feet) was in the Southern Comfort area, first found in late 1997. Pushing

through some tight crawls in late 1998 led to a series of larger rooms, which were pushed in 1999 to the top of an impressive pit. A rappel to the water-filled bottom revealed that this is Slash-down dome, the southern-most point in the cave, only reachable from the bottom when water levels are extremely low. A lead heading south from the top of the pit will require a bolt climb to access. Several side passages were also surveyed, including one that connects to the Mousetrack area. Also in the southern end of the cave, low water levels have permitted easier access to the Thanksgiving Hall area, where over 700 feet have been surveyed and several good leads remain heading away from known cave. The third biggest area of activity was the Schreiber Complex and Clay Palace, where the availability of newly completed quads allowed revealed several overlooked leads.

The map of May's cave had been considered finished except for one small lead, which on a quick inspection trip in February led to a substantial new section. Survey marks indicated that at least part of this was known to the 1970s survey project led by Ellis Hedlund. A couple of rather tight squeezes are involved, but near the bottom of the cave, the passage can get as large as 20 feet tall and 5 feet wide. A small stream flows into a tight crawl that could be enlarged by removing rocks when the water flow is sufficiently low. This might lead to a connection with Lilburn, about 100 feet away. The new area was mapped in four survey trips for 680 feet in 81 stations, more than doubling the length of the known cave. Several leads remain.

2000

Slow but steady progress was made during the year 2000. Nine survey trips in Lilburn Cave netted 1166 feet of new survey using 127 stations, and 550 feet of replacement survey using 46 stations. A loop in Mays cave was surveyed in a single trip for 80 feet in 14 stations. No trips were made to Cedar Cave this year. A surface survey was made to locate a blowing dig site in Pebble Pile Creek.

The Memorial Day weekend was the most productive, with five survey trips. Checking an area near the Yellow Floored Domes revealed two interesting side leads, one large but intimidating due to large, unstable granite boulders, the other tight but opening to a small room with a promising dig site. A party checking Pandora's Passage mopped up about 300 feet in side leads, one of which had a previously unrecorded small stream. In the north part of the cave, short surveys added 70 feet to the Great Central, and 55 feet to the Attic-Attic. A replacement survey of a confusing section of the Schreiber Complex was begun in May, and continued in June. Also in June, a tight canyon was pushed in the 2 by 2 Complex. This was surveyed in August for 65 feet. The most

interesting discovery was made on the Labor Day expedition. Low water finally allowed a party to reach the new area above Thanksgiving Hall. Continuing the previous year's survey, 340 feet was added in a pleasant series of canyons and breakdown rooms heading north-east into a blank part of the map. The survey stopped at a 50-foot tall canyon with a flowing stream: possibly the Pebble Pile creek. The area is cold, wet, and breezy, but has good potential for future extensions.

Progress was also made on the project to install easily readable survey markers at major passage intersections, to aid researchers to tie their studies to known locations in the cave.

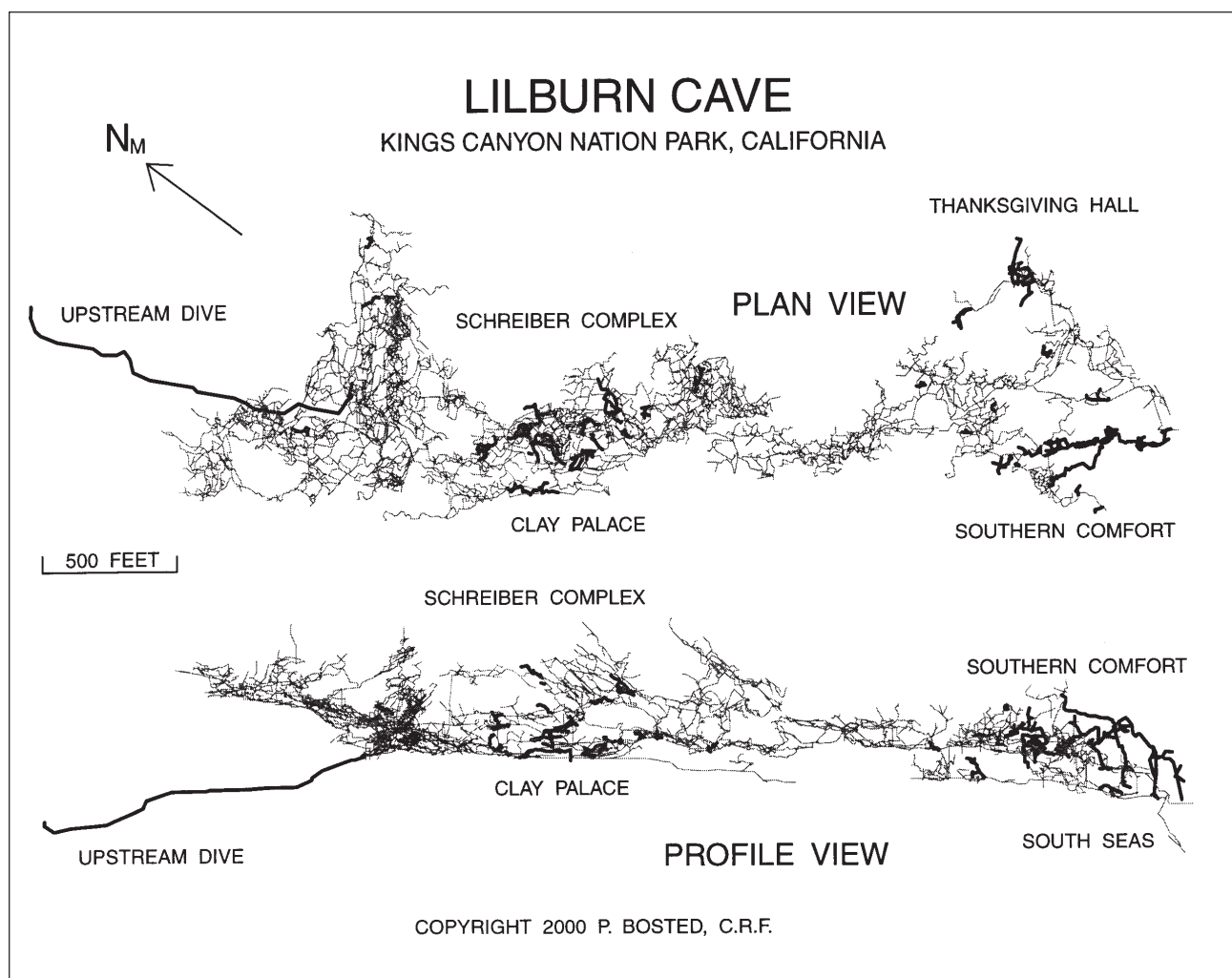
2001

Great progress was made during the year 2001. A total of 34 survey trips into Lilburn Cave, spread over 10 expeditions, netted 5465 feet of new survey using 583 stations, and 1030 feet of replacement survey using 84 stations. This is the most new survey in a single year since the CRF project began in 1980. The average new survey shot length of 9.3 feet is only 25% below the average for the entire cave (12.1 feet), showing that much of the new passages are reasonably large, at least for California.

A single trip to Mays cave may have found some new passage, but the explorers were not sure. No trips were made to Cedar Cave this year, nor were any surface surveys done.

The most new footage came from the area above Thanksgiving Hall, which includes the newly-named Prize in the Narrows and Outback areas. These areas fall in previously blank quadrangle maps, so serve to increase the "footprint" of Lilburn. Of particular interest is a large deposit of a green mineral, possibly malachite. There are also some nicely decorated flowstone areas. A new route to this area was found from Hog Heaven, allowing access without having to wait for the water levels in Thanksgiving Hall to recede sufficiently to reach Pom's Chimney. A total of 1600 feet was surveyed in five survey trips in the Outback area. Several leads remain; most requiring vertical gear. Trips to this most remote section of Lilburn were long and tiring, averaging about 12 hours in duration. Below the Outback, a team pushed the upstream end of Thanksgiving Hall through a very tight constriction to find 180 feet of small stream passage in a tall canyon. An upper level filled with extremely loose breakdown was not surveyed. It would be interesting to dye-trace this small stream: is it an infeeder or an overflow route of the main river?

The next largest area of new survey came from pushing a tight breakdown choke above the West Stream. This led to



the Grand Foyer and Opera House, which are relatively large rooms filled with breakdown blocks that are sometimes more than 15 feet long. There are many mazy side passages as well. The entire area is less than 100 feet below the surface, as evidenced by many granite boulders and granitic sand. A vertical connection was also made using an 80 foot rope down to "That Room", near the Hex Room. A total of 890 feet was surveyed in five survey trips in the Opera House area. The discovery trip was spent widening the tortuous route through the breakdown, and an additional trip re-surveyed much of main loop, finding several errors that fixed the initial 35-foot mis-closure.

The Attic-Attic area also saw a lot of activity, especially early in 2002, with 600 feet surveyed in five trips. These were mostly small passages, found by working from the newly available Attic-Attic quads (D.3.M and D.3.U). It was also discovered that TG1-20 stations exist in the cave, but there is not record

of this survey. If it cannot be found, these passages will need to be re-surveyed. Many small question marks remain in this area.

Two trips were made to the Pandora's complex, with a bold climb yielding 220 feet. This followed a small seasonal stream, which was observed to come from a high lad in the terminal room. This room is almost directly below the Historic entrance, which has a small stream of similar size that flows in the spring, so a dig was done near this entrance, below the ladder, that quickly led to a tight fissure passage. This was surveyed in two trips to connect to the new Pandora's room after 290 feet, using several ropes.

The very low water levels in the fall inspired eight trips to the Enchanted River, where a 1450 feet of new survey was found, mostly following leads from the original 1984 survey that we

were reminded of by the recent availability of these quadrangles. Two good leads remain: one was pushed for over 100 feet with no end in sight. By using the shortcut via the Clay Palace, and rigging the 15-foot falls with a rope, it was possible to stay mostly dry above the waist on these cold, wet trips.

A trip to River Pit netted 140' of new passage, with leads remaining. Vertical gear is recommended for a return trip.

A trip to Mud Heaven and Southern Comfort via Mousetrack found 170 feet of new passage. A strong breeze indicates a surface connection somewhere in this area. A good possibility for finding this is a climb at the top of Mud Heaven Shaft (which was left rigged with doubled 30-year-old Goldline that seems to be still use-able).

Three trips were partially dedicated to find loop closure problems in the Schrieber complex and the Elevator. Three major problems were fixed.

Development and Testing of Three Components of the Process of Transferring Digital Cave Survey Data from the Cave Research Foundation to Mammoth Cave National Park

Mike Yocum

Introduction

Determining best management strategies and practices for the karst ecosystem partially encompassed by the boundary of Mammoth Cave National Park (MCNP) requires the integration, analysis, query and display of various types of data from a range of scientific disciplines. A principal software product used by MCNP staff to perform these tasks is ArcView, a GIS (geographic information systems) product.

A key component in the integration of many of the MCNP's databases is the cave survey data set that has been collected by the Cave Research Foundation (CRF) over a period of some 40 years. The cave survey data set is the framework to which many other data sets, both surface and sub-surface, must be related in order to understand and assess numerous resource management responsibilities incumbent upon MCNP staff.

At the beginning of this project CRF cave survey data did not exist in a format compatible with ArcView, there did not exist metadata¹ describing the transmitted data, nor did MCNP have a procedure for tracking it as it was transferred.

The goals of this project were 1) to develop and test procedures for converting CRF survey data to ArcView format, 2) to determine which data items and manipulations are most significant in maximizing the accuracy of the data in order to

provide appropriate metadata, and 3) to develop a framework and procedures for recording the content and status of CRF cave survey data as it is conveyed from CRF to MCNP.

Method

The first stage of the project was to assemble a team of knowledgeable, professionally experienced personnel to review and evaluate the status of original digital data sets, possible transfer procedures, and potential metadata items. For the most part, discussion took place via email. Some telephone conversations and face-to-face meetings took place among a few of the participants.

The second stage was creation of a digital database of surface features and surveyed cave passages to be included in the investigation. A study area was chosen in consultation with staff at MCNP's Division of Science and Resources Management and personnel from CRF's Eastern Operations Cartography Program. The area selected was that part of the cave system between the Historic and Violet City entrances of Mammoth Cave.

For surface features, the selected files included geospatial data in four commonly available formats: DEM, DLG, DRG, and DOQQ². In its GIS applications, Park standards for projection, datum and units are UTM, NAD27 and meters. The geospatial data files were obtained in, or converted to, these standards.

Cave survey data files for passages within the study area were obtained from CRF's Eastern Operations Cartography Program. They were available in formats corresponding to software that had been used by CRF personnel ^{3,4} Compass, CML (Cave Map Language), SMAPS and Walls. Each of these programs features some form of ASCII output. Data in these files was in a confidential coordinate system devised by CRF many years earlier at the request of the Park administration in order to protect sensitive locational information from misuse should anyone gain unauthorized access.

After survey data in each format had been collected for the study area, it was processed using each of the respective programs. Any data items or processing procedures that were problematic, or were deemed important for insuring the accuracy of the final data set, were noted.

Only two programs, Walls and Compass, allow conversion to ArcView shapefile format.³ Walls exports shapefiles directly. Compass plot files can be converted to shapefiles using CaveTools, an ArcView extension. Output from SMAPS and CML cannot be converted to shapefiles without first being converted to either Walls or Compass.

The most complete data set was in SMAPS format. It was imported into both Compass and Walls, where it was converted from the CRF coordinate system to UTM, NAD27 meters, with copies of the data in the original CRF coordinates being retained. Conversion to shapefiles was then performed on all four of these data sets, and the results registered to a DOQQ of the study area.

Using results of the registration, along with insights gained from discussions among project team members, an FGDC-compliant metadata set was constructed. An expanded shapefile format, containing supplementary cave survey attributes requested by MCNP or suggested by team members, was also created.

A framework for tracking transferred data was proposed. CRF's map production at Mammoth Cave has been organized by the Cartography Program into a series of map sheets that cover the extent of the cave, each sheet being assigned to a CRF cartographer. Map production as a whole is charted on a map sheet index that shows all of the maps and their relation to each other and the Mammoth Cave system. The proposed framework for tracking CRF digital data transfers is to assign each station in the delivered station shapefile to the appropriate map sheet.

Discussion

In the context of GIS, the term "legacy data" is applied to data previously collected without reference to use in GIS applica-

tions. Often it has been collected over an extended period of time, for many different purposes, and may be stored in a variety of formats. Conversion and integration of legacy data sources into current GIS applications are common tasks for every project that seeks to turn existing feature data into functional GIS information. Typically, legacy systems use different data structures, software architectures, and even different computing environments.⁴ GIS is a relatively new field and data transfer technology is often limited. Much of the work may have to be done manually. In either case, whether automated or manual, reconciliation of legacy data is a complex process, and the amount of money spent on it each year runs into many hundreds of millions of dollars. A review of some of the challenges and strategies applicable to importing legacy data is helpful to anyone planning to implement GIS in their work.^{5,6,7,8}

Fortunately, conversion of CRF's legacy data did not require the substantial re-engineering that is often the only viable alternative for many federal, state, and municipal agencies. A project team able to contribute its time and professional expertise was adequate for the tasks that needed to be accomplished.

Members of the project team were chosen for their specific professional experience or administrative responsibilities in cartography or GIS, and their differing viewpoints about data processing issues. The qualifications of each team member relevant to this particular undertaking are briefly summarized below.

Aaron Addison is a cave surveyor familiar with automated cartography as well as having extensive professional experience with the MicroStation suite of CAD/GIS products. Larry Fish is a cave surveyor and computer programmer who is the author of the Compass cave survey data processing program. Gary Fisher is a caver employed with the USGS, where he worked for many years on converting geospatial data to the SDTS format. David McKenzie is a computer programmer, mathematician and cave surveyor who is the author of the Walls cave survey data project management program. Bob Osburn is a cave surveyor who is CRF's Chief Cartographer for Mammoth Cave. Mel Park is a cave surveyor and computer programmer who is the author of the CML cave survey data management program. Bernie Szukalski is the author of CaveTools, a cave survey data conversion utility, as well as a product manager at ESRI, the GIS firm that produces ArcView. Mike Yocum is a caver with professional experience in importing legacy data into ArcView, as well as being the Director of CRF's GIS Resource Development Program.

This group carried out an extended email discussion over a period of approximately eight months. Additional detailed,

software-specific discussions between some of the members continued for over two years. Given their collective level of knowledge, lengthy experience, and differing viewpoints regarding these topics, members expectably engaged in protracted discussions that served to highlight key issues and points of contention, without always agreeing on best methods or procedures for producing the highest quality data.

In particular, although loop closure statistics were agreed upon as key indicators of survey quality, there was no consensus as to the best method of performing these calculations. Measurement and processing of passage dimensions was another instance in which no unanimous position was reached. (Passage dimensions, commonly referred to as LRUD, are measurements of the distance from a survey station to the left wall, right wall, ceiling, and floor.)

On occasion, the discussion drifted into areas more relevant to data collection and data processing than data transfer. Data collection and data processing are topics familiar to most cave surveyors and cartographers. They are the frequent subject of debates that have lasted for many years, with no indication of ending or reaching consensus. Although useful in providing a context for some questions that could arise during data transfers, the data collection and data processing discussions did not directly contribute a great deal to achieving the goals of the project. Work might have proceeded more efficiently had the Principal Investigator refocused the group on the task at hand more frequently.

The study area was chosen not only because of its relevance to MCNP projects, but also because CRF survey data for this part of the cave is tied to the Walker benchmarks, which provide a reliable set of control points. In 1935 and 1936, H. D. Walker of the US Geological Survey established a horizontal and vertical control net by running a transit traverse, and subsequent leveling lines along the same route, in Mammoth Cave. In addition to in-cave benchmarks, the net extends to the surface at several entrances. As a result of later surface triangulation conducted in the area, the original Walker data were corrected in 1972 to incorporate a datum shift. The results were published in 1973.⁹ Although a few errors have since been discovered in the Hosley publication, the Walker benchmarks represent the most reliable subsurface survey data for Mammoth Cave to date. They are the foundation to which CRF survey data is joined.

One development not anticipated at the start of the project occurred when it was learned that many of CRF's Mammoth Cave cartographers were changing data processing software. Most had used SMAPS for years, and many now were adopting Walls. One or two began using Compass. It was not within the scope of the project to evaluate or recommend

survey data processing software, but simply to examine the output of the software in use and bring to light key issues involved in converting that output to GIS format. As a result of cartographers choosing new software, the final phase of the project focused in more detail on the shapefiles produced by Walls.

Conversion of survey data from its native format to Walls, Compass, CML, SMAPS, or any other software format - and conversion from any one of these formats to any other one of them - raises questions about the conversion process since there is no standard for selection of data fields that will be included in the conversion. Nor, for any given data field, are there standards for how it will be parsed and translated. Each software author has chosen what he believes to be relevant or manageable data, but each differs in his choices. Each author has also chosen what he believes to be the best processing algorithms, but again differ in choices. It thus becomes crucial to know the processing and conversion history of any shapefile since both processing and conversion algorithms may differ from program to program and significantly alter the output.

The raw data-to-GIS shapefile "transformation pathways" are different for Compass and Walls. While both programs permit internal conversion to a projection, datum and units (e.g., UTM NAD27 meters), conversion to shapefile format is performed differently. The output from Compass is a plot file in ASCII format. This file is read by CaveTools, which converts it to a shapefile. Walls creates a shapefile directly without the need for additional manipulation by a conversion utility.

To date, no problems have arisen using the SMAPS-Walls-shapefile route, but an example that appeared in a SMAPS-COMPASS-Cave Tools-shapefile conversion will serve to illustrate the potential for results to be radically affected by the conversion processes. During a transfer of data from the CRF coordinate system, the Historic Entrance of Mammoth Cave (along with the rest of the cave passages in the associated file) was displaced by over 3,000 feet. Larry Fish discovered the causes of the problem, use of two different standards for definition of a foot in Compass, combined with a rounding error in CaveTools. Although these errors have since been corrected in the software, the question is worth examining in some detail because it dramatically demonstrates that seemingly trivial differences can drastically affect final results. Below is part of Fish's explanation.

The problem you are seeing occurs because we are multiplying very large numbers by values in the range of tens of millions of feet for the UTM coordinates. For example, the difference between the conversion constant I am using and the one Bernie is using is:

$$3.28083989501312 - 3.2808 = 0.00003989501312$$

This is a very small number, but not compared to the large UTM values. If you multiply this very small difference by the large UTM values, the difference is surprisingly large:

$$13496183.399 * 0.00003989501312 = 538.43 \text{ meters}$$

I ran into a similar problem a few weeks ago because I was using the International Foot (0.3048) in some parts of COMPASS and the "US Survey Foot" (0.304800609601) in other parts of the program. My logic was that the Survey Foot would be more accurate for geographic measurements. However, that 0.000000609601 difference was enough to cause an eight-meter discrepancy in the data.¹⁰

In an article published in *Compass and Tape*, Fish notes:

Multiple conversions can make any conversion problems worse. For example, if you convert a UTM coordinate to feet using the US Survey Foot and then convert back using the International Foot, you will cause an error, not just a units discrepancy. This is most likely to happen if you are using differing software packages that support different units. Each transfer can cause increasing errors.¹¹

The Mammoth Cave data that was so spectacularly displaced was originally in SMAPS feet, which were converted to Compass feet (prior to Fish's correction of Compass code), then converted to ArcView meters (prior to Szukalski's correction of CaveTools code). Fortunately, because the resulting displacement was so conspicuous, it brought the problem to light.

Fish notes, "I have done a lot of research on this issue. The problem is more pervasive than I had thought and it appears to affect ALL cave survey programs and ALL GIS software."

¹² His *Compass and Tape* article should be required reading for anyone using different software packages to work with their data, or anyone converting data from one set of units to another.

Even after all such data conversion errors have been corrected, there still remain the different algorithms by which different programs process data. This became strikingly apparent when four survey data shapefiles were registered to a geodata file.

The process began with a single CRF data set. It was imported into both Compass and Walls, where it was converted from the CRF datum and feet to UTM, NAD27 and meters by each program. Copies of the data in the original CRF datum

and units were retained in both Walls and Compass. There were then two Walls sets of the data (in both CRF and UTM datums) and two Compass sets of the data (in both CRF and UTM datums).

Conversion to shapefile format was performed on all four of these data sets, and the results superimposed on a DOQQ of the study area. (Figure 1) All survey data files were registered to a Walker benchmark located near the Violet City entrance to Mammoth Cave. (Figure 2)

Comparison of the differing locations of the converted cave passage line plots to known and well-defined surface features made it graphically clear that data processing algorithms also play a key role in the final result. Although a single original CRF data set in SMAPS was the source file fed into each transformation pathway, variations of approximately 100 feet over a linear distance of approximately 8,000 feet were noted in the final locations of cave passages in relation to points on the DOQQ image (Figure 3), depending on datum and software.

Nor do problems of working with different data sets begin and end with cave survey and GIS software. It has long been known that the geodata files to which cave survey data may be registered for use in GIS applications are not in alignment with each other. Figure 4 shows a section of a DOQQ in which are visible the Park's visitor center, a couple of parking lots and other facilities. Over this are yellow lines traced around some of the same features on a DRG for the same area. The "Y" is a standard symbol for a cave entrance, and denotes the location of the Historic Entrance to Mammoth Cave on the DRG. The blue triangle labeled "TT 1 H 1972" is a location on the cave floor beneath the dripline at the midpoint of the entrance passage, established by the Natural Sciences Resource Study Group in 1972 during work on the Walker benchmark net.¹³ The red dot is the author's "eyeball" estimate of where the entrance "really" is on the DOQQ.

Cave survey data can be tied in to or registered with surface data at various stages in the data collection and conversion process. Surface data can be collected specifically as an extension of the underground survey net. Existing surface data can be incorporated into legacy or newly created cave survey data. A shapefile created from cave survey data can be registered to a geodata file that contains surface data of varying degrees of precision and accuracy.^{14,15}

However, in order for the result to be useful for management purposes requiring both high accuracy and high precision, the surface data set to which the subsurface data is to be matched must be chosen in advance since existing standard surface data formats are not themselves precisely or accurately aligned with each other. Cave survey data registered to one format, e.g., DOQQ will not be in registration with

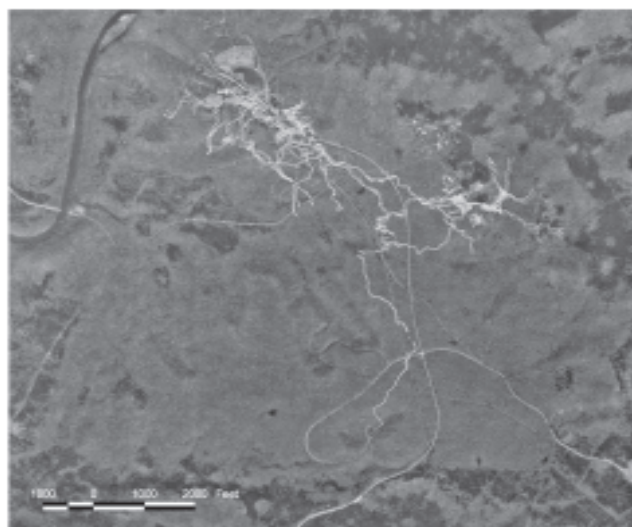


Figure 1:DOQQ of study area

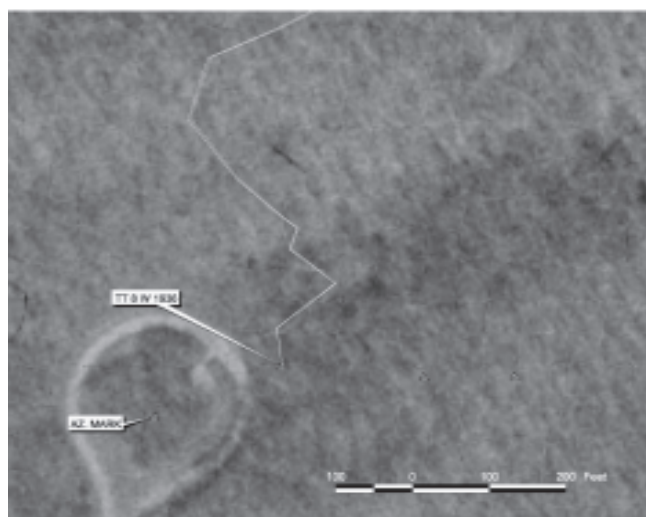


Figure 2 Registration to Violet City Entrance of Mammoth Cave

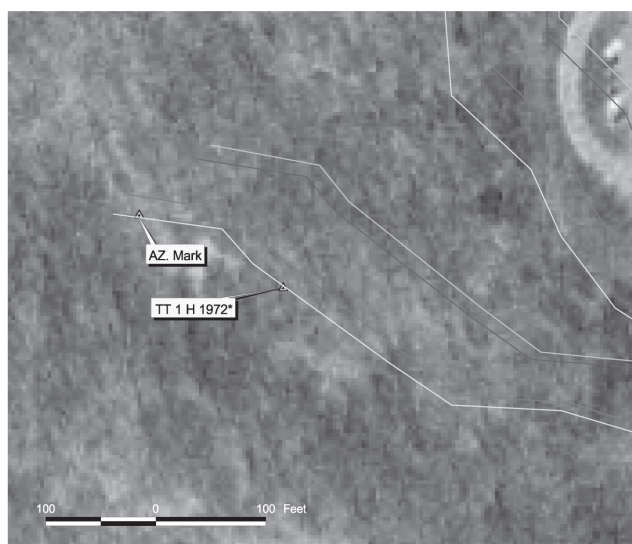


Figure 3 Discrepancy in cave passage locations

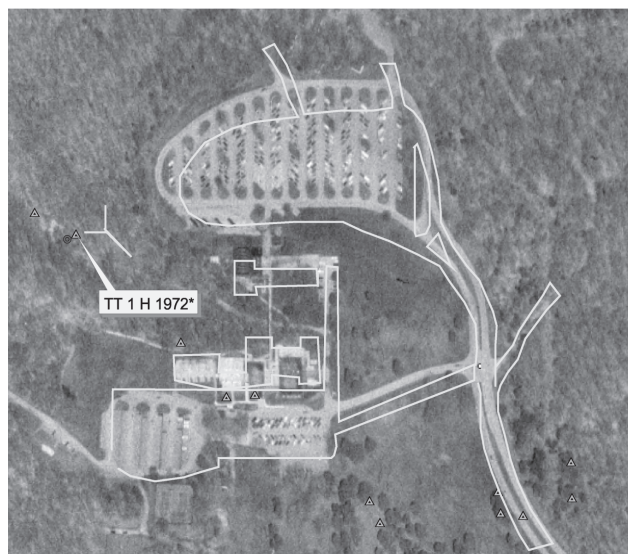


Figure 4: DOQQ with Park Visitor Center overlayed on cave passage

other formats, e.g., DRGs, DLGs, or DEMs. Before embarking on any major project, selection of a final standard surface data set becomes a priority.

To provide information that might assist in the surface data selection process, as well as offering useful metadata about the cave survey data and complying with federal metadata requirements, David McKenzie and the author created an expanded shapefile format for use with Walls. (Appendix 1) The expanded format allows users to access metadata directly within ArcView. In addition, it contains a field – Sheetname – that assigns each station in a processed station shapefile to the appropriate CRF map sheet. This allows MCNP to track the content and status of CRF cave survey data as it is conveyed from CRF to MCNP. Finally, the shapefiles produced by Walls can be parsed by SMMS, MCNP's current standard metadata management software, to produce FGDC compliant metadata.

Conclusion

The results of this study indicate that the most critical problems when utilizing cave survey data for resource management at Mammoth Cave National Park currently arise not in data collection, but in data management – including data processing. A crucial component of data management is metadata that is relevant to the data sets being manipulated and integrated, including a history of any previous data manipulation. Data management should also include thoughtful and careful long term planning for final data uses and needs since these will partly determine appropriate data transformations.

Acknowledgements

I would like to thank the members of the project team, who were tolerant of my ignorance, patient with my slowness to grasp obvious facts, and forgiving of my lapses in memory. They were: Aaron Addison, Larry Fish, Gary Fisher, David McKenzie, Bob Osburn, Mel Park, and Bernie Szukalski. I would also like to thank Teresa Leibfreid and John Fry of the Division of Science and Resources Management at Mammoth Cave National Park, who went out of their way to work with my difficult schedule for the sake of the project. Finally, I would like to single out David McKenzie, who displays a rare attention to detail and an admirable dedication to not just getting a job done, but getting it done correctly.

1 “Metadata” is data about data. It is data that describes the content, quality, condition, and other characteristics of data. Federal agencies are required by Executive Order 12906 (April 11, 1994) to include metadata with all digital geospatial data. Executive Order 12906 also established the National Spatial Data Infrastructure and adopted the FGDC (Federal Geographic Data Committee) Content Standard for Digital Geospatial Metadata to provide a consistent approach and format for the description of data characteristics. The standard, and an electronic workbook are available at: <http://www.fgdc.gov/metadata/metadata.html>

- 2 DEM is an acronym for Digital Elevation Model, DLG is an acronym for Digital Line Graph, DOQQ is an acronym for Digital Orthophoto Quarter Quad, and DRG is an acronym for Digital Raster Graphic
- 3 Compass is available at: <http://fountainware.com/compass/>
Walls is available at: <http://davidmck.home.texas.net/walls/>
- 4 Peters, D., *System Design Strategies*, Environmental Systems Research Institute, Redlands CA. 2001.
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¹³ Hosley, R. J., *Bench Marks in Mammoth Cave, Kentucky*, Natural Sciences Resource Study Group, 1973, p.4

¹⁵ U. S. Geological Survey, Standards for Digital Raster Graphics: National Mapping Program Technical Instructions.

¹⁴ U. S. Geological Survey, Standards for Digital Orthophotos: National Mapping Program Technical Instructions.

APPENDIX 1

DESCRIPTION OF WALLS CAVE SURVEY SHAPEFILES FOR MAMMOTH CAVE NATIONAL PARK VERSION DATE: 2001-06-15

This document describes the data set that will be supplied periodically to Mammoth Cave National Park by the Cave Research Foundation. Each named file set (indicated below by the “filename” prefix) will consist of at least four shapefile assemblies and a separate metadata table containing information about the set as a whole. The current version of this document will also be supplied.

VECTOR DATA (SHAPEFILE ATTRIBUTES - FILENAME_V.DBF)

A.	Field Name	Field Type	Field Size
Field Description			
CAVENO	Text	4	Number assigned by MCNP (metadata table field value).
CAVENAME	Text	64	Name or project title associated with cave (tracked by MCNP).
CAVEAREA	Text	128	Name hierarchy associated with vector's location in cave. See Note 1 .
SURVEYNAME	Text	48	Letters (often just one) identifying survey where vector measurements were recorded. Alternatively, it can be a long survey title. See Note 2 .
FSBNUMBER	Text	4	Field survey book number if applicable. See Note 2 .
DATAFILE	Text	8	Base name of raw survey data file containing defined vector.
DATAHIST	Text	128	Data processing history (metadata table field value).
SURVEYDATE	Number	8	Date of vector measurement, format YYYYMMDD.
FR_NAME	Text	17	Name of 'FROM' station. See NAME in station table and Note 4 .
TO_NAME	Text	17	Name of 'TO' station.
LENGTH	Number	10.2	Length of measured vector in meters.
AZIMUTH	Number	6.2	Azimuth of TO station from FROM station (grid North degrees).
INCLINE	Number	6.2	Incline of vector from FROM station to TO station (degrees).
CTR_EAST	Number	12.2	UTM NAD27 easting of vector's midpoint.
CTR_NORTH	Number	12.2	UTM NAD27 northing of vector's midpoint.
CTR_ELEV	Number	12.2	Elevation ASL of vector's midpoint in meters.
ATTRIBUTES	Text	40	Named vector attributes separated by vertical bars. See Note 3 .
LINETYPE	Text	8	A string identifying an assigned line style in Walls.

SURVEY STATIONS (SHAPEFILE ATTRIBUTES - FILENAME_S.DBF)

Field Name	Field Type	Field Size	Field Description
NAME	Text	17	Station name. Usual format for MCNP: <FSB No.><Survey
etter><Number>			(Example: 196A200) Other formats are technically possible. See Note 4 .
X	Number	12.2	X coordinate in meters: UTM Easting, Zone 16S, Datum NAD27 CONUS
Y	Number	12.2	Y coordinate in meters: UTM Northing, Zone 16S, Datum NAD27 CONUS
Z	Number	12.2	Z coordinate in meters: Elevation ASL
LEFT	Number	8.1	Distance in meters to left wall. N/A if this and the next 4 field values are zero.
RIGHT	Number	8.1	Distance in meters to right wall.
UP	Number	8.1	Distance in meters to the ceiling.
DOWN	Number	8.1	Distance in meters to the floor.
LRUD_AZ	Number	8.1	Observer's facing direction in degrees when measuring LEFT, RIGHT, UP,

and

DOWN.

Field Name	Field Type	Field Size	Field Description
SHEETNAME	Text	10	Name of sheet on CRF Index of Map Sheets (not yet initialized by Walls).

ADDITIONAL SHAPEFILES

The survey station shapefile described above contains one record for each established location in the project, including the “fixed” control points. (The latter are *not* represented in the vector shapefile except possibly as FR_NAMES and TO_NAMESs of compass and tape survey measurements.) The shapefile export function of Walls can optionally provide two additional shapefiles involving smaller subsets of stations. As themes in ArcView, they can be used to mark and/or label special categories of stations, such as benchmarks and entrances.

Flag shapefile: Survey data files can define any number of named station attributes: Cave Entrance, Benchmark, Walker BM, etc. The station-attribute pairs are submitted as a separate shapefile with base name **filename_F**. This corresponds to the FLAGS shapefile export option of Walls. There can be multiple attributes per station. The flag attribute table has the first four fields of the station attribute table plus a 64-character FLAGNAME field.

Note shapefile: Long descriptions can also be assigned to particular stations. Station-description pairs are submitted as a separate shapefile set with base name **filename_N**. This corresponds to the NOTES shapefile export option of Walls. There is at most one such description per station. The note attribute table has the first four fields of the station attribute table plus a 64-character NOTE field.

METADATATABLE (FILENAME_.DBF)

The metadata table, **filename_.dbf**, is a customizable one-row table that conveys information about the content of the shapefiles as a whole. Its structure and content is defined in a text file, **filename_.def**, which Walls processes just prior to shapefile export. The particular .def file that was used to generate the table will also accompany the shapefiles. The following table structure is an example of what might be produced. Note that the first five fields are always present and that FILENAME, PROC_DATE, and SURVEY_SW will be automatically assigned values by the export function.

Field Name	Field Type	Field Size	Field Description
CAVENO	Text	4	Required: Unique number assigned by MCNP (duplicated in vector shapefile).
FILENAME	Text	8	Required: Base name for the shapefiles (GIS theme) transferred to MCNP.
PROC_DATE	Number	8	Required: Date survey data file was converted to shapefiles (YYYYMMDD).
DATAHIST	Text	128	Required: Data processing history (duplicated in vector shapefile). See Note 5 .
SURVEY_SW	Text	40	Required: Name of cave survey software and version.
GIS_SW	Text	40	Name of GIS software and version.
HORZ_UVE	Number	8.2	Horizontal component unit variance estimate. See Note 6 .
HORZ_LOOPS	Number	8	Horizontal component loop count.
VERT_UVE	Number	8.2	Vertical component unit variance estimate.
VERT_LOOPS	Number	8	Vertical component loop count.

NOTES

1. The shapefile export function of Walls supplies for each survey vector a hierarchical area name based on named branches of the project tree. Whether or not a given branch node contributes to the hierarchy is a property setting labeled “Name defines segment”. The area name is stored in the CAVEAREA field, where vertical bars separate name components. Example: Historic Section | Albert’s Dome | Beyond Henry’s.

2. The SURVEYNAME field value is obtained from the title assigned to the survey data file (not the actual file name), which is indicated in Walls as a project tree leaf title. In CRF projects, the title will typically be a number followed by one or more letters, such as “1320A,B”. The numeric prefix, in this case, will be interpreted as the field survey book (FSB) number while the remaining text is considered the survey name. If the leaf title contains no numeric prefix then the shapefile’s FSBNUMBER field is blank.

3. The ATTRIBUTES field of the vector shapefile contains a list of “flag-like” properties that may have been assigned. In Walls, the attribute names are not predefined but are created and assigned by #Segment directives in the data files. The attributes are anything considered important by the surveyors or data manager (“Surface”, “Underwater”, “Needs resurvey”, etc.) and can control how surveys

are displayed on maps. Like the CAVEAREA field, the ATTRIBUTES field contains a list of names separated by vertical bars.

4. Except in special cases (e.g., Walker benchmarks like TT8W), the MCNP station names should conform to the CRF naming convention (<FSB No.><Survey letter><Number>). In Walls projects, a name can also have a prefix qualifier, delimited by a colon, to ensure uniqueness across a project with multiple caves or sub-projects. (Example: HISTORIC:TT8W.) Unprefixed names are limited to 8 characters in length while prefixes technically can be up to 128 characters long. Having concluded that prefixes of 8 characters or less will be sufficient if needed at all, we have chosen a 17-character field length for station names in MCNP shapefiles.

5. The length of the metadata table's DATAHIST field can be made larger than 128; however, only the first 128 characters will be used as a vector shapefile attribute. The shapefile's DATAHIST field has a fixed length of 128.

6. The unit variance estimate (UVE) is a consistency measure closely analogous to sample variance. It should correlate with expected survey accuracy when there is a sufficient number of surveyed loops. Smaller UVEs are better. The best cave surveys typically produce UVEs with values less than 2.0. The loop counts measure the significance of UVEs and allow those from different data sets

Geoscience

Updated Stratigraphic Section in Mammoth Cave National Park

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On the basis of field work during the past decade, we have updated the stratigraphic column for the Mammoth Cave System beyond the one we published earlier (Palmer, 1981), by clarifying certain names and adding the beds below the Horse Cave Member (see Figure 1). These beds were mapped in Logsdon River in Mammoth Cave, and correlations were made with the strata exposed in the entrance sinkhole of Hidden River Cave in the nearby town of Horse Cave. The Hidden River sinkhole extends from approximately the top of the Lost River Chert (at the local road level) to at least 15 m below the bottom of the section in Mammoth Cave (level of the cave stream below the sinkhole). We are still examining the details of the Hidden River column, and this information will be available soon.

The first stratigraphic column for Mammoth Cave National Park was distributed in 1975, based on hand-level surveys of Crystal Cave and on correlations in major passages elsewhere in the Mammoth Cave System (Palmer, 1975). Occasional updates have been made since (e.g. Palmer, 1981), especially in the names of units. These were not errors; they simply reflect the uncertainty of correlation from where the units were first described. To choose a single example: the Karnak Member of the Ste. Genevieve Limestone was first described in Karnak, Illinois (it has nothing to do with the Ruins of Karnak in Mammoth Cave). But whether the beds attributed to the Karnak in Mammoth Cave represent exactly the same rock interval that was described in Illinois is very hard to establish. Over distance, the beds change in thickness, rock type, and time interval of deposition. We based our correlation on published work in surrounding areas, most notably that of Pohl (1971).

The USGS geological maps for Kentucky are among the best in the country, and it is possible to obtain a map of the geology covering any topographic quadrangle in the state. The Mammoth Cave Geologic Quadrangle (Haynes, 1964) gives very little information, even as to how to distinguish between the three major limestones (the St. Louis, Ste. Genevieve, and Girkin), and no mention is made of the individual members within these formations. None of the geo-

logic mappers (even CRF member Pohl) seem to have ventured into the cave for stratigraphic information – or at least they make no mention of having done so. A glance at the chaotic stratigraphic column on the Mammoth Cave Quadrangle shows how difficult it is to make sense of the isolated patches of rock exposed at the surface. Within the caves, the entire section is clear.

Of the nearby geologic quadrangles, the Cub Run map to the north of Mammoth Cave has the most detailed stratigraphic information (Sandberg and Bowles, 1965). Until recently, we have identified the individual members within the Girkin on the basis of this map. With this interpretation, the Beaver Bend Member occupied about half of the Girkin. Later, more careful (but unpublished) work in the Horse Cave area by Garland Dever of the Kentucky Geological Survey showed the Reelsville Member to occupy much of what Sandberg and Bowles called the upper Beaver Bend. As a result, the Sample Member had to be moved downward to what we once called the BB2 unit of the Beaver Bend. What was originally considered the Sample became simply a sandy unit within the Reelsville.

Name changes in the stratigraphic column have only affected the upper Girkin members, which appear in only a few places in the system (the most accessible being Collins Avenue in Crystal Cave and the descent from the New Entrance in Mammoth Cave). These changes are shown in Table 1.

So it goes in the stratigraphic name game. Our goal at Mammoth Cave is not to advance the science of stratigraphy, but simply to assign usable names to recognizable strata so that the various beds can be traced easily throughout the cave area. Knowing the stratigraphic position of a passage helps to explain how it fits into the system. For example, Cleaveland Avenue in Mammoth Cave is located at exactly the same rock interval as the Lost Passage in Crystal Cave (the J1 unit of the Ste. Genevieve). Is that why the passages look so similar? Yes and no. Their bedrock walls and ceilings have the same pleasant sandy appearance because that is the nature of the J1 unit. Both passages are tubes with elliptical cross

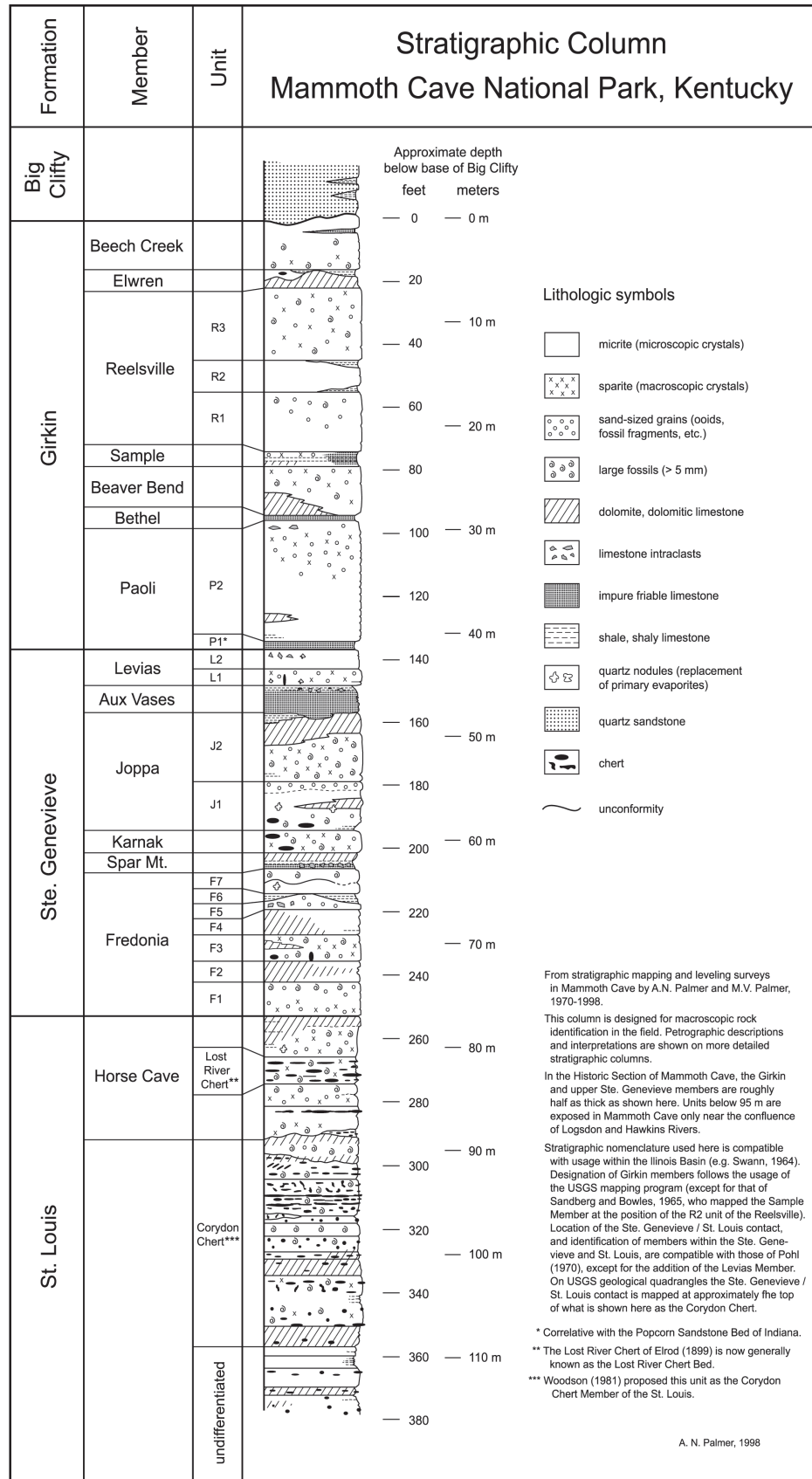


Figure 1: Stratigraphic column for limestones exposed in the Mammoth Cave System.

1974	1981	2001
Beech Creek	Beech Creek	Beech Creek
Upper Elwren	Elwren	Elwren
Upper Reelsville	Reelsville	Reelsville (R3)
Lower Elwren	Sample	Reelsville (R2)
Lower Reelsville	Beaver Bend (BB3)	Reelsville (R1)
Sample	Beaver Bend (BB2)	Sample
Beaver Bend	Beaver Bend (BB1)	Beaver Bend

Table 1: Change in stratigraphic names in the upper Girkin Formation of the Mammoth Cave System (Palmer, 1974, 1981, and present update).

sections, but they formed at different times at different levels. The well-bedded nature of these beds helped to give the passages their wide, low cross sections, although a great many other units within the limestone sequence could also have had a similar influence.

The formation and member names on the stratigraphic column were established elsewhere by other workers, mainly in Indiana, Illinois, and Missouri. We added the subdivisions of members (F1, F2, etc.) to indicate clearly identifiable units that can be traced throughout the Mammoth Cave System. These have no formal status and should not be used out of context. It is likely that most of them become indistinguishable at distances beyond a few topographic quadrangles from Mammoth Cave.

Many people have made use of the stratigraphic column over the years to help understand why passages look the way they do, to establish their altitudes, and to correlate them with other passages throughout the system. They usually

find it is not so simple as it might appear. The units vary in thickness and composition from place to place, and many different beds resemble each other without close scrutiny. The only way to sort out the different units is to measure a large interval of beds and then to find the best match with the stratigraphic column. A good way to start is to examine places where the beds have already been described, for example along the tour routes in Mammoth Cave (see Palmer, 1981). The greatest discrepancy with the generalized stratigraphic column shown here is in the Historic Route, where the Girkin and upper Ste. Genevieve are compressed to about half their thickness, compared with elsewhere in the system. Also in that area the F3 unit of the Ste. Genevieve is about twice as thick as elsewhere, and chert is much sparser in the upper St. Louis.

A detailed description of the strata will be published soon, so that those who wish to make their acquaintance can identify them more easily. We spend so much time crawling through them that it is appropriate, as with friends, to recognize them by name.

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Sedimentology of the Redwood Canyon Karst

John C. Tinsley

The karst of Redwood Canyon lies in the Grant Grove section of Kings Canyon National Park. It contains more than 60 sinkholes, three caves including Lilburn Cave, and a major Vaclisian ebb-and-flow spring (Big Spring). These elements comprise a single karst system containing a 3-dimensional maze more than 18 miles in mapped length. The karst is developed as a mantled karst, situated wholly within the eastern part of the Redwood Mountain roof pendant, a highly metamorphosed suite of rocks intruded by Mesozoic plutonic rocks of the Sierra Nevada mountains. Scientists of the Cave Research Foundation have conducted research, monitoring, and mapping studies of the sediments of the karst for more than 25 years. Several aspects of the karst's sedimentology have been studied during the past couple of decades. These topics include studies of the rates of sediment yield to the sinkholes above ground during the past 700 years, the provenance or source characteristics of the sediment mapped in the channels of surface streams and subsurface deposits in Lilburn Cave, the impact of a single sinkhole collapse on the hydrology of the cave and spring system, and the response of the cave to various levels or intensities of runoff events.

The studies of sediment yield to sinkholes depend on the presence in plugged sinkholes of a volcanic ash deposit that was erupted about A.D. 1240 from the Deadman Dome area of the Inyo Craters volcanic chain in the eastern Sierra Nevada near Mammoth Lakes resort. Owing to westward-directed winds that prevailed at the time of the eruption, this tephra made it across the Sierran crest where it is preserved in alpine meadows as a distinct layer, and it comprises a buried identifiable marker bed in some sinkholes of Redwood Canyon. Hand-powered auger equipment readily intersects both the tephra and its post-depositional sediment cover in the sinkholes, and the volumes of tephra and post-tephra sediment are readily computed from isopachous maps of the sinkholes, and the results compared to aspects of the karst including drainage basin area and slope. Sinkholes that have been "leaky" or that have collapsed since the tephra was deposited do not yield reliable results. About 10 of the sinkholes have a decent stratigraphic record useful for the purpose of this study.

Contrasts in rock types within Redwood Creek basin provide useful keys indicating the source of sediment within the pas-

sages of Lilburn Cave. The main surface stream, Redwood Creek, flows mainly south towards the Kaweah River. Redwood Creek's tributaries from the north and west drain a basin that is dominantly underlain by non-carbonate metamorphic rocks (mainly schists, hornfels, and quartzites) of the Redwood Mountain pendant; tributaries from the east side of the drainage come off Big Baldy mountain, an 8000-foot-high Cretaceous granite pluton. Consequently, sediment along Redwood Creek's modern channel contains 70% metamorphic lithologies, in contrast to the nearly pure granitic sand and gravel deposits of the drainages that emanate from Big Baldy. Within the cave, these lithologic contrasts are preserved and enable investigators to determine which passages have received water and sediment from Redwood Creek, which passages have retained apparently an exclusive eastern tributary association, and which passages preserve an interplay between the two source rock associations.

In 1989, a portion of the bed of Pebble Pile Creek, a westward-draining tributary to Redwood Creek, dropped into Lilburn Cave in the general area of the Yellow Floored Domes. The minimum volume of sediment dumped into the cave was estimated to amount to 140 cubic yards by surveying the volume of the new sinkhole preserved in the bottom of Pebble Pile Creek. The estimate is a minimum because an undetermined volume of sediment was shed from the precipice along the north side of Pebble Pile sink. The effect within the cave was to cause subterranean Redwood Creek to aggrade vertically about 10 feet from the Z-Room to the South Seas. There was a corresponding 10-foot rise in the standing water level of the South Seas sump during episodes of low discharge in the late summer and autumn. These new conditions persisted for nearly 8 years, until the El Nino winter of 1996-1997. At that time, substantial early season snow was melted by warm intense rains (the proverbial "Pineapple Express" condition in California weather parlance), and the cave was filled with water such that about 130 feet of head was applied to Big Spring. This was sufficient to construct a low fluvial terrace in Redwood Creek downstream of Big Spring; the sediment was derived mainly from Lilburn Cave via Big Spring, on the basis of grain size, composition, and spatial association. Within the cave during the 1982-1983 El Nino winter, a sediment wave at least 10 meters in amplitude went through the Z-Room area, as recorded by a static sediment

sampler. During the next two years, the aggraded sediment in lower Lilburn Cave that was derived from Pebble Pile sink was eroded progressively away. By 1999, conditions within the cave were back to pre-1989 conditions. In 1999, the Pebble Pile sink also was re-filled such that water flowing into the sink could flow out the lower end of the reach, once again displaying an integrated thalweg. For the preceding decade, the entire water and sediment discharge of Pebble Pile creek had been trapped by Pebble Pile Sink. Thus, we have documented an example of a sinkhole “cycle” that has had a duration of about 10 years. Other subdued scars along Pebble

Pile creek probably record similar sequences of geomorphic events, but these have not been dated or studied in any detail. The wall of Pebble Pile sink continues to decline, and headward migration of the sinkhole lip is threatening to excise the present course of Redwood Canyon trail. Several mature conifers have contributed their undermined carcasses to the sinkhole, with more to come.

Lilburn Cave is a wonderfully dynamic natural laboratory in which to study, monitor, and document sinkhole development and evolution, and sediment transport processes above and below ground.

Transport and storage of trace metals in a karst aquifer: An example from Fort Campbell, Kentucky

Dorothy J. Vesper

Introduction:

The overall purpose of this study was to provide a more comprehensive understanding of how and when metals and contaminants are transported and stored in karst aquifers. The study evaluates both the water and sediment quality in springs. The focus of the water quality investigation was metal and contaminant transport to two springs at Fort Campbell, Kentucky. The focus of the sediment chemistry investigation was to evaluate the accumulation and speciation of metals in different types of springs in a similar geologic setting. In combination, the water quality and sediment studies assess the impacts from upgradient contamination. Given their downgradient location, springs are the most likely location for human and ecological receptors to be exposed to subsurface contamination in a karst ground water basin. Understanding the spring water quality variability and the potential of sediment contamination is necessary if the consequences of contamination are to be understood. Furthermore, this knowledge furthers our ability to predict which springs are the most vulnerable and, thus, to protect their water resources.

Site Background

The data were collected on and near the Fort Campbell Army Base. The base is located along the Kentucky-Tennessee border approximately 65 km northwest of Nashville, Ten-

nessee (Figure 1a) and encompasses approximately 430 km². Of that, approximately 80 percent is used for ranges and is largely undeveloped. Over 30 perennial springs have been identified within an area of approximately 250 km² around the base (Figure 1b). The area surrounding Fort Campbell is largely agricultural with some commercial and industrial uses.

The region is located on the Western Highland Rim of the Nashville Basin and is underlain by the limestones of the Mississippian St. Louis and Ste. Genevieve formations (Klemic, 1966a; Klemic, 1966b). The Ste. Genevieve is found in the topographically high areas and largely consists of thick-bedded limestone with thinner beds of dolomite. Discontinuous layers of chert and fossils are present. The St. Louis Formation outcrops primarily in the waterways and topographic lows to the south. It is thin to thick bedded, dolomitic, argillaceous, silty, and fossiliferous. Ball chert and corals are profuse in some layers. Numerous caves have been found and surveyed in the area around Fort Campbell (Mylroie, 1984). The Glover cave area, located east of the base along the West Fork of the Red River, has two major caves - Glover and Twin Level. As of 1981, the two caves had a reported survey length of over 4,500 m (Mylroie, 1978, 1981). Between 0 and 30 m of unconsolidated materials are present above the limestone. This regolith consists of an upper layer of reddish brown clays and a lower layer of gravelly clay (Arthur D. Little Inc., 1997). Chert nodules are commonly found at the regolith – rock contact.

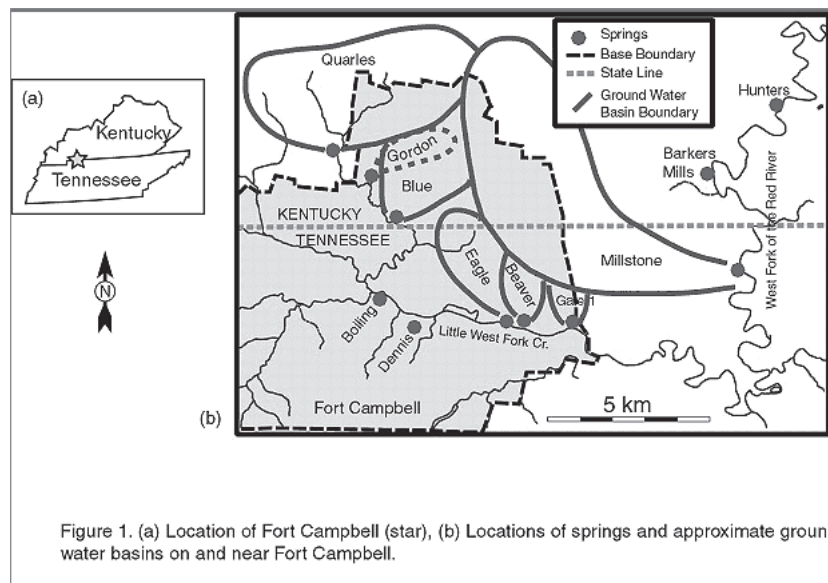
Water Chemistry Study

Water samples were collected from Beaver and Millstone Springs in 1999 and 2000 and from Eagle Spring in 2000 (Figure 1b). The samples were collected at intervals ranging from 0.5 hour to 12 hours; closely-spaced intervals were used initially and when the springs were undergoing rapid changes and widely-spaced intervals were used as the springs neared baseflow conditions. Data collected concurrently with the water samples include precipitation, stage, specific conductance (SpC), temperature, turbidity, pH and alkalinity. Stage, SpC and temperature data were collected by Ewers Water Consultants, Inc. The water samples were analyzed for total organic carbon, anions, and metals. The samples collected during 2000 were analyzed for both digested metal concentrations and filtered metal concentrations so that the contribution of sediments to the total metal transport could be evaluated. The samples were filtered using dedicated, tortuous path, 0.45- μ m cartridge filters.

The 1999 data from Beaver Spring provide the best illustration of how various chemical concentrations change during storms because it has a small basin (approximately 2 km²), a fast response to storms (approximately 8 hrs from storm to crest of hydrograph), and highly variable water chemistry. As expected, the Ca concentration decreases during storms when fresh recharge water mixes with the high-Ca baseflow water (Figure 2). The coincidence of this minima with the stage peak suggests that the physical hydrogeology of this basin is vadose, conduit flow-dominated, and has a strong component of quick-input recharge.

The nitrate concentration has a temporal variation similar to the Ca. Both constituent concentrations are controlled by dilution, but their sources differ. While Ca is present due to the dissolution of the carbonate bedrock, the nitrate is more likely to be present due to the use of fertilizers. Similar changes in nitrate have been observed in springs in Kentucky, Iowa, and Arkansas and have been attributed to storage of nitrate at the epikarst and its gradual release into the aquifer during baseflow conditions (Hallberg et al., 1985; Iqbal and Krothe, 1995; Peterson et al., 2002).

The suspended sediment transport over a storm is illustrated by the change in the Al concentration and trace metal transport is illustrated by the change in the Pb concentration (Figure 2). These concentrations are from digested samples and



thus they indicate the total material being transported regardless of whether it is in the solid-phase, colloidal, or dissolved form. The similarity of the chemographs, and the high regression coefficient for the Al-Pb linear correlation ($R^2 = 0.94$), indicate that the sediment and trace metal transport is coupled. Other trace metals - As, Cr, and Ni - have similar chemographs and relationships to Al. When the spring water samples are filtered, both the non-carbonate major metal (Al, Fe, Mn) and trace metals concentrations decrease significantly further supporting that their transport is linked to sediment movement.

Total organic carbon (TOC) concentrations also increase during storm events (Figure 2). The most likely source of the TOC is that it is flushed from the land surface and injected into sinkholes. The coincident rise of the Al, trace metal and TOC chemographs point to a surface origin for all. Understanding the variation in TOC is important from an ecological perspective. Springs are known to be nutrient poor and this variability may affect spring biota (McCabe, 1998).

A limited number of volatile organic compound (VOC) data were available for comparison via the Fort Campbell spring monitoring program (Arthur D. Little Inc., 2001). Chloroform and trichloroethene (TCE) were detected at low concentrations at Beaver Spring during 1999 (Figure 2). The data suggest that the concentrations are either nearly constant or decrease slightly during storm events. Both compounds are capable of existing as dense, non-aqueous, phase liquids (DNAPL) within the aquifer. It has been suggested by Loop and White (2001) that DNAPLs will continuously release low concentrations of VOCs into the ground water. The VOC data from Beaver Spring agree well with Loop and White's suggested conceptual model.

Spring Sediment Chemistry Study

Sediment samples were collected from four springs at Fort Campbell. The springs are significantly different in terms of geomorphology and sediment type: Beaver Spring is a gravity spring from a rock outcrop and is lined with gravel and cobbles, Eagle Spring is a steephead spring located adjacent to a major creek and has scoured its base down to hard-packed native clays, Gordon Spring is a shallow circular spring with organic materials mixed with fossiliferous quartz gravel, and Quarles Spring is a decanting circular rise pit that collects fine-grained sediments in the spring and spring run.

The bulk sediments were analyzed for grain size distribution, TOC, cation exchange capacity, and total digestible metals. The sediments were also submitted to a sequential extraction procedure that identifies the chemical fraction in which the metals are bound. The procedure (Quevauviller et al., 1993; 1994) operationally defines the fractions as exchangeable, carbonate-bound, oxide-bound, organically-bound, and residual. This information is essential in understanding environmental impacts because metal toxicity and bioavailability are a function of metal chemical form (Luoma, 1983; 1989).

Total trace metal concentrations in the sediment and soil samples could not be correlated to TOC, percent sand, exchange capacity or any other specific metal. This suggests that the trace-major metal relationships commonly found in the digested water samples (suspended sediments) cannot be applied to either the source soils or the accumulated sediments in storage at the spring.

The sequential extraction data indicate that some metals are consistently found in a single fraction in both soils and sediments while others vary considerably location to location. For example, Al and Si are both almost solely present in the residual (mineral) form regardless of the sample location. An interesting distinction occurs between Fe and Mn. Mn is more variable between fractions than is Fe and both are more variable at Quarles Spring than in the other springs. The sediments depth (up to 18 inches) and the presence of organic contaminants are likely to create a reducing environment in the sediments at Quarles. This environment allows for the extraction of metals from their residual form and their redistri-

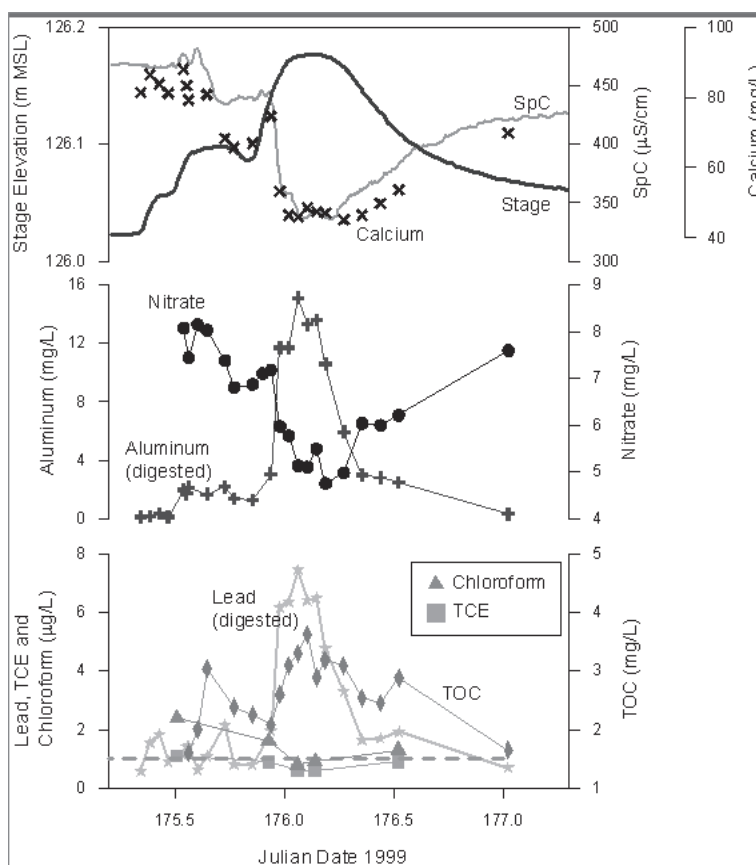


Figure 2: Hydrograph data

bution into other chemical forms. Hence the local conditions (particularly the contamination) and the spring's geomorphology (which enhances sediment accumulation) influence the final speciation of the redox-controlled metals in the sediments.

The trace metals show a similar range of behaviors. While Cr and Ni appear to be primarily present in the mineral form, Cd and Pb are more likely to be split between several fractions. The preliminary analysis does not suggest a clear control on how the metals are bound at each location. However, the metals are unlikely to be controlled by Fe and Mn oxides, a common location for metal accumulation in natural settings.

Summary

The downgradient impacts of contamination in karst settings are most likely to be found at springs. At springs with variable water chemistry, the impacts can be acute but dramatic. In contrast, springs that accumulate sediments may also accumulate metals and pose a chronic risk to spring ecosystems. Sediment accumulation is believed to be controlled by

the spring geomorphology and the ability of the spring to scour or flush itself of fine-grained material. Once metals are deposited in spring sediments, their chemical form can be altered from that of their source materials.

Acknowledgements

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Temporal Links Between Climate and Hydrology: Insights from Central Texas Cave Deposits and Groundwater

by MaryLynn Musgrove

Introduction

Relatively little is known regarding how groundwater evolves over time (e.g., decades to millennia), yet this knowledge provides a framework for assessing the controls of factors such as climatic variations on aquifer and karst development, long-term patterns of recharge, and changes in flow regimes. An improved understanding of the links between hydrology and continental climatic fluctuations has far-reaching contributions to many aspects of Earth and environmental science, including processes important for water management and water quality.

Carbonate cements deposited from groundwater in caves (speleothems) may provide continuous temporal sequences of growth and corresponding records of aquifer and karst development, groundwater geochemistry, and paleoclimatic parameters. Speleothems are precisely datable over a range of time scales for the Pleistocene and Holocene. Temporal changes in groundwater over recent geologic time may be utilized to understand mechanisms and time scales of variations in groundwater chemistry and their relation to climatic and hydrologic factors.

Speleothem samples and temporal series of cave dripwaters were collected across central Texas from multiple caves developed in Cretaceous carbonates. A regional sampling coverage facilitates discerning local variations at individual sites versus regional variations. Integrated geochemical techniques (including Sr, U, C and O isotopes, and Mg/Ca and Sr/Ca values) provide constraints on paleoclimatic and paleohydrologic changes in central Texas that may be recorded in cave dripwaters and speleothems on different time scales, as well as the complexities associated with such records.

Hydrologic and Geologic Setting

The Edwards aquifer region of central Texas is developed in karstified Cretaceous limestone. The study area encompasses the Edwards (Balcones Fault Zone) aquifer, and includes portions of two other regional aquifer systems, the Edwards – Trinity (Plateau) aquifer, and the Trinity aquifer (Fig. 1). The Edwards Plateau is a distinct physiographic region characterized by unique climatic, vegetational, geologic, and pedogenic characteristics (Kastning, 1983; Abbott & Woodruff, 1986).

Many studies have investigated the development of the aquifer, fluid hydrodynamics, groundwater geochemistry, and the aquifer's water balance (e.g., Clement & Sharp, 1988; Sharp, 1990; Oetting et al., 1996; Sharp & Banner, 1997). Rainfall, which may vary significantly from year to year, is the primary source of aquifer recharge. Natural discharge occurs via springs within the fault zone. The Edwards Plateau is extensively karstified with many caves with active speleothem deposition. Regional historical records detail the relationship between rainfall, recharge, and discharge in the aquifer and indicate a clear link between rainfall and effective moisture, which may be controlling the growth of cave speleothems as well as modern dripwater variability.

Soils are developed from underlying limestones and are generally thin and stony, consisting of calcareous clay and clay loam (Godfrey et al., 1973). Although there are local variations, the soils and vegetation across the region are similar (McMahan et al., 1984; Godfrey et al., 1973). Small or local-scale differences, however, in the stratigraphic settings, geomorphologic settings, and soil cover of the caves may contribute to differences in dripwater and speleothem geochemistry.

Speleothem Geochronology and Growth Rates

The development of high-precision thermal ionization mass spectrometric techniques for uranium-series geochronologic measurements has resulted in significant advances in obtaining high-resolution records of sea level change, terrestrial and marine climate, and the calibration of the ^{14}C time scale (e.g., Edwards et al., 1987, 1993, & 1997; Winograd et al., 1992; Dorale et al., 1998). Studies of calcite deposited from groundwater in caves (speleothems) and fracture-fills have demonstrated their potential to record high-resolution changes in groundwater chemistry, hydrology, and paleoclimatic variables (Winograd et al., 1992; Gascoyne, 1992; Dorale et al., 1998; Bar-Matthews et al., 1997; Banner et al., 1996). Speleothems are precisely datable over a range of time scales for the Pleistocene and Holocene. In contrast with many terrestrial climate proxies that lack temporal and/or spatial continuity, speleothem records may provide continuous temporal and spatial sequences of growth, and correspondingly, records of aquifer and karst development and paleoclimatic parameters.

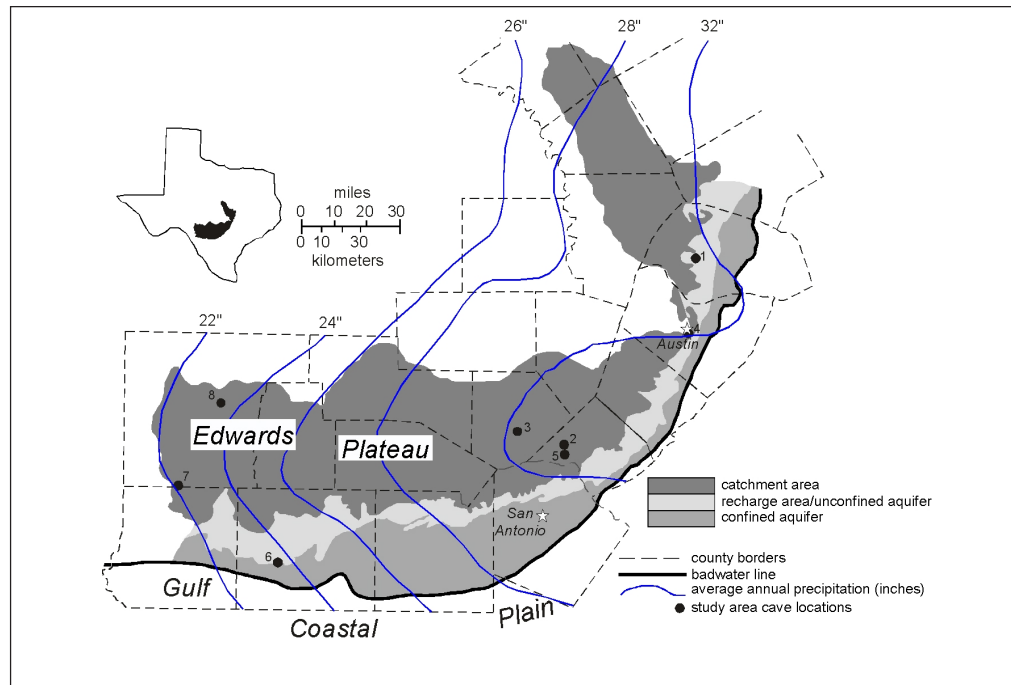


Figure 1. Hydrologic zones of the Edwards (Balcones Fault Zone) aquifer of central Texas, and cave and sample locations. Precipitation contours are from Larkin and Bomar (1983). The badwater line defines the down-dip limit of potable water in the aquifer (1000 mg/L). Study area cave locations, noted by filled circles are: 1) Inner Space Cavern, 2) Double Decker Cave, and 3) Cave Without a Name, 4) District Park Cave, 5) Natural Bridge Caverns, 6) Indian Creek Cave, 7) Kickapoo Cavern, and 8) Devil's Sinkhole. The majority of the caves are described in Elliott and Veni (1994) and Kastning (1983). Water samples from Inner Space Cavern (1) and, particularly, Natural Bridge Caverns (5) were studied in the most detail and temporal sequences of samples were collected from these caves. Results of the data from these two caves are focused on in the text. Regional aquifer map after Burchett et al. (1986) and Brown et al. (1992).

A detailed geochronology and growth rate history of four central Texas stalagmites from three caves that are up to 130 km apart on the eastern portion of the Edwards Plateau provides a record of temporal changes in hydrology and climate (Musgrove et al., 2001). Fifty-three geochronologic ages were determined by mass spectrometric uranium-thorium and uranium-protactinium analyses. The accuracy of the ages and the closed-system behavior of the speleothems are indicated by inter-laboratory comparisons, concordancy of ^{230}Th and ^{231}Pa ages, and the results that all ages are in correct stratigraphic order. Over the 71,000-year record the stalagmites have similar growth histories with periods of relatively rapid and slow growth (Fig. 2). The growth rates vary over nearly three orders-of-magnitude, with three periods of rapid growth from 72-60 ka, 39-33 ka, and 24-12 ka. These growth rate shifts correspond in part with global glacial-interglacial climatic shifts.

Paleontological evidence indicates that around the Last Glacial Maximum (20 ka) climate in central Texas was cooler and wetter than at present. This wetter interval corresponds with the most recent period of increased growth rates in the

speleothems, which is consistent with conditions necessary for speleothem growth. The temporal shift in wetness has been proposed to result from a southward deflection of the jet stream by the presence of a continental ice sheet in central North America. This mechanism may also have governed the two earlier intervals of fast growth in the speleothems (and inferred wetter climate). Compared with the Last Glacial Maximum, however, ice volume was lower and temperatures in central North America were higher during these earlier glacial intervals. The potential effects of temporal variations in precession of the Earth's orbit on regional effective moisture may provide an additional mechanism for increased effective moisture coincident with the observed intervals of increased speleothem growth. The stalagmites all exhibit a large drop in growth rate between 15 and 12 ka, and very slow growth up to the present, consistent with drier climate during the Holocene. These results illustrate that speleothem growth rates can reflect the regional response of a hydrologic system to regional and global climate variability.

The central Texas speleothem growth rate record represents the first continuous regional climate record for central Texas extending beyond the last glacial period. Variability in individual stalagmite samples indicates the necessity of an approach that integrates data from multiple samples and multiple sites in order to distinguish a response to regional variability versus local conditions. Variations in growth rates provide a framework within which to evaluate the influence of climatic variations on aquifer and karst development, long-term patterns of recharge, and changes in hydrologic flow regimes.

Geochemistry of Vadose Zone Cave Dripwaters

Although the major element chemistry of phreatic groundwater systems has been well studied, many basic processes of groundwater evolution in karst terrains, such as vadose zone chemical evolution and the influence of soil composition on water chemistry, are still largely unexplored. Although climate variability must play a fundamental role in hydrology (e.g., Barron et al., 1989; Blum and Erel, 1995; Wadleigh et al., 1985; Gascoyne, 1992), the specific mechanistic interdependence of climatic, hydrologic, and geochemical processes is not well understood.

Previous work in the Edwards aquifer (e.g., Oetting 1995) has investigated regional processes of phreatic groundwater geochemistry and provides an ideal framework within which to examine temporal and spatial controls on vadose processes. A four-year study of central Texas soils, vadose waters (i.e., cave dripwaters) and phreatic groundwaters offers new insights into controls on vadose groundwater evolution, the relationship between vadose and phreatic groundwaters, the temporal influence of climate on groundwater evolution, and the fundamental influence of soil composition on groundwater geochemistry. Integrated variations in Sr isotopes and trace elements (Mg/Ca and Sr/Ca ratios) of multiple dripwaters and soils from different caves, as well as phreatic groundwaters, provides the potential to distinguish 1) between local variability and regional effects, and 2) a framework for understanding the links between climatic and hydrologic processes. This work has specifically focused on water samples collected from Natural Bridge Caverns in Comal County, Texas, and, to a lesser extent, Inner Space Cavern in Williamson County, Texas (Fig. 1).

The Sr isotope composition of vadose cave dripwaters (mean $^{87}\text{Sr}/^{86}\text{Sr} = 0.7086$) and phreatic groundwaters ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7079$) generally falls between values for host carbonates ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7076$) and exchangeable Sr in overlying soils ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7089$). Dripwaters have lower Mg/Ca and Sr/Ca ratios, and higher $^{87}\text{Sr}/^{86}\text{Sr}$ values than phreatic groundwaters. Dripwater $^{87}\text{Sr}/^{86}\text{Sr}$ values inversely correlate

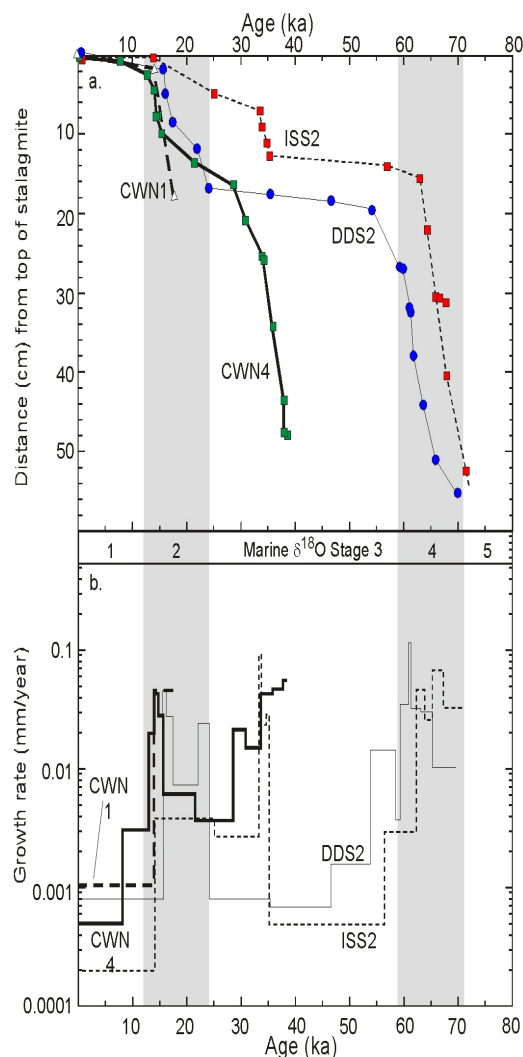


Figure 2. Growth rate histories for four central Texas stalagmites for the last 72 ka.

2a. Growth-layer ^{230}Th age versus depth of the growth layer from the stalagmite tip. The slope of the line for each sample represents the growth rate. Steeply sloping portions of the curves correspond to fast growth rates, whereas flat portions of the curves correspond to slow growth rates in the stalagmites.

2b. Calculated growth rate versus time for the last 72 ka. The stepped nature of the curves is a consequence of interpolating constant growth rate between dated intervals. Shaded bands represent glacial intervals (marine oxygen isotope stages 2 and 4) based on the time divisions of Imbrie et al. (1984). The stalagmite records, from three caves up to 130 km apart on the Edwards Plateau, contain consistent shifts in growth rates that correspond to global glacial/interglacial climate shifts.

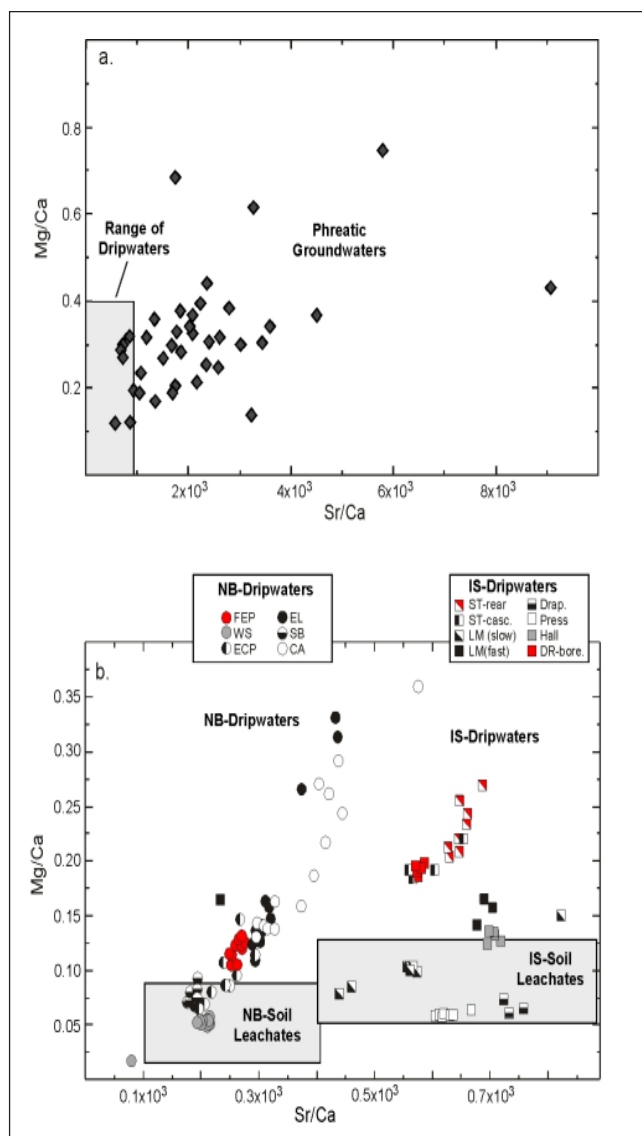


Figure 3. Mg/Ca vs. Sr/Ca ratios for Edwards aquifer system components: (a) phreatic groundwaters (triangles), and (b) dripwaters and soil leachates from Natural Bridge Caverns (NB) and Inner Space Cavern (IS). Note scale difference between (a) and (b). Shaded box in (a) marks area expanded in (b). Shaded boxes in (b) denote the range of Mg/Ca and Sr/Ca in soil leachates from the two caves (NB: Mg/Ca = 0.17 to 0.08, Sr/Ca = 0.41 to 0.95 $\times 10^3$. IS: Mg/Ca = 0.05 to 0.12, Sr/Ca $\times 10^3$ = 0.40 to 0.91 $\times 10^3$). Soil leachates represent exchangeable Sr in soils near cave recharge zones. Symbols for NB (circles) and IS (squares) represent different dripwater sites within the caves, which were resampled multiple times over the course of the study. Dripwater locations within the caves are detailed in Musgrove (2000). Regional phreatic groundwaters (a) exhibits a similar trend as the dripwaters of increasing Mg/Ca with increasing Sr/Ca, but range to markedly higher values. Phreatic groundwater data from Oetting (1995) and Musgrove (2000).

with both Mg/Ca and Sr/Ca ratios. Mass-balance modeling and geochemical relationships suggest that variations in fluid compositions are predominantly controlled by: 1) vadose groundwater residence times, and 2) water-rock interaction with overlying soils and host aquifer carbonate rocks. Consistent differences in dripwater geochemistry (i.e., $^{87}\text{Sr}/^{86}\text{Sr}$, Mg/Ca, and Sr/Ca) between individual caves are similar to differences in soils above the caves (Fig. 3). While these differences appear to exert significant control on local fluid evolution, geochemical and isotopic variations suggest that the controlling processes are regionally extensive. Temporal variations in $^{87}\text{Sr}/^{86}\text{Sr}$ values and Mg/Ca ratios of dripwaters over the four-year interval appear to reflect changes in both aquifer and climatic parameters, which are a function of rainfall amounts.

Changes in vadose flow routes as a function of rainfall-recharge is a mechanism by which these parameters in groundwater geochemistry may vary temporally by 1) receiving varying fluxes of dissolved constituents from geochemically distinct sources (i.e., soils versus host limestones), 2) fluctuations in residence time, and 3) different water-rock interaction pathways. In this model, groundwater migration is predominantly along slow seepage routes during periods of low rainfall, which results in relatively long residence times in the host limestones. During high-rainfall periods, the capacity of seepage routes is exceeded and groundwater migration is dominated by low residence time conduit flow along paths of enhanced permeability.

Geochemical and Isotopic Constraints on Late Pleistocene to Holocene Speleothems

Aquifers may be strongly influenced by regional and global scale phenomena and thus, may represent unique archives of paleoclimate (Fontes et al., 1993; Shuttleworth, 1999). Geochronologic constraints on growth rates and the timing of growth phases in speleothems have provided insight into the timing of glacial/interglacial periods and related variables such as precipitation and effective moisture (e.g., Baker et al., 1993, 1995; Genty and Quinif, 1996; Musgrove et al., 2001). Variations in carbon and oxygen isotopes in speleothems have been used to assess paleoclimatic conditions such as temperature, rainfall, and vegetation (Gascoyne, 1992; Bar-Matthews et al., 1997 and 1999; Dorale et al., 1998; Winograd et al., 1992). Pollen and organic matter contained in speleothems may provide insight into vegetation and soils (e.g., Brook et al., 1990; Lauritzen et al., 1990; Baker et al., 1996). Trace elements and strontium isotopes yield information about paleohydrology and the balance of rainfall-recharge (Banner et al., 1996; Roberts et al., 1998).

Temporal geochemical variations in central Texas speleothem Sr and U isotopes, and Mg/Ca ratios, are consistent with major aspects of regional and global climate records of glacial - interglacial climatic shifts. The timing of geochemical fluctuations in the speleothems, as well as the inferred processes that they reflect, are generally consistent with 1) growth rate variations in the same speleothems, 2) independent paleontological evidence for the region, and 3) aspects of global climate records. In spite of complexities of regional and local variability across the broad area of the Edwards Plateau, groundwater migration during the Pleistocene and Holocene shifted between higher and lower permeability pathways as a function of rainfall-recharge. This rainfall-recharge hydrologic model indicates that variations in geochemical parameters in cave dripwaters and speleothems are linked, via paleoclimatic and hydrologic processes over multiple (yearly to millennial) time scales. These results have implications for other paleohydrologic and paleoclimatic terrestrial records preserved in speleothems. Variability in individual samples indicates that data from multiple samples and/or sites is necessary to distinguish regional variability versus local conditions. Local variations in parameters such as lithology, soils, vegetation and climate may contribute to geochemical differences in speleothem samples from across the region. However, the consistency of regional geochemical trends in parameters such as strontium, carbon and oxygen isotopes, and Mg/Ca and Sr/Ca ratios, combined with results of water-rock interaction models suggest that the controlling processes affecting speleothem geochemistry are regionally extensive.

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Roppel Cave

Cave Research Foundation supports and participates in the ongoing work at Roppel Cave that the Central Kentucky Karst Coalition is doing in Roppel Cave. In 2000, CRF entered into an official partnership with the CKKC in order to pursue our...

Activities of The Central Kentucky Karst Coalition

by Jim Borden

The Central Kentucky Karst Coalition continues to be active in the survey and exploration in and around the caves of Toohey Ridge, just east of Mammoth Cave National Park. Although the year 2001 was not a banner year for survey, many leads promising leads were found throughout the cave. We had about three months of access problems; that, combined with other personal issues, conspired to keep trips subdued for the year. For the year, we surveyed 1.02 miles (in contrast, 2.07 and 1.78 miles were surveyed in 1999 and 2000, respectively).

Highlights

Roppel Cave, South end: In Roppel Cave, work in 2001 continued, albeit at a reduced rate, to find a way into the promised land of south Toohey Ridge. The flurry of work over the last few years in the land of Dixie had tailed off without the hoped-for breakthrough. Areas of Dixie were tantalizingly close to the broad sandstone expanse of south Toohey Ridge, but our efforts were continually thwarted by valley collapse and the "Great Wall" (The "Great Wall" is a long, linear collapse feature that effectively blocks all passages going south. This occurs over a significantly long distance, but has proven to be a formidable obstacle.)

A neglected inlet to Zabrok Pit, which is the southern end of the Green Eggs Dome Complex below Dixie, led to a long passage that drains the southeastern arm of the overhead valley. As of this writing, exploration ends at a collapse zone with possible routes into upper level domes and passages.

The southernmost point of Dixie is a large dome/waterfall that appears to lie south (beyond) of the Great Wall. A strong wind suggests that this may be the key to a breakthrough. During the middle part of the year, Dick Market, Peter Zabrok, and Seamus Decker completed a sixty-foot bolt climb to the top of the waterfall. By the time they completed the climb, it was late in the trip, and there was only time for a cursory look

at the small passages above. Possibilities, but not the big breakthrough—yet.

Roppel Cave, Other Exploration

Despite the frustrations to the south, the renaissance of exploration continues throughout the year. Long neglected areas, lost passages, and ghost leads dominated the efforts. Since the early days of the Roppel project, there has been nearly a full turn of a generation of cavers. A fresh eye and new approach was being applied to old leads. New technologies in climbing, better understanding of the cave morphologies, and new determination in difficult leads opened the path of exploration.

Peter Zabrok and Dick Market have been the leaders in the climbing efforts in the caves and, in addition to the Dixie climbs, they picked off one climbing lead after another. In North Downey Avenue, Bibble Boulevard was uncovered at the top of a long-known climb. This became too tight. In Walter Way, The Breach was climbed in the large dome just fifteen minutes from Arlie Way. This led to a small canyon network, still unpushed. At the White River Domes in the eastern BWOB (upstream end of Texas Canyon), upper level climbs were probed and leads remain. In the Great White North, at Fort Wilderness, Zabrok and James Wells climbed into the upper level canyon, almost connecting to the eastern end of the Ping-pong Crawl off Yahoo Avenue (six miles travel by the next closest route). Additional climbs off the Kumquat at its south end near Jakes Cave failed to yield cave.

Elsewhere, the search for Borden's Lost Walking Passage at the far Northwest End (Lower Elysian Way) continued with no success (Borden reports a 14' high x 3' wide walking canyon at the end of a long passage, found in 1991 — three trips have yet to find it through fourteen hundred feet of since-surveyed cave). Snorkland was pushed further to the west

to a point above Yahoo Avenue. The west end of the Grand Canal was surveyed, laying the framework for a climbing effort into the upper level canyons in this area. Iguana Falls off Lower Black River just south of Grand Junction, a long known tributary was pushed to an upper level walking canyon, Ponchos Paradise, that has been unpushed. Downstream Nexus Creek was connected to Upper Elysian Way. Near the Fisher Ridge Special, Bills Creek was pushed downstream through a canyon to open passage — Kathleen Krawl, unpushed.

Other Work

GPS Work: The primary satellite caves were located with GPS and incorporated into the database.

Sammy Monroe Cave (2,625 feet surveyed) was positioned over the Emerald City area (end of OZ, at the end of the Yellow Brick Road, above the eastern BWOB). Possible con-

nection to Roppel Cave is possible via the numerous narrow, but blowing, drains below Monroe Cave's main level.

Wolf Tree Cave, whose location was previously only vaguely known, was positioned to likely be the upstream reaches of the Death Trap (upstream Bills Creek, off the Fisher Ridge Special), 600 feet away. Wolf Tree Cave has 1,407 feet surveyed (mostly a trunk fragment), with a low strongly blowing drain heading north toward Bills Creek. This is a doable and worthwhile connection to complete, although useless for exploration. Upstream Bills Creek has been explored a significant distance, so it is likely that a connection is very close.

Meredith Cave is above the approximate location of Borden's Lost Walking Passage, at the Northwest End. Meredith Cave ("a cave composed totally of obstacles" — James Wells) is a series of drains that lead through tight passages to pos-

Cave Books

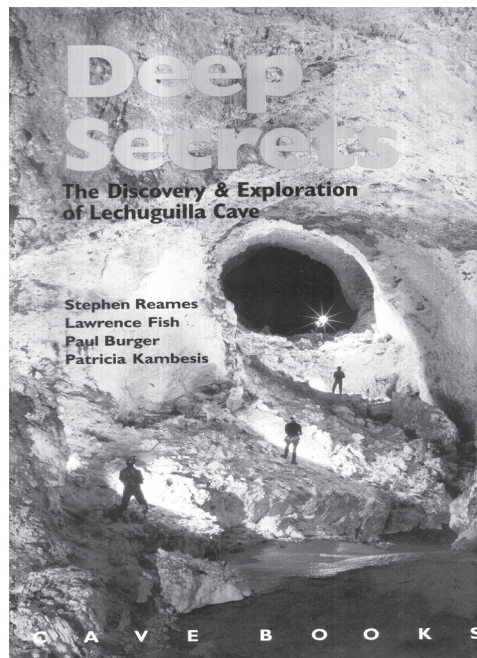
Cave Books Report 2001

Paul Steward

CAVE BOOKS is now twenty years old and still going strong! In 1981, several cavers combined their money, knowledge, and their love of books to form a non-profit press devoted to the publishing of cave and karst related material. CAVE BOOKS, an affiliate of the Cave Research Foundation, was formed to do just that.

Our first book was *The Grand Kentucky Junction*, a companion to *The Longest Cave*, this book provides an intimate glimpse into the personal thoughts of the seven cavers who made the connection of the Flint Ridge Cave System to Mammoth Cave. Since that first book, CAVE BOOKS has gone on to become the largest publisher of cave and karst books in the world. We also publish CRF annual reports, newsletters, research monographs, historical reprints, and cave maps. Solicitation of manuscripts is an ongoing endeavor, and new items are continuously being added to the inventory. We recently printed our first mail order catalog, increased our presence with on-line book dealers, and now have our own web page <www.cavebooks.com>.

Publishing books is expensive. To keep costs down and prices low, we depend entirely on a staff of volunteers. At present, CAVE BOOKS staff consists of Roger McClure, Publisher; Richard Watson, Editor; Paul Steward, Promotions; Pete Lindsley, Web Design; and David Hanson, Sales. Revenue from this effort provides the primary support for many CRF Foundation programs.



Books published by CRF under CAVE BOOKS, (ISBN prefix 0-93978), are listed in Books In Print. CAVE BOOKS is also listed in the standard directories as a publishing house with interests in nonfiction and fiction having to do with caves, karst, and speleology.

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Cave Research Foundation Activities 2002

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Orcenectes in the River Styx, Mammoth Cave, Kentucky
Photo: Rick Olson

2002 Highlights

Annual Meeting

Elizabeth Winkler and Pat Kambesis

On November 8, 2002, the CRF Board of Directors convened the 68th annual meeting of the Cave Research Foundation at the national headquarters at Hamilton Valley, Cave City Kentucky. A reception was held after the meeting for all CRF members and local agency guests.

On the 9th, members participated in the Hamilton Valley Land Management Symposium hosted by Sue Hagan and Mick Sutton. In addition to the symposium, members from all the operations areas participated in survey, science, and photography trips in Mammoth Cave as part of the Eastern Operation project. After the conference and the cave trips, a splendid banquet was held, catered by CRF's own master chef Alan Welhausen.

On the morning of the 10th, a general members' meeting was held. First, the Operation Area managers gave short reports on the activities and accomplishments of their areas:

Dave West, Eastern Operations (EO) detailed the ongoing Mammoth Cave projects which mostly support cartography, but also digital photography, paleontology, and the lesser caves inventory for Mammoth Cave National Park. EO is additionally assisting MCNP with sediment surveys, enhancing their public displays and educational materials, among other projects. EO is also working outside the park with projects in conjunction with Stan Sides and Gary Berdeaux at Diamond Caverns and the ACCA at Hidden River Cave.

Scott House described the activities in the Ozarks Operations Area, in particular, the Buffalo National River and Fitton Cave. Mick Sutton is also working in the Mark Twain National Forest in Missouri doing biological inventory and cave survey. They plan to do a bat census of the endangered Indiana Bat in the caves there. In the state parks they are continuing the survey of Fisher Cave and Devil's Icebox Cave. They are also involved in the training of park personnel.

Barbe Barker reported on Southwest operations. They have been actively involved in restoration projects in Guadalupe, in particular, Carlsbad, Guadalupe Escarpment and Ft. Stanton. The restoration work is quite time intensive. For

example, it took 3 years of continual work to restore the Guadalupe Room which had been severely impacted by tourists from earlier less protection-oriented times. In addition, scientific and geological (mineral) inventory are ongoing projects. The park and CRF personnel were trained for this by Harvey Duchene.

In Ft. Stanton cave there has been a recent big breakthrough which has caused a stop in survey and exploration in that area until the park and CRF negotiate how the research will be carried out. The floor of this area is gypsum and the walls and ceiling are mud. How do you work in this area without impacting the cave negatively? CRF and the park are in the process of writing the proposal to specify how this will be done. CRF assisted in constructing a gate to protect this area (the cave is open to the public via permit).

The Sequoia Kings Canyon Area projects accomplishments were presented by Peter Bosted and Joel Despain. There are two main project areas in Sequoia: Redwood Canyon and Lilburn Cave. Both of these projects are located in exquisite forested areas. Lilburn Cave requires a five mile backpack hike to the field house through the largest redwood forest left. The park service let CRF rebuild a cabin at the site for expeditions. This year, they fielded 50 trips into Lilburn. A number of trips, led by Joel France, were dedicated to restoration projects. John Tinsley also conducted a sediment study in Lilburn.

Forty-five cartography parties worked in Lilburn cave. Lots of virgin passage was identified and mapped. They made a major discovery of over 5500 feet of canyons which they named "Happy Canyon". It's a long linear mazy cave in general with lots of small survey shots. The 2003 CRF Annual Meeting will be hosted by the Sequoia Kings Canyon Area over Veteran's Day Weekend.

CRF Board member Joel Despain talked about the events at Mineral King project which is run by Roger Mortimer. Mineral King is located in a large alpine valley, up in the mountains. The caves are formed in marble rather than limestone. White Chief Cave project passed a mile of survey this year. This is a really real cold cave, about freezing which floods quite a bit, so there is limited formation development. But the passages are fairly roomy and are composed of white polished marble bedrock walls. There are some special challenges to this area as well - in the winter, expedition participants arrive on skis!

In addition to survey, other activities are ongoing as well. For example, Carol Vessey is working with the national park to develop an inventory protocol for caves. Joel Despain, who is a long distance graduate student of Chris Groves at Western Kentucky university is doing his research in the Mineral King area. He is looking at the water chemistry coming out of karst springs which have a high oxygen content. It is speculated that caves may be able to offset the rising carbon dioxide in the atmosphere.

Because Janet Sowers was unable to attend, Rick Toomey elaborated on the projects at Lava Beds Operation Area. CRF people there have been working with the National Park Service to build a research station at Lava Beds. CRF donations include significant quantities of money and in kind donations of the architectural designs. They will be starting very soon on the construction of the building. John Tinsley will be managing the construction. They are also constructing the visitor's center as well at Lava Beds - the hope is to combine the two construction projects to speed things up.

In addition to this major building project, they fielded 31 expeditions - 101 person trips - up from 78 the year before. In addition to survey, they have an ice level monitoring project. In addition, they have been making GPS installations and marking where all the cave locations. They have been performing a general inventory of the park caves and searching for new caves as well. Currently, they are working on a memorandum of agreement with the Modoc National Forest to do cave surveying and monitoring there as well.

Next Pat Kambesis talked about the Hawaii project run by Don Coons and Pat Kambesis. Although Hawaii is not an official operations area, we have an informal agreement with the Hawaii Speleological society to let CRF cavers participate in its surveys. The Hawaii Cave Conservancy is a new group which Don was instrumental in getting that started. Contact Don Coons if you are interested in what is going on.

The meeting finished with a report from Cave Books, now completing 20 years of Operations. Last year Cave Books sold \$44,000 dollars worth of books last year. A great deal of the profits from Cave Books have generously supported the operations of CRF including contributions to the CRF national endowment for science, the production and printing of the annual report, among many other

projects. We also bid goodbye and gave many thanks to outgoing national treasurer Paul Cannaley. He is being succeeded by Roger Smith. Roger announced a new way to donate to the individual CRF Operations areas and to the other funds like the Mike Yocum and Doris and Burnell Ehman Memorial Funds.

For Sunday afternoon, Roger McClure provided free passes to the members to visit Diamond Caverns, and Pat Kambesis arranged for a trip to Hidden River Cave and the ACCA Museum.

Special thanks should be given to Pat Kambesis (Hamilton Valley Director) and Dave West (Eastern Operations Manager) for hosting and organizing this interesting and fun 3 day event.

The following individuals received CRF's Certificate of Merit Award.

From Eastern Operations:

Bill Putnam	(support of the CRF website
Paul Cannaley	(treasurer)
Dave Hanson	(work with HV and Cave Books)
Roger McClure	(HV and Cave Books)
Mark Depoy	(MCNP)
Janet Hubner	(general area support, Tinsley
and Bosted)	
Brian Andrich	(trip report project)
Carter Hayward	(trip report project)
Lois Lyles	(Newsletter support)
Paul Nelson	(Newsletter editor)
Charles Fox	(EO Safety Officer-Computer
	Networkin)
Bob Hoke	(Newsletter)
Rick Nelson	(HV work)

Fort Stanton Area (New Mexico)

Gate Building of Feather Cave and the Gate into Priority 7 Area of Fort Stanton Cave:

Jim Cox	Excellence in Gate design, building and installation
Ed Peyton	Gate building and installation
Cal Currier	Gate building and installation
Rick Reynolds	Gate building and installation
Doug Woods	Gate Installation

The following Bureau of Land Management personnel received Certificates of merit for extraordinary effort in preservation of caves in the Fort Stanton Special Management Area:

Tim Kreager
Paul Happel
Mike Bilbo
Bill Murray
Frank J. Everitt
Stephen Carter

Carlsbad Caverns National Park:

Sherry McClure	Leadership, Database and Personnel Management
Greg McCarty	Consistency in attendance, excellence in survey and team leadership

Kelli Bergthold	Excellence in Restoration techniques
Sara Bergthold	Excellence in Restoration techniques
William Payne	Photographic excellence in restoration and report writing

The following members were elected to Fellowship for their long-term commitment to Cave Research Foundation

Paul Steward
Bob Parrish
John Feil
Janice Tucker
Damian Grindley
Dale Pate

The 2002 Cave Research Foundation Karst Fellowship Competition

Art and Peg Palmer

Each academic year, the Cave Research Foundation (CRF) sponsors a Karst Fellowship competition, which is supported by the CRF Endowment Fund. The Foundation may award as much as \$10,000 distributed among one or more Karst Research Fellowships and as one or more Grants for graduate research in karst-related fields of study. The truly exceptional proposal may receive a Karst Research Fellowship (limit \$3,500.00); meritorious proposals that do not receive a Karst Research Fellowship may receive a Karst Research Grant, typically in amounts less than \$2,000.00, awarded to qualified students in the natural or social sciences. Work at either the Masters or Ph.D. level is eligible for the awards.

The Foundation attaches two conditions to these awards:

- The awardee will prepare a summary or progress report of the research for publication in the CRF Annual Report. If the project is short duration (2 years or less), a single final report is required. Longer projects should provide yearly progress reports.
- The Cave Research Foundation is acknowledged as a supporter of the research in any publications deriving from the research.

The application procedure is as follows. As an applicant for a Karst Research Fellowship you must submit four copies of a proposal describing the study to be supported, one copy each of two letters of reference (one must be from your project supervisor/advisor), and one copy of transcripts of undergraduate and graduate work. The body of the proposal should be no more than ten pages in length and should discuss the problem to be addressed, background, significance of the research, methods to be used, schedule for research, and a budget.

In preparing the proposal it is important to remember several things. Proposals will be reviewed by several karst scientists, who may include geologists, biologists, hydrologists, archaeologists, and scientists from other disciplines. Thus, proposals should be free of jargon and understandable by an interdisciplinary group of reviewers. Also, CRF is more likely to fund research that has broad significance to karst science.

The CRF Science grants for 2002 were handled by Peggy Palmer while Chris Groves was on sabbatical. The awards committee consisted of Ira Sasowsky, Rick Fowler, Tom Poulson and Peggy Palmer. There were quite a few well writ-

ten, convincing applications, so the \$7000 available for the award was split among several people. The following people received awards.

Patricia Kambesis, Western Kentucky University, Bowling Green KY: A systems approach for the understanding of agricultural contaminant sources and transport within a karst groundwater drainage basin (grant award, \$3500). pnkambesis@juno.com

Jennifer Buhay, Brigham Young University, Department of Integrative Biology, Provo UT : Molecular ecology and conservation of troglobitic crayfish in the Genus *Orconectes* (grant award, \$1000). crayfish@email.byu.edu

Karen Samonds, Stony Brook University, Stony Brook, NY: The origin and evolution of extant Malagasy mammals: implications of new Late Pleistocene fossils for reconstructing Madagascar's biogeographic history (grant award, \$500). ksamonds@ic.sunysb.edu

Ann Scott, University of Texas, Austin TX: An archaeological study of ancient Maya pilgrimage at Cueva de Las Pinturas (grant award, \$500). mayacaver@mail.utexas.edu

Heather Jones, Louisiana State University, Baton Rouge, LA: Extending and refining the magnetosusceptibility event cyclostratigraphy (MSEC) record of cave sediments in Europe (grant award, \$500). joneshl21@yahoo.com

Elizabeth Horton, Washington University, St. Louis MO: Investigation of perishable materials found with Fawn Hoof: a desiccated burial in Short Cave, Kentucky (grant award, \$500). ehtorton@artsci.wustl.edu

Holley Moyes, State University of NY, Buffalo, NY: Site formation and ritual use in Chechem Ha Cave, Belize (grant award, \$500). hmoyes@anth.ucsb.edu

Reports from Recipients:

Molecular ecology and conservation of troglobitic crayfish in the Genus *Orconectes*

Jennifer E. Buhay

I collected over 300 tissue samples from cave crayfish, including 126 *Orconectes australis australis*, 23 *O. a. packardii*, 1 *O. pellucidus*, 7 *O. incomptus*, 23 *O. inermis inermis*, 25 *Cambarus jonesi*, and 28 *Cambarus hamulatus*. I am also helping Dr. John Cooper with his *Cambarus tenebrosus* research, so I collected specimens for him from the twilight zone and from deeper in the caves to determine if there's a morphological difference with habitat and light availability. *Cambarus tenebrosus* (a troglophile) is the ancestor species

for the 3 closely related *Orconectes* species: *O. inermis*, *O. pellucidus*, and *O. stygocanei*. I collected approximately 80 tissue samples and 30 whole specimens of *Cambarus tenebrosus*.

DNA extractions are complete for all the cave samples, and I am currently sequencing 16S data for all the samples. I've decided to include two other gene regions (Cytochrome Oxidase I and 12S) for a total of 2500 base pairs for each cave sample. I'm also currently testing out microsatellite primers from other published crayfish research to determine if they are useful for my study.

I am planning a trip for this summer to collect more *O. pellucidus* and *O. inermis*. There is also a species in North-western Alabama currently known as *Procamburus pecki*, only found in 3 caves along the Tennessee River. It is doubtful that it is correctly placed in the genus *Procamburus*, so I will include it in my analysis. All of the cave *Orconectes* are erroneously placed in the genus *Orconectes*. They will be revised into the genus *Cambarus*.

I presented a poster at last year's Evolution society meeting. My collaborators and I presented the preliminary results of our phylogenetic examination of cave *Orconectes*. I will be presenting my cave *Orconectes* research this year at the NSS meeting, with focus on the phylogeography of *Orconectes australis*.

Investigation of Perishable Materials Associated with Fawn Hoof, a Desiccated Burial in Short Cave, Kentucky *Elizabeth Horton*

The focus of my MA research has been the artifact assemblage associated with a desiccated burial discovered in Short Cave, Kentucky. "Fawn Hoof" was discovered by saltpeter miners in 1811 and described by Ebenezer Meriam, a businessman and scientist, in 1813 (Meriam in Bullitt [1845] 1985). The details provided by Meriam provoked a great deal of interest in Fawn Hoof, and she has been discussed in much of the literature, both popular and scientific, concerning the Mammoth Cave region (Bullitt [1845] 1985; George 1990, 1994; Meloy [1968] 1998; Powell 1996; Watson and Meloy 1969; Watson 1997). There has been never a full and detailed analysis of all of the material interred with Fawn Hoof that remain in curation today.

The artifacts associated with Fawn Hoof are curated at the Peabody Museum of Archaeology and Ethnology, Cambridge, Massachusetts, and the Smithsonian Institution, Washington D.C. In June 2002, I aveled to both institutions

to carry out a detailed analysis of those materials. The research emphasis was to complete a detailed attribute analysis of the Fawn Hoof collection using current methods for textile technologies, and to collect samples for fiber analysis and accelerator mass spectrometry (AMS) dating. Additionally, I assessed the reliability of two historical accounts describing the discovery of the burial:

Ebenezer Meriam's 1813 description (in Bullitt [1845] 1985) and F.W. Putnam's (1875) examination of Fawn Hoof for the Boston Society of Natural History. My intent was to determine whether there was support for the proposed interpretation of Fawn Hoof as a medicine woman (Powell 1996).

AMS dates garnered from samples of the textiles curated at the Peabody Museum in Cambridge were instrumental in determining a chronological placement for Fawn Hoof, which as turns out, was significantly earlier than the assumed Mississippian date for her. At approximately 2900 BP, Fawn Hoof's burial was at the cusp of the Terminal Archaic / Early Woodland transition in Kentucky.

My analysis of the artifact assemblage indicated substantial correspondence between the remaining collection and Ebenezer Meriam's 1813 description of the Fawn Hoof burial. In addition identification of some of the materials in the collection was possible and include rattlesnake skin (*Crotalus horridus*), Cooper's Hawk feather's (*Accipiter cooperii*) and beads made of the seeds of either Jack-in-the-pulpit or Green Dragon (*Ariseama* sp.). Integrated with the validity of the artifact rich description provided by Meriam in 1815, which included a bear jaw pendant, and a musical instrument, a whistle, as well as other items, these material identifications indicate that the suggested interpretation of Fawn Hoof as shaman, or medicine woman, is likely.

The research was presented at the 25th annual Kentucky Heritage Council's Archaeological Conference held in Louisville, Kentucky in March of 2003. This paper has also been submitted for publication in the proceedings of the conference.

Chechem Ha Cave Micromorphology Study

Holley Moyes

The purpose of this project is to investigate ritual cave use at the ancient Maya site of Chechem Ha cave located in Western Belize. Its primary focus is to examine the changes and continuities in ritual practice over time by evaluating trampling by analyzing stratigraphic profiles using micromorphology and by assessing the relative degree of usage

in different areas of the cave by quantifying the amount of charcoal present in the sediment strata. A rigorous dating program will be used to place the data within secure time frames. Preliminary results from radiocarbon dating have demonstrated that the cave deposits have considerable time depth. The earliest date, 2780±40 rcybp, calibrates using Calib 4.2 to cal BC 917 with a two-sigma range of cal BC 1004-831 (Beta-170518). With the exception of the Pleistocene levels discovered at Loltun Cave in Yucatan, this is the earliest radiometric evidence of cave use in the Maya Lowlands.

Twenty-six micromorphology samples were collected during the 2002 summer field season. These were resin impregnated and thin sections were cut from these blocks. Preliminary analysis of the thin sections suggests that not only can trampling and charcoal density be evaluated using this method but other unanticipated valuable data are also present. For instance, by comparing the void patterns in trampled areas, it can also be argued that some trampling occurred in wet conditions whereas some occurred in dry conditions. This adds the dimension of seasonality to the data. Additionally, by evaluating the micromorphology some local paleoclimatic reconstruction may be possible. In one sample, a calcium carbonate travertine-like layer is present, which suggests a very wet period in local climatic conditions. Preliminary results from the study demonstrate the utility of micromorphology and illustrate that new techniques allow archaeologists to ask different sets of questions that add new dimensions to archaeological inquiry.

The origin and evolution of extant Malagasy mammals: Implications of new Late Pleistocene fossils for reconstructing Madagascar's biogeographic history

Karen E. Samonds

A newly discovered collection of fossil bats from Madagascar is the focus of my dissertation research. This richly fossiliferous breccia from Anjohibe Cave has been dated at 60,000 years old, more than twice the age of the oldest known Cenozoic vertebrate fossils from Madagascar. The objectives of my dissertation are to prepare the breccia samples, identify and describe the bat fossils, and employ them as a foundation for a cladistic biogeographic analysis addressing how, when, and from where Malagasy bats originated.

The fossil preparation part of this project has advanced considerably, and I have used some of the funds from CRF to buy equipment for acid preparation. The lab is now fully functional, and I have two students assisting me in the lab, learning techniques of both acid preparation and fossil identification. I have also started scoring morphological characters for my cladistic biogeographic analysis, and plan to return to Madagascar this summer to explore Anjohibe Cave.

This research is significant in that it will include the description and analysis of new bat fossils from Madagascar's Cenozoic "fossil gap", including the identification of potential new fossil forms. It is also the first attempt to evaluate the phylogenetic relationships of Malagasy bats. Understanding their relationships, and including new fossil species, will help address broader biogeographic questions. The results of this study, in the context of findings from similar studies focusing on other Malagasy plant and animal groups, will contribute a missing piece of Madagascar's complex evolutionary and biogeographic history.

An archaeological study of ancient Maya pilgrimage at Cueva de Las Pinturas

Ann M. Scott

The Cave Research Foundation provided funding to analyze ceramics recovered from Cueva de las Pinturas, located about 15 km south-southwest of Flores, Peten, Guatemala. A portion of the ceramic assemblage was made available for analysis during the summer of 2002. Using the type-variety method, the analysis recorded data in the following attribute categories including: rim form and diameter, base diameter, vessel form, maximum thickness (rim, base, or body), lip form, and interior and exterior finish and color (using Munsell book). Paste was also examined with a 10x eye loupe recording paste texture and color (using Munsell book), presence of carbon center, and temper color, shape, type, and grain size. The analyzed ceramics were photographed using a digital camera. The majority of the ceramics fell into the Paso Caballos Waxy Wares and consisted mainly of red to orange slipped monochromes (Sierra Red) and white to light brown waxy slipped Flor Cream. Vessel forms included bowls, plates, jars, and a cup. *Tecomate* forms, attributed to the Middle Preclassic Joventud Red were also represented. Eight of the vessels exhibited tetrapod mammiform supports, a possible indicator of an Early Phase of the protoclassic stage. These varied in color from red to red-brown to orange brown and were classified as Aguacate Orange or Gavilan Black-on-orange depending on the surface treatment. A few protoclassic forms also appeared with a Flor Cream waxy slip. Preliminary results of the study suggest that the ceramic assemblage dates from the end of the Middle Preclassic but is most strongly represented by Late Preclassic ceramic wares. The most interesting component is a well represented Early Phase of the Protoclassic.

Contaminant Source and Transports in the Coldwater Cave Karst Groundwater Basin

Patricia Kambesis

Agricultural land use in areas that are located in karst groundwater basins negatively impact groundwater quality because

karst terrains provide multiple, direct hydrologic connections from the surface into karst aquifers. The connections and rapid velocities associated with surface and subsurface flow in karst aquifers allow for contaminants to move quickly into and through a groundwater basin. When groundwater returns to the surface via a spring or springs, any contaminants within the water become part of surface streams and rivers. These in turn, impact water quality in areas located downstream of the spring or springs.

The purpose of this study is to identify the source and movement of agricultural contaminants in a karst groundwater basin within the context of local climate, hydrogeology and land use. The study area is a fluvio-karst groundwater basin located in a portion of northeast Iowa and southeast Minnesota. The land use of the area includes row crop agriculture, livestock operations, and homesteads. A shallow, unconfined karst aquifer is the primary water source for agricultural and livestock needs and also serves as a drinking water source in some areas of the basin. Previous analyses of water quality in the region revealed that both surface streams and groundwater contained high concentrations of nitrates, bacteria, and pesticides. Evaluation of water sampling data showed that temporary degradation of water quality was significant after storm events. Long-term water quality testing documented that agricultural contaminants affected the water quality of local shallow water wells and impacted the drinking water supplies of the town of Decorah, Iowa, located ten km downstream of the study area.

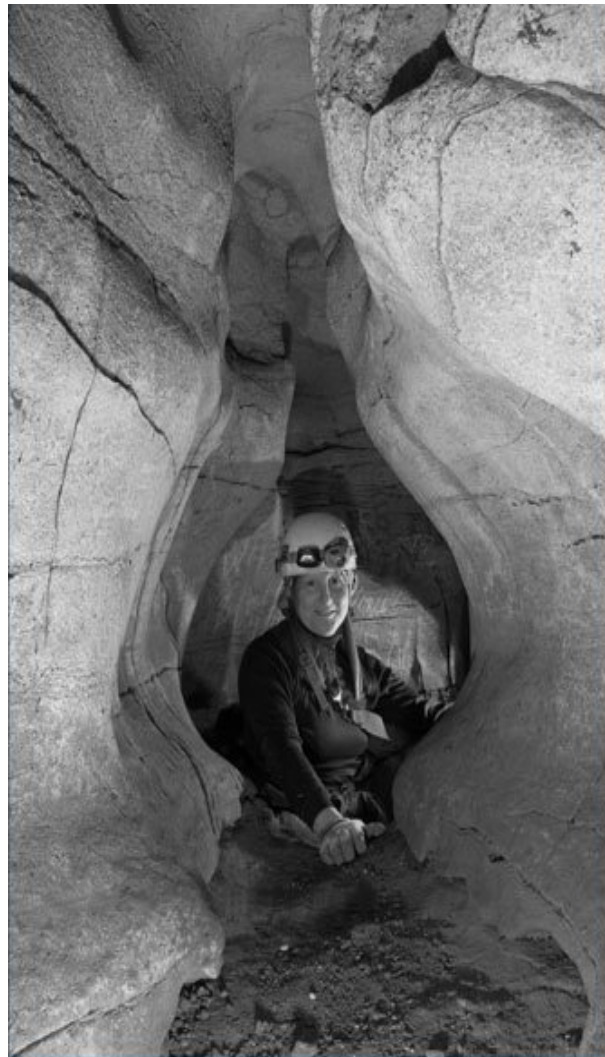
Dye tracing, both qualitative and quantitative, will be used delineate the Coldwater Cave Groundwater basin and determine hydrologic flow paths within the basin. Investigation of basin and aquifer characteristics, and evaluation of cave map data and karst feature inventories will establish the relationship between surface and subsurface hydrogeology. Water sampling and analysis will determine the quality of the surface water and groundwater within the basin. The sources of nitrates, bacteria, and pesticides will be determined by a variety of methods including isotopic analysis, ribotyping, and general water quality testing. Analysis of cave and surface stream temperatures, hydrograph data, and climate records will help determine the relationship between surface climate and cave climate and document the seasonal nature and event-dependence of groundwater flow and agricultural pollution. Land use will be evaluated in order to help determine the potential sources of contamination. It is hoped that the results of this study will identify the sources of agricultural contaminants, and how they are transported within the karst groundwater system.

Extending and refining the magnetosusceptibility event cyclostratigraphy (MSEC) record of cave sediments in Europe

Heather Jones

Variations in the signature of magnetic susceptibility measurements of cave sediment has been shown to be the result of pedogenic processes associated with changes in climate. Deep rock shelters and cave sites are preferentially investi-

gated rather than open-air sites. The sediments acquire their varying MS signatures due to differential weathering processes outside of the cave before the sediment is deposited within the relatively undisturbed cave setting. A major goal of continuing this cave sediment research at archaeological sites is to create a paleoclimate proxy that is at a finer scale than is currently available. The cave that will be studied is Theopetra in central Greece.



Eli Winkler in Keyhole, Diamon Caverns, Kentucky
Photo: Gary Berdeaux

Operation Area Reports

Eastern Operations Accomplishments

Dave West, Eastern Operation Manager

During this period, Eastern Operations fielded 79 parties, expending over 3,422 hours, in support of various projects as follows:

Mammoth Cave National Park (MCNP) Cartography – 63 parties
Small Cave Inventory – 15 parties
Paleontology – 1 party
Saltpetre Inventory – 1 party
Digital Photography – 1 party
Dig on Stan Side's farm – 1 party
Diamond Caverns Survey – 4 parties
Hidden River Survey – 1 party
Hidden River Sediment Sampling – 2 parties

Obviously, many trips supported multiple objectives. Our relationship with the MCNP has continued to improve. Additional backlog copies of archival survey notes have been provided to the park, nearly completing its set of data. Work has continued on bringing the survey data and maps into the park's GIS system. The entire data set has now been entered into Compass.

Much thanks to Don Coons for his tremendous effort in that work. This year Mark DePoy, the Chief of the Science and Resource Management Division, as well as Bruce Powell, the park's new Assistant Superintendent, have joined us on survey trips. Both did very well and made a terrific contribution to their respective trips.

On a sadder note, we were surprised by the sudden passing of Mike Yocum from advanced lung cancer. As a former Area Manager in Eastern Operations, Mike made a terrific contribution in helping shape EO as it transitioned from an overseer of CRF work at Mammoth Cave National Park into a Logistics Operation for any approved Research Proposal within or around the park, whether CRF driven or not. He was instrumental in helping to formulate our current operating agreement with the park, and set up lasting procedures to provide more efficient operation of the group. His work in the realm of GIS was truly groundbreaking as he began the process of integrating CRF survey data and maps into a comprehensive information system. He will be sorely missed.

Ozarks Operation Cave Inventory, Mapping and Management

By Scott House

CRF Ozarks has had a very good year thus far, working on a variety of areas and projects.

Buffalo National River

CRF began coordinating an effort in Fitton Cave back in the early 1980s. A map was produced in 1990 showing much of the surveyed cave. Our major goal at Fitton Cave is to create a new map series that will include all the presently surveyed passages. Protocols and standards for this new series have been worked

out and work is now focusing on correcting errors, resurveying certain errors and adding survey in areas for which we may have an old map but no data. Four expeditions this year have fielded a total of ten survey crews. These crews have put in 7200 feet of survey line. Work is progressing in three areas: the southeast end of Crystal Passage, the Out Room/Roundhouse Room complex, and the Bat Passage near the intersection with the East Passage. Drafting is currently waiting on the resolution of some loop problems in the Bat Passage.

Expeditions have operated out of the NPS facility at Steel Creek.

A new project proposal for the monitoring of temperature changes in Fitton Cave has been tentatively approved and should be well underway in 2003.

Mark Twain National Forest

The Mark Twain National Forest consists of 1.7 million acres of land, mostly in southern Missouri. Work by CRF Ozarks on the Forest has been ongoing since 1986. There are approximately 420 known caves on MTNF land.

In the 1990s most of the CRF Ozarks work was on an area known as the Eleven Point - Doniphan District. However the past few years' field efforts have mostly been in other districts. Several caves were inventoried and surveyed in the Cassville district of southwest Missouri. Several caves remain to be surveyed; one of which we have started but not completed. The concern in this area is with illegal use patterns, including ATV use. Additionally, one cave (Crocker Cave) was inventoried on the Willow Springs District in an area that the Forest Service is trying to obtain.

One trip was taken to caves in the Salem District to assess affects of visitation by ATV riders.

Several trips involved inventorying a cave in the Potosi District that is used by nearby educational groups for trips. CRF also provided training for trip leaders to the cave.

Funding from Mark Twain National Forest supported these efforts.

Ozark National Scenic Riverways

The Ozark National Scenic Riverways consists of approximately 80,000 acres along the Current and Jacks Fork Rivers in southeast Missouri. A long term CRF project here has increased the number of known caves from 80 in 1980 to over 320 today, over 200 of which have also been surveyed. Survey and inventory continue on Riverways lands when time permits. One cave survey was initiated this year and will have to be continued in dryer conditions. Other trips were mostly in the form of volunteer support for cave monitoring, cave restoration, and educational activities.

Mick Sutton and Scott House continue to participate in the OZAR Cave Management Team. Scott House has been employed on a part-time basis by the National Park Service to work on cave management issues.

CRF Ozarks continues to map caves and assemble all data in conjunction with the Riverways. The data is maintained in FileMaker Pro format and is constantly integrated into the state files. An ongoing major effort is the successful integration of data from a five-year NPS archaeological survey of certain caves within the Riverways. New cave locations and improved locations for others have resulted from this effort. This process is not yet finished and will still require additional field trips to verify cave locations. Some of this work is now being done in conjunction with the NPS.

A proposal is in the works for CRF Ozarks to undertake a funded endangered bat census in the Riverways. The Riverways has several caves providing maternity and hibernation roosts for gray bats and hibernation roosts for Indiana bats.

Pioneer Forest

Pioneer Forest is a privately held forest of approximately 180,000 acres in the Lower Ozarks. CRF Ozarks has been involved in survey and inventory of caves (of which there are about 100) located on these lands. In addition, we have been providing services to the forest in the form of data and cave management. Specifically, we have integrated additional data into the database and provided that information to Pioneer Forest.

Missouri Department of Conservation

CRF Ozarks continues to map and help inventory caves owned by the Missouri Department of Conservation, an agency that manages state forest lands and wildlife. We also continue to provide services to the Department in the form of cooperative data management and consultation.

Powder Mill Creek Cave is a large, transitional cave (phreatic passages currently being modified by ground water movement) located in the Lower Ozarks area less than a mile from the Current River. Although within the legislated boundaries of the Ozark Riverways, it is actually owned and managed by the Department of Conservation. The cave is closed except for research purposes and harbors an increasing number of Indiana bats in the winter. CRF has been surveying the cave for the past fifteen years and it is now over eight miles in length. Grueling trips to the end of the survey now take upwards of fifteen hours and involve more than a mile of watercrawl one way. The 2000 feet of survey gained this year required 290 person hours of work or about seven feet per person hour.

Other survey projects that CRF has undertaken on MDC land remain unfinished, specifically surveys of Shop Hollow,

Forester, and Cradle Hollow Cave. Hopefully, we can make some headway on these projects in 2003.

One trip was taken as part of an MDC educational program encouraging women to take part in outdoor activities. CRF provided leadership and guidance for the trip.

Lastly one trip was taken to inventory a small cave in an important hiking trail area that is undergoing considerable use.

Missouri Department of Natural Resources:

Geologic Survey and Resource Assessment Division

CRF Ozarks continues to work with the DNR/DGLS and the Missouri Speleological Survey on cooperative cave files. CRF continues to work with the MSS and DGLS on updating the computer database of state caves. Presently those files exist in FileMaker Pro format where outputs of data can be created in a variety of formats.

State Parks Division

CRF continues its new survey of Fisher Cave, a large show cave in Meramec State Park. Partially surveyed several times previously, Fisher is a well-decorated, historic cave that is shown to visitors by lantern light. Three trips this year so far have netted nearly 800 ft of survey, mostly watercrawl.

Two trips have been taken to the Devils Icebox, a large (seven mile) cave in Rockbridge Memorial State Park, north of the Missouri River. Grants from the Departments of Conservation and Natural Resources are allowing us to establish census areas and protocols for studying the rare pink planarian, a species known only from this site.

Missouri Speleological Survey

The MSS works to collect all cave info in the state. We cooperate fully:

-Maps and reports are turned in to the MSS and are archived by the Missouri Department of Natural Resources.

-Scott House is finishing up a two-year stint as Vice-President of the MSS.

-We are leading the way by facilitating the development of the state cave database.

-From 1996 – 2001, 87 cave maps were repositied with the Missouri Department of Natural Resources - Geologic Survey

and Resource Assessment Division. 71 of those were from CRF Ozarks, a rate of 82%.

United States Geological Survey

We have been cooperating with the USGS on projects involving geologic mapping of lands around the Ozark Riverways.

-Bob Osburn and Scott House are helping develop models of cave and karst development in the Lower Ozarks.

-We are sharing our database information with this project.

-We are mapping some privately owned caves as part of this project.

Personnel and Management

We continue to attract a select group of people. Folks usually start caving with us because they want to do more science-based caving. Ozark cavers are generally very pleased with the level of CRF interaction with agencies and caving groups. The merger of our two operations areas has proved to be beneficial to attracting quality help. Occasional government funding of our various projects and wise investment management by our CRF treasurer has given us the funding stability to perform work that we would otherwise not be able to do. Lastly, our trip report database enables us to better track our many various projects and report on them to our sponsors in a more efficient and accurate manner.

Statistical summary of work:

Trips/parties:	40
People/days:	120
Man/hours in field:	1302
Survey footage:	11,389
Mileage driven:	18,904

At rates of \$12/hour, \$35 per diem for subsistence, and \$0.32/mile our field work alone thus far in the year has a value of over \$25,000. This does not count time driving to expeditions, drafting and management work, data entry, cleaning gear, equipment costs, etc.

Ozarks Operation Area

Operations Manager - Scott House

Assistant Operations Manager - Pete Lindsley

Reporter and Ecologist - Mick Sutton

Geologist - Bob Osburn

Powder Mill Project - Doug Baker

Southwest Operation Guadalupe Escarpment & Fort Stanton Range

Barbe Barker

CRF Southwest has had a very productive year thus far, working on a variety of areas and projects.

Carlsbad Caverns National Park (CCNP)

Five Expeditions were held at CCNP this last year during the usual three and four-day holiday weekends. The breakdown of survey and restoration projects is determined and planned according to the expertise of the group on each expedition. Our relationship with the Park and Cave Resource Office continues to be good. 37 people worked 1,200 hours last year.

Survey has continued in Lower Cave with ongoing projects by the approved sketchers of the Park. We are now checking tie-in and loop closures in order for the Park to complete the cartography of Lower Cave.

Scientific & Geology Inventory has yielded several more trained and qualified people this year due to three classes and in-cave training during the expeditions.

Restoration projects in Lake of the Clouds, The Guadalupe Room, New Mexico Room, The Dome Room, The Rookery and Long Fellow's Bath have kept many people busy and coming back to work on projects.

Fort Stanton Cave

Five expeditions were held during the last year at Fort Stanton Cave. Though the cave is still closed, CRF was allowed to continue expeditions in cave and surface work. Overall efforts include: Geological reconnaissance of surface karst features, resistivity studies, surface survey and measurements, in-cave survey, ridge walking, GPS locations of seven small caves on Bureau of Land Management (BLM) property, digging in Shepherd's Hut Passage, and geological studies in the Main corridor.

Gates of Fort Stanton:

CRF SW paid for a new gate for Feather Cave, which is an archeological site (archaic period). There had been repeated intrusions, and the 1973 gate was not deterring entrance into this known histoplasmosis site. The old gate was removed, and a new one installed over the Fourth of July and

Labor Day weekends. Participants in building this gate included Jim & Ann Cox, Ed Peyton, Cal Currier, and Rick Reynolds. This same crew, with additional help from Frank Everitt and Barbe Barker, completed the installation. According to Tim Kreager, Assistant Field Manager, Resources, BLM, CRF SW contributed the cost benefit equivalent of \$6,968 in material and labor donations to the BLM. The material cost paid for by CRF SW was \$370. 24 CRF members contributed 1,486 volunteer hours to the BLM managed Fort Stanton Range.

After the discovery of the Snowy River Section in Fort Stanton Cave, during the October 2002 CRF Expedition led by John J. Corcoran, III, the cave was closed until that part of the cave could be protected and an Environmental Assessment done. In April 2002, an environmental enclosure was put in place and an assessment of where to place the gate was done by BLM and CRF.

After that determination was made, the same gate building team, aided by 14 CRF and 20 BLM volunteer cavers from NM, TX, CO, NY and Norway, hauled 1200 pounds of cement and 50 gallons of water to the beginning of the dig site during two 8 hour work days in Sept. and Oct. The Priority 7 gate foundation has been poured, and the gate will be built during the winter. Installation of the gate will be in the spring of 2003, when the bats are no longer in hibernation. In the meantime, a gate built by the Cox team and installed with help from the NSS/SWR in 1994 is protecting the cave and its resources.

The Environmental Assessment has not been completed or sent out for public review as of this date. Corcoran, Barker, and Everitt have each had extensive input into the EA as it stands now which will allow for closure of the new section, preserving it for scientific research in a pristine environment while allowing recreational trips to resume in other parts of the cave.

Our relationship with the BLM is good. They continue to look to us for guidance and leadership on most projects. Last year, I met with all of the Resource Specialists in the Roswell Field Office. We worked up Cost/Share Agreements totaling around \$15,000. Unfortunately, due to budget cuts and money being channeled to Afghanistan, they will be put off until the next fiscal year when we will review them.

Summary:

It is enlightening to put a dollar value on the number of hours and days we volunteer. Therefore, using the same equation the BLM used when figuring our contribution to the Feather Cave Gate, I offer the following:

Fort Stanton, BLM

1,486 hrs @ GS-7 equiv. Of \$16.19 p/hr: \$24,058

CCNP-NPS

1,200 hrs. @ GS-7 equiv. Of \$16.19 p/hr: 19,428

Total Volunteer Hour Contribution by CRF SW for this period: \$43,486

FSC, 28 days, 24 volunteers @ \$35. per diem/day = \$23,520

CCNP, 13 days, 37 volunteers @ \$35. per diem/day = 16,835 \$40,355

Approximated Total of Volunteer Value:

\$83,841

CRF SOUTHWEST AREA:

Area Manager – Barbe Barker

CCNP Asst. Manager – Lois Lyles

CCNP Survey Manager – Tim Kohtz

Personnel & Database Manager – Sherry McClure

Fort Stanton Research Manager - John J. Corcoran, III

Fort Stanton Restoration Manager – Frank J. Everitt

Lincoln Co. Manager – Dick Venters

Annual Report of Operations, Sequoia and Kings Canyon National Parks

John Tinsley

The 2002 field year has been a productive one at Sequoia and Kings Canyon National Parks. The year started slowly, with the first four expeditions cancelled owing to inclement weather (in our graying years, we seem not to mess around with Sierran storms). I guess Shakespeare was correct that old age makes cowards of us all. The CRF effort in Redwood Canyon continued on four fronts, cartography (P.I. = Bosted), sedimentology (P.I. = Tinsley), cave restoration (P.I. = Frantz), and hydrology (P.I. = Hess). During the late summer, Jeff Cheraz and Roger Mortimer continued cartographic and resource inventory efforts in Mineral King. Main efforts are to get maps prepared for the National Speleological Society Convention which will convene early next August at Porterville, CA. CRF members will have important roles at the 2003 convention, including leading cave trips, chairing the Convention itself, coordinating one of two geology field trips, and other great things of a logistical nature. Brief reviews of each discipline's activities in 2002 are appended below. I'll expand on these for the CRF Annual Report.

Cartography:

As usual, the cartographic effort mustered by Peter Bosted occupied most of the volunteer hours, with time spent in checking leads off of completed quadrangle maps, and new survey was added grudgingly. Then, late this summer, a large

new discovery mainly east of the trunk passages and sub-parallelizing the Meyer Parallel passage has fully engaged all cartographers for several months, and the efforts continue during low water. Peter Bosted has filed reports on this effort that will appear in the another section of this report. Suffice it to say that more than a mile of new passage has been found, much of it between sumped reaches along the Enchanted River (the subterranean equivalent of Redwood Creek). A recently located connection to the Meyer Parallel passage will allow access to some of the new areas even during high water. Surveyed length of Lilburn Cave is just over 20 miles, I believe, in result of the recent surveys, which occupied 3/4 of the weekends between Labor Day and Columbus Day weekends.

Sedimentology:

The continuing series of mild winters with cool spring season that limits snowmelt rates and ensures sparse runoff has meant that essentially nothing has changed within the cave during the past three years, in terms of sediment plugs migrating here and there along the active water routes. Five sinkholes north of the Meyer entrance have shown renewed activity, but these sites are not located above Lilburn Cave proper, so are not likely to become new entrances to the present cave. They might connect with elements of the "Great

North Cave;" however, they will have a long way to go to be a viable natural entrance. Robison Sink, the modest sinkhole located across the Redwood Canyon Trail in front of the field station, continues to deepen. Big Spring had a nice season of flushing that continued into early July, but the runoff lacked the high peak discharges that really tend to move the dirt around through the cave.

RESTORATION: Bill Frantz continues efforts to rehabilitate the area below the Jefferson Memorial, with two trips to the area. He is preparing a sequence of Before and After photos to illustrate the progress.

Hydrogeology:

Long term monitoring continues via dataloggers installed at Big Spring and in Redwood Creek above the karst area. Parameters logged include temperature, electrical conductivity, stage, and pH. Jack Hess, the P.I., has taken a position as executive director of the Geological Society of America and has relocated to Boulder, Colorado. He has hopes of escaping the clutches of his job to enjoy Redwood Canyon, but we haven't seen him on site as yet this year. Perhaps later this fall, now that GSA is over.

MINERAL KING: Roger Mortimer and Jeff Cheraz continued cartographic and karst inventory work in White Chief Cave, the area's largest single cave system. This cave occurs within a former in-holding that was added to the Park about 3 years ago, when the NPS was able to buy the property from the owner. It is a marvelous example of an alpine cave, and is one in a chain of caves and karst aquifers that extend from House/Cirque Cave in the White Chief cirque to Tufa Spring, about 150 meters above the White Chief-Eagle Lake basin trailhead at Mineral King proper.

Future Happenings:

2003 NSS Convention, Porterville, California

Our research efforts may flag a bit while we prepare to shoulder responsibilities associated with the 2003 NSS Convention, convening at Porterville, California, from August 4 to August 11, 2003. Lilburn is one of the featured caves, and we will be staging a post-convention field expedition, as well as two other overnight trips to the cave, one prior to the convention and one during the middle of convention week. Joel Despain is in charge of cave trips, and has done a superb job of selecting caves for the convention. The Mineral King/White Chief basin caves, owing to their alpine nature, general lack of extensive decorations, and the fact that they are covered by 20-30 ft of snow each winter that then melts and shoots great volumes of water through the caves, will be among the caves offered up for virtually unlimited pounding during the Convention. Of course, to get there, folks will have to drive two hours from Porterville, including another hour along 25 miles of twisty bad road to the trailhead, hike 3-4 miles, then go caving. We call White Chief the local cardiac test run. If you pass that one, then there is Panorama, higher and further south, and then the caves to the north of Mineral King across Timber Gap. Should be truly a fine experience.

Finally, I've agreed to be chairman of the CRF Lava Beds Building Committee, by virtue of my persistent lack of common sense and inability to say "NO!" Actually I am fortunate to have a capable committee behind me, each of whom has recent experience with remodeling on all scales from a single room to an entire house to the Oakland Museum. It is an interesting cadre of advisors.

We have submitted an application for a building permit two days ago and will send out for bids from general contractors this week. May have to wait for spring to pour much concrete, but that will be up to the contractor. Should be able to declare a winner by Thanksgiving, I hope. More on this from Janet Sowers in another section of this report.

Lava Beds Operation Area

Lava Beds Research Center

Janet M. Sowers

The Lava Beds Research Center is finally on its way to realization. The plans have been submitted to Siskiyou County for a building permit, and sets of plans have gone to contractors for bids. John Tinsley has taken on the job of heading up the building committee. He has done an admirable job in seeing the plans through to completion and working with both the architect and the Lava Beds monument staff.

The monument staff has finalized the Environmental Assessment and received NPS approval for the construction, and has completed the site preparation work. If the weather cooperates and the bid process goes smoothly, the contractor may be able to pour the slab before freezing weather sets in. If not, we wait until spring.

Our bank account sits at about \$154,000. We thank all of you who donated so generously, and we especially appreciate the support of the CRF Board.

Field Operations Report CRF Lava Beds

Bill Devereaux

Our project year begins October 1 and ends September 30 of each year. This allows us to make our annual report to the Lava Beds NM (LBE) staff for the Thanksgiving weekend annual meeting. The period also coincides with the weather patterns that dictate our research rhythms.

This report will detail the projects that I am responsible for, as well as detailed numbers from a spreadsheet that I use to keep track of people, projects, and expeditions. This coming year, I hope to expand the sheet back into previous years to quantify our work since 1990. I have expanded the sheet to track people who come here to work, and quantify the number of trips they have been present for. I have numbers for 2000, 2001, and 2002.

The year we call 2002 saw 30 people work on 10 different projects over 31 expeditions while contributing 1383 hours of work in the Monument. There were 101 person/trips compared to 78 the year before. Those hours do not include the hours the people spend getting to and from LBE, drafting maps, working on COMPASS files, building or repairing equipment, writing reports, composing, and responding to e-mails from each other or the LBE staff. Those hours also

do not reflect the hours that Park staff (both permanent and seasonal), SCA's, and volunteers who went on trips with us to support our work. There were also local NSS cavers who gave us materials and assistance.

The success of this project belongs to people who care about this Monument and the caves herein. There were at least two trips that were mainly dedicated to planning for the new Research Center. Bruce Rogers has also acted as an advisor to the Staff on the new Visitor's Center that will be built this coming year.

The projects that I worked on this last year were Ice Level Monitoring, GPS Location and Monument Installation, General Inventory, and Cave Reconnaissance Inventory.

The Ice Level Monitoring project has been going on since the 1970s under the guidance of Mike Sims. I have been helping him since about 1988 when it became a CRF project. I have now taken on the job of Principal Investigator, with Mike assisting me in the final report writing for the year. This last year we made 17 measurements in eight caves during five expeditions. We use a digital thermometer that measures in 1/10ths of a degree. We measure with a fiberglass tape the distance from a stainless steel screw mounted in the cave wall to the surface of the water and to the ice surface in 1/100th of a foot. We record the date, measurements, and a brief remark on quality of the ice, dead critters, or conditions of the room at each measuring station. Between the two Labor Day expeditions, the ice floors in four have declined, whereas the floors in four have risen. Two others are still iceless.

The GPS Location and Monument Installation project has been going on since the fall of 1994. Each cave or 'feature' that is recorded in the files or database receives a LBE number by lava flow and sequential number. The staff marks a brass monument, and then we go install it at the cave entrance. The location is written and drawn on the Reconnaissance Card. The cave monument becomes the site for the GPS location session. We record three different sessions at a point two meters above the brass monument. We use a tripod for the sub-meter antenna that is connected to the Magellan 'rover' unit. We have the base station running simultaneously with the rover unit. The file name on the rover session is labeled one, two, and, three for the cave name. Later, the three files are compared with the base station to get a differential location. The software makes a scatter plot, and a printout is viewed to see if the diagram is tight enough to

make the location within a 1 cm circle. If the answer is yes, then we declare it good. If not, we go back and start over. When the UTM coordinates of the three sessions are accepted, then the Monument staff put the location into the GIS system. One of the new wrinkles in both GIS data gathering and cave mapping here, is to tie the brass monument and the GPS location one meter above it to the published cave map. Many cave maps are dated from the 1930s to last year. They obviously do not have the monument or GPS location on them. We are trying to do that as we go. There is a separate project to work on that correction. This year we did 11 GPS fixes, and installed 35 new monuments. We completed three entire flows.

Cave Reconnaissance Inventory

This project also started long before CRF became a player at Lava Beds NM. What we did in 1988 was define the project, create standards, a card/form, train our people how to use the form, and work with the Monument staff to apply it. Many of the other projects use the 'card' as a starting point for their work. It is the most basic document that must be completed when a cave is found, recorded, studied, or marked. Mike Sims created the project, invented the form, and trained most of in its use. The form is a joint form called LABE, CRF 5/93. The card comes in two forms. The two-sided card is 5"x7". The one-sided version is 8 1/2" x 11". We found that the card version often did not get the flip side filled out. So the single sheet with both card sides on the front meant that all the data got filled in the first time to the cave. The 'short' inventory consists of 19 specific items in four categories that the field researchers look for in the cave during their first visit. They can circle the Yes or No symbol, and make remarks to the side of the entry. They look for bats, pictographs, access problems, formations, ice, etc. The card is a living document. It is filled out in pencil, and is updated

as new information comes to light. This year we made eight new cards, and fixed 68 older ones. The decline between last year and this year in new cards from 40 to 8 is due to the Monument Staff getting more proficient in making good cards for the caves they or we find, and also our reducing the backlog of undocumented caves. This year the Monument Staff had a Cave Specialist and an assistant through the summer. They made many cards and maps that would have otherwise fallen to us to do.

We completed one General Inventory this year. It was actually begun a year ago, but it took a long time to complete, field verify the results, and get it signed and turned in. No report would be complete with credit given to some of the CRF JVs who make the projects happen. Dr. Janet Sowers is the overall PI who makes the projects stay on track and keeps me focused. Fred Douglas, David and Anna Kuhnel have been with me on many of the trips and made my progress possible. Dr. Bill Broekel and his family have stepped forward and taken on a lot of mapping and recon duties this year. He has also begun the process to establish a CRF/USFS MOA with the Modoc National Forest to map the caves on their property, and which lie outside the Monument. Iris Heusler came onboard as Co-PI for the mapping project. One of her chief missions is to eliminate the backlog of maps that are overdue. She has reduced the number from 38 to 28, with more soon to arrive at Lava Beds to be put in the flat drawers. Amy Ponsetti took on the GIS project as a favor to the Park. The ultimate goal is to render 3D data on the old Water's maps for the Interpretation staff to use in the new Visitor Center. Last, but not least, Dr John Tinsley has been essential this summer in getting the Research Center project moving along. He has done this while not coming up to Lava Beds even once. He has attended meetings, made phone calls, and written countless e-mails to Superintendent Dorman and us.

Archeology

CRF Archeological Project Update, 2001-2002

Patty Jo Watson

Research in and near Mammoth Cave National Park

In October of each year, P.J. Watson presented two talks on prehistoric archeology of the Mammoth Cave System and of the information so well preserved there concerning early pre-maize agriculture in Eastern North America. On those occasions and whenever else possible, project members monitor the stand of *Eryngium yuccifolium* (rattlesnake master, button snakeroot) at the south end of Hamilton Valley just below the CRF field station. This plant is receiving increasing attention by archaeologists and archeobotanists concerned with the sources of raw materials for prehistoric textiles (especially footgear) found in Salts Cave, Mammoth Cave, and other dry caves and rockshelters in the Midwest, Midsouth, and Southeast (Gordon 1999).

A pre-MA graduate student at Washington University, Elizabeth Horton, supported in part by a CRF research grant, is investigating perishable materials associated with "Fawn Hoof," a prehistoric individual buried in Short Cave nearly 3000 years ago and found by saltpeter miners in the early 19th century (Horton 2003, Meloy 1968). She and Angela Gordon (Washington University Ph.D. candidate), together with Joan Miller (Miller 1986) and P.J. Watson, visited Short Cave in April 2002 to see the locale from which Fawn Hoof was removed nearly 200 years ago. Our visit was facilitated by Gary Berdeaux and Gordon Smith (of Diamond Caverns and CRF) who introduced us to the management staff at Diamond Caverns Resort and Golf Course, and — together with the Diamond Caverns Resort guides (Georgia and Bill) — accompanied us to the cave. We are grateful to all these people, and to Gary for his excellent digital-camera images of the cave trip. In June of 2002, Elizabeth Horton visited the two institutions who curate the only remains of Fawn Hoof's burial goods that are still extant: the Smithsonian Institution's Museum of Natural History, and the Peabody Museum of Archaeology and Ethnology. She was able to document the relevant accessions in detail, and to obtain two small fragments for radiocarbon dating from cordage fragments at the Peabody.

Also in April 2002, Gordon, Horton, and Miller made careful observations of several whole or nearly whole ancient slippers stored at the Mammoth Cave National Park Curatorial Facility, and at the Western Kentucky University

Kentucky Building museum. We are grateful to Bob Ward (Division of Science and Resource Management at Mammoth Cave National Park), and to Darlene Applegate and Sandy Staebell at Western Kentucky University for making these studies possible.

In October 2002, thanks to the assistance of CRF Expedition Leader Bob Osburn and a mapping crew led by Micaela Evans, a new map of Short Cave was produced in support of Elizabeth Horton's Fawn Hoof study. The map will be an important part of Horton's MA thesis.

Research in Hourglass Cave, Colorado

CRF Archeological Project personnel carried out archeological investigations in this high-altitude cave during the late 1980s and early 1990s (see summary in Mosch and Watson 1996, 1997). During 2001 and 2002, two small samples of charcoal obtained from the findspot of the human remains and from a point some meters beyond the remains, respectively, were submitted for identification prior to radiocarbon dating. Chronological determinations for these two charcoal fragments (aspen and pine, respectively) are listed below, together with the previous dates we had secured from archaeological materials in Hourglass Cave.

Radiocarbon determinations for Hourglass Cave (all are conventional 14C ages b.p.)

University of Arizona-	
AA11808, human bone:	7714 +/- 77
AA11808, 2 nd run, same sample:	7944 +/- 84
Univ. of California, Riverside-	
UCR3494, torch smudge	1560 +/- 340
UCR3495, charcoal	1690 +/- 60
UCR3496, charcoal	1530 +/- 40
UCR3497, torch smudge	3880 +/- 70
Beta Analytic-	
Beta172282, aspen charcoal	7820 +/- 40
Beta172283, pine charcoal	3370 +/- 40
Beta 38554, human bone	8170 +/-100
Beta 81201, charcoal	1960 +/- 80
Beta 81202, charcoal	2310 +/- 50

As the list makes clear, there may have been as many as four prehistoric trips into Hourglass Cave. The first was about 8000 radiocarbon years ago when a ca. 45-year-old man entered the cave and died there some 300 m inside the dark zone. The cave is too wet for the kind of preservation with which we are familiar in Salts Cave and Mammoth Cave, but the bones of the ancient caver were in excellent shape. The later trips were at about 3800 radiocarbon years ago, roughly 2000 r.c.y.bp, and ca. 1500-1600 r.c.y.bp. Other than a thin scatter of charcoal (6 fragments of which we have dated) and at least 155 torch smudges (two of which we have dated), there are no archaeological remains beyond the partial human skeleton to bear witness to these putative prehistoric cave visits. It is also important to note that small bits of charcoal could have been carried along by rivulets of rain or melting snow filtering down through cracks into the cave passage. Hence, the only seemingly undeniable evidence for pre-Columbian human presence in Hourglass Cave is the

human skeleton (three dates) and the two smudges (two dates), which attest to three prehistoric trips: one nearly 8000 radiocarbon years ago, one ca. 3800 r.c.y.bp, and one roughly 1500 r.c.y.bp (this one has a big plus-or-minus factor, however).

References

- Gordon, Angela. 1999. The Salts Cave Slippers: Fiber Identification and Context. Unpublished M.A. Paper, Department of Anthropology, Washington University, St. Louis.
- Horton, Elizabeth. 2003. Investigation of Perishable Materials Associated with Fawn Hoof, a Desiccated Burial from Short Cave, Kentucky. M.A. Thesis, Department of Anthropology, Washington University, St. Louis.
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Biology

Foraging Ecology of The Cave Cricket *Hadenoeus subterraneus*: Effects of Climate, Ontogeny, and Predation

Kurt Lewis Helf

Cave crickets (*Hadenoeus subterraneus*) spend most of their time roosting on cave ceilings but will periodically leave caves throughout the year to forage on the surface. From 1995-2000, I examined the impact of abiotic and biotic factors on a hypothesized sequence of decisions *H. subterraneus* (hereafter, crickets) makes before and during foraging bouts on the surface. I hypothesized winter surface temperatures might reduce and/or preclude foraging bouts for crickets because they are adapted to relatively constant cave temperatures. Indeed, I found a significant negative correlation between temperature and locomotory ability in crickets. Using an electronic device to count when/whether crickets exit a cave to forage, I found significant numbers of exiting crickets were positively correlated with surface temperatures during cold months. However, during warm months, surface temperatures explained little of the variation in numbers of exiting crickets. Thus, surface temperatures in winter, likely the time when crickets' natural food is most scarce, can preclude cricket foraging bouts.

I used experimental food patches to examine the effects of abiotic factors (e.g., precipitation) and biotic factors (e.g., perceived predation risk) on where crickets fed and how much food they consumed. I found significant negative correlations between numbers of crickets feeding at my food patches and average precipitation during the growing season. This suggested annual net primary productivity, as measured by precipitation, reduced availability of crickets' preferred food, and/or their ability to detect preferred natural food patches. In addition, I found significantly greater numbers of crickets used my food patches in winter than in summer; this supported π inference that crickets' natural food is scarce in winter. I found crickets' highly distensible crop, when full, significantly affected jumping ability in large crickets. However, a full crop did not significantly affect small crickets' jumping ability. Thus, I hypothesized that food patch distance from cave entrances would affect large crickets perceived predation risk, and so they would eat less food; juveniles would eat more food with increased patch

distance due to energy constraints. However, I did not find any association between the distance of my food patches from cave entrances and crickets' food intake.

A posteriori, I found season significantly affected crickets' food intake. In summer, a significant interaction between crickets' food intake and the total biomass of crickets feeding at my food patches from my food patches among my three study cave entrances suggested interspecific exploitative competition occurred at Frozen Niagara Cave. Among all three caves in winter, a significant positive correlation between total cricket biomass feeding at my food patches and their food intake suggested crickets' perceived predation risk was reduced with increasing numbers of conspecifics feeding; this may be due to a reduced per capita predation risk or the effect of increasing numbers of foragers being able to better detect predators.

Finally, I found cricket antipredator behavior is likely related in part to the predators frequency, density, and lethality. For example, crickets egg-laying behavior has undoubtedly evolved to reduce predation pressure from a cave adapted beetle (*Neaphaenops tellkampfi*) that specializes on finding and eating its eggs. However, cricket behavior is not affected in any way by the presence of an orb-weaving spider (*Meta ovalis*) that inhabits caves, but rarely catches crickets. In some caves, crickets must run a gauntlet of cave salamanders (*Eurycea lucifuga*) when exiting/entering the cave but this did not seem to affect their food intake. On the surface, crickets' food intake was apparently little affected by potential predation risk from white-footed mice (*Peromyscus leucopus*) even though mouse density increased significantly with proximity to cave entrances. Because at least three communities amongs caves in the South Central Kentucky Karst are subsidized by crickets and their foraging in the local surface habitat around cave entrances likely attracts small predators, crickets may directly affect the dynamics of both surface and subsurface food webs in the Mammoth Cave ecosystem.

Baseline Mapping and Biological Inventory of Caves on the Mark Twain National Forest, Missouri

Michael Sutton

This report covers the period October 1, 2001 through September 30, 2002. Fieldwork during that period took place within the Cassville, Salem-Potosi, Willow Springs and Eleven Point-Doniphan Districts. In the Cassville District, four field trips continued the ongoing effort to assess caves potentially impacted by increasing ORV recreation in and around the Radium Creek and Rock Creek drainages. A total of six caves were visited. In the Salem-Potosi District, one heavily used cave in an area of unauthorized ATV roads was assessed, and two caves on the West Fork Black River near the Sutton Bluff ATV trail system were visited. In the Eleven Point-Doniphan District, there was a single trip to do a follow-up search for a rare, cave-adapted millipede. A bioinventory was begun of Crocker Cave, Howell County which, when its purchase by the Mark Twain National Forest takes place, will be one of the longest caves in the Willow Springs District.

Cave map production has now switched completely to computer-assisted drafting. Fourteen cave maps were completed and are included with this report. Details are given under "Cartography" below. Also included are six cave locator topographic maps.

An updated database in FileMaker of cave fauna collected on the Mark Twain National Forest together with ecological details and the specimen's disposition is appended to this report. Detailed records for each cave visited, including biological summaries, are also appended in a FileMaker database file. Also included in the FileMaker cave file are updated records for caves whose maps have been completed. Results are summarized below for each cave.

CASSVILLE DISTRICT

Barry County

Bear Waller Cave (BRY 093)

Bear Waller Cave was inventoried and mapped on separate trips. The biological survey, conducted at a time of high water with the cave in partial flood, supplements an earlier Gene Gardner survey. The faunal count included several accidental insect species, presumably introduced by the flood waters. The stygobitic amphipod reported by Gardner was not encountered, again possibly as a result of flooding having rendered the water temporarily turbid. The mapping crew completed the cave survey, with a total of about 350 ft. The map draft is in progress.

Fungus Gnat Cave (Number to be assigned)

This small cave in the Radium Hollow drainage was found while en route to Radium Cave. It was mapped, and a biological survey conducted. As the name suggests, the most prominent wildlife were mycetophilid gnats. The cave lacks a dark, constant temperature zone. The cave has not yet been given an MSS catalog number, and the map has not yet been drawn.

Horse Collar Cave (BRY 086)

Horse Collar Cave is in the Williams Creek valley, part of the Rock Creek Drainage. The relatively small (130 ft. long) cave was mapped and inventoried. The cave consists of a single short but wide passage, and contains a good deal of forest-type fauna as well as more cave adapted species such as webworms and pipistrelles. The map has not yet been drawn.

Mushroom Rock Cave (BRY 048)

This relatively small but interesting cave was inventoried. The cave contains a stream inhabited by a rare stygobitic isopod, *Caecidotea dimorpha*, as reported by Gardner. The stygobites appeared to be confined to the farthest accessible reaches of the stream, with the surface isopod *Lirceus* sp. replacing it through most of the cave. The stygobitic amphipod reported by Gardner was not encountered. The cave is remote from ATV roads and receives little visitation. It still needs to be mapped.

Radium Cave (BRY 016)

There was a single mapping trip to begin the survey of this fairly large, complex, and historically interesting cave. A maze of small, low crawlways near the main entrance and leading past one of the artificial pit entrances was completed, and the main passage was surveyed as far as the first deep pool. Several wet-suit trips will be required to complete this survey. Details of the mining history of the cave were obtained from historian Dwight Weaver, and his preliminary history of the cave is included with the appended cave report.

Twin Cave (BRY 053)

This small stream cave is a close neighbor to Bear Waller Cave and of a similar nature. It too was inventoried and mapped on separate trips. Although shallow, it contains the relatively rare troglobitic millipede "*Scoterpes*" *dendropus*. The accessible section of stream is short, and no aquatic fauna were found. The mapping crew completed the survey (about 110 ft.); the map has not yet been drawn.

ELEVEN POINT-DONIPHAN DISTRICT

Carter County:

Upper Camp Yarn Cave (CTR 003)

There was a follow-up biology trip to collect additional specimens of the very rare troglobitic millipede (*Chaetaspis* sp.) encountered previously. The three specimens collected were all female, resulting in no taxonomic advance. The population will be allowed to recover before a further attempt is made to obtain a mature male.

SALEM-POTOSI DISTRICT

Reynolds County:

West Fork Caves 1 and 2 (REY 019, REY 020)

The neighboring West Fork (Black River) Caves were inventoried. Unusual fauna in both caves included numbers of jumping bristletails (*Petrobius* sp.). Also present were large numbers of alien millipedes and pill-bugs. The West Fork 2 cave stream is inhabited by stygobitic isopods, but the specimens collected were both female, resulting in no specific identification. Although the caves are within an area of heavy legal and illegal ATV use and are shown on the USGS topographic map, they are fairly difficult of access and appear to be seldom visited.

Washington County:

Estes Cave (WSH 035)

This cave was visited incidentally as part of an educational effort in collaboration with YMCA of the Ozarks at Trout Lodge, but after ascertaining that it was on the Mark Twain National Forest, a follow-up biological inventory was arranged. The cave is about 650 ft. long and includes an intermittent stream populated with stygobitic isopods. Among unusual fauna were diving beetles of a genus not previously recorded in Missouri caves. Another interesting result was the collection of an adult webworm fly from a dark-zone setting. Although webworms are common in Missouri caves, the adult fungus gnat appears to have been collected only once before in the State.

The cave is readily visible and accessible from a dense network of (apparently illicit) ATV roads, and as a result is undergoing intensive visitation with some vandalism. There are indications that stream ecology may be suffering from heavy trampling in the more accessible parts of the cave.

WILLOW SPRINGS DISTRICT

Howell County:

Crocker Cave (HWL 037)

Although the cave entrance and 80% of the passages are on private lands, the property is being acquired by the US Forest Service.

There was a biological inventory trip to this lengthy stream cave, examining the outer sections as far as the first main stream passage. The population of stygobitic isopods in this stream was exceptionally dense, suggesting a relatively high-nutrient environment. Stygobitic amphipods occur in the entrance area pools. Large numbers of cave salamanders occurred in twilight, suggesting the possibility that the cave is a breeding site for the species. Numerous bear beds were found, complimenting the earlier observation of a black bear skeleton in a deep cave site. Pipistrelle numbers were surprisingly high for summer, and a few patches of concentrated bat guano suggest occasional use by small numbers of colonial bats.

CARTOGRAPHY

Cave maps completed during this period were drawn using Adobe Illustrator software. Print-outs of map sheets together with a CD of the maps in .jpg format are included with this report. Larger caves with stream passages were drawn in two versions, one with standard cave symbols, and the other with color representing certain floor features (sediments, pools, streams). The following cave maps were completed:

AVADISTRICT

Christian County:

Camp Ridge (CHR172);

Camp Spring (CHR207)

CASSVILLE DISTRICT

Barry County:

Currey (BRY087) 2 sheets, one showing underlying passage;

Twilight Joint (BRY080);

Panther (BRY008);

Salamander (BRY079);

DONIPHAN-ELEVEN POINT DISTRICT

Carter County:

Mosquito (CTR032) 2 sheets, one in color;
Tucker Bluff (CTR073);
Tucker Spring (CTR074);
Turley (CTR033) 2 sheets, one in color. Each sheet is in a 4-page mosaic; a printout on one large page will be provided as it becomes available.

Oregon County:

Beaver Spring (ORE046) 2 sheets, one in color;
Long Point (OR125);
Muddy (ORE047);
Prickerbush (ORE048)

Maps still to be completed include: Pole Cave in Christian County; Bear Waller Chimney Rock, Fungus Gnat, Horse Collar, Twin, and White Oak Onyx Caves, all in Barry County.

Another innovation during this period has been the production of cave locator maps, based on software topographic maps for Missouri. The locator maps show cave locations together with the route(s) used by survey crews to access the cave. Vehicular access routes are shown in

blue, parking places are marked with "P", and hiked routes are shown in red. Six locator maps are appended to this report, showing the locations of all caves visited during this period.

Appendix: WILDLIFE RECORD UPDATES.

Taxonomic revisions

The following recent taxonomic revisions apply to previously reported results.

The bats ascribed to *Myotis keeni* in the Phase 1 report are now considered to be long-eared bats, *M. septentrionalis* since the previous eastern subspecies, *M. keeni septentrionalis* has been elevated to species level (Van Zyll de Jong 1979, 1985).

Missouri populations of the *Plethodon glutinosus* complex (slimy salamander) are now assigned to *P. albagula* Grobman.

The gastropod family Zonitidae is revised to Vitrinidae Fitzinger 1833, following Burch and Pearce, 1990.

The bristletail family Malichiidae, previously reported in the order Thysanura is now considered to belong to the Microcoryphia.

Cartography

Redwood Canyon Cartography Summary for 2002

Peter Bosted

Tremendous progress was made during the year 2002. A total of 40 survey trips took place in Lilburn Cave, spread over 12 expeditions. These netted 8108 feet of new survey using 920 stations, and 573 feet of replacement survey using 63 stations. This is the most new survey in a single year since the CRF project began in 1980. The average survey shot length of 8.8 feet shows that many of the new passages are reasonably large for a California cave. The official length of Lilburn is now 20.01 miles (32.30 km). The 30 km mark was passed early in the season, with the last few shots of the last survey trip passing the 20-mile mark.

No trips were made to the other caves in Redwood Canyon this year. Efforts in the first half of the caving season (May through July) concentrated on mopping up leads in many parts of the caves. Six survey trips were made to the Attic and Attic-Attic, where newly updated quadrangle maps showed a plethora of small question marks. While most turned out to be too tight, several led to significant extensions. This is one of the most complex areas in this 3D maze cave, and a lot of effort was spent trying to figure out how the various levels connect with each other. Malachite and azurite were found at two new locations.

Three trips to the Angels Perch were made to fix bad loops and check leads. One possibility remains for small cavers. Several trips to areas quite close to the Lilburn Entrance revealed passages overlooked by the early surveys. It was found that one of the largest passage segments in the entire cave (15 feet wide and about 100 feet tall) had accidentally been left off the map! Several passages in the Canopy area were re-surveyed to fix loops closures and improve sketches. This led to the discovery of several hundred feet of previously unknown passages, which connected to a question mark at the top of a dome (saving the trouble of a future aid climb). A new section of cave was found in a blank part of the map by dropping down to an intermediate level in DuChene Pit. A couple of long trips to the remote Outback area (the big discovery of 2001) mopped up most remaining leads, although some intriguing dig possibilities remain. One trip down River Pit mopped up two leads, only to reveal several more for next year.

The big breakthrough came on August 30, when it was finally dry enough to go back to last year's Enchanted River leads. Just upstream of the sump, a difficult 35-foot climb was made up to a small hole near the ceiling. A nice walking

canyon was quickly found, and a permanent rope was set from a more convenient ledge. A hastily-organized mini-expedition the following weekend revealed the area to be extensive, and another five mini-expeditions were quickly added to the regularly scheduled Columbus Day expedition.

Altogether, there were fifteen survey trips to the new area, and almost a mile of new survey was accumulated. Survey totals ranged from 150 to almost 1000 feet per trip, in relatively large passage, for California. The first section was called Happy World. After the map began to reveal that much of the lower level was a series of tall, narrow canyons with sandy floors, it was decided to dub the entire area Canyonlands. A large section of river passage was found that provided the missing link between the downstream sump of the Enchanted River and the upstream sump of River Pit. This newly found section of Redwood Creek was called Echo River, for the tremendous echoes in the beautiful, clean washed passage with the alternating black and white banding that Lilburn is famous for. An upper level was also found, named Area of Low Hanging Fruit (LHF). This area is much muddier, and is noted for a large room (30 feet wide by 100 feet long) and a very confusing maze of canyons, crawlways, and interesting climbs.

The most remote part of LHF (a three hour trip from the entrance) comes within ten feet of known passage in the 2 by 2 complex (only ten minutes from the entrance), but a connection proved elusive. Several new deposits of malachite were found near Happy World. Because the Enchanted River is only dry enough to get to Canyonlands a few months per season (and then only in dry years), a significant effort was made to find an alternate route. By having teams in both Happy World and the Meyer Parallel, several possibilities were identified, and eventually an obscure route was opened up through a boulder choke.

Although most of the obvious leads in Canyonlands have been pushed, several small question marks remain, and strong air movement can be felt at several boulder chokes that might lead to more discoveries next year. Most of the cartography effort this year was focused on drawing up the new discoveries as they took place. Canyonlands has generated another two quadrangles, bringing the total to 84. About 90% of the quadrangles are currently up to date.

Geoscience

Records of Climate Change in Central North America From δD variations in speleothem fluid inclusions

Feride Serefiddin¹, Henry P. Schwarcz, Derek C. Ford, and Homer Seywerd

Introduction

The interpretation of oxygen and carbon isotopic variations in speleothems remains rather problematic because local and regional environmental conditions can alter the global climate signal (Linge et al. 2001, Serefiddin et al. 2002). The ratio of stable isotopes of hydrogen (δD) of fluid inclusions in speleothem calcite can be used to investigate changes in precipitation and calculate paleotemperatures as an additional proxy to refine climate models. The isotope geochemistry of speleothems from Reed's Cave, in the Black Hills of South Dakota will be used as a proxy for climate change in this region. Modern dripwater and Holocene fluid inclusion samples will be compared to the speleothem records from the Wisconsin glacial period. A high resolution record of temperature change for the Black Hills of South Dakota will give insight on the extent of cooling in the mid-continent during the glacial period.

Paleotemperature reconstructions using fluid inclusions

When calcite forms in oxygen isotopic equilibrium with water, we can calculate the temperature of formation from the isotopic fractionation, a_{c-w} , between calcite and water, where $a_{c-w} = (^{18}O/^{16}O)_{calcite}/(^{18}O/^{16}O)_{water}$. The calculation of paleotemperatures using the O'Neil *et al.* (1969) calcite-water fractionation equation

$$1000 \ln a_{c-w} = 2.78 \times 10^{-6} \times T^{-2} - 2.8 \quad (1)$$

requires knowledge of the $\delta^{18}O$ of the drip water from which the speleothem was precipitated. We assume that this is equal to the initial $d^{18}O$ of fluid inclusions trapped in the speleothem. Although these fluid inclusions can be analyzed for both $\delta^{18}O$ and δD , $\delta^{18}O$ is not used because the isotopes of the calcite and the water may have exchanged following deposition of the speleothem. Instead, we calculate the initial $d^{18}O$ value of the trapped water from its measured δD , using the appropriate meteoric water line for the period in which the sample grew.

Methods

The speleothems were dated using uranium-series disequilibrium dating techniques (Schwarcz 1986, Dorale 2000). Crushed or powdered calcite samples ranging from 200 mg for multi-collector inductive coupled plasma mass spectrometry (MC-ICPMS) analysis to 2 g for thermal ionization mass spectrometry (TIMS) were prepared by anion exchange chemistry in the McMaster clean laboratory, with the addition of a $^{229}Th/^{236}U$ spike calibrate by J. Lundberg, Carleton University. The extracted uranium and thorium components are run by single and double filament technique on a VG 354 TIMS at McMaster or on the VG MC-ICPMS at GEOTOP in Montreal. For thermal ionization mass spectrometry (TIMS), uranium and thorium are loaded on rhenium and tantalum filaments and analyzed in a VG354 mass spectrometer; the ratios of $^{234}U/^{238}U$ and $^{230}Th/^{234}U$ are used to determine the age. The precision of measurements averages 1%. For analysis of U and Th by MC-ICPMS, the elements are introduced into the instrument dissolved in 1% nitric acid. The advantage of MC/ICP-MS is faster throughput and higher precision (< 0.5%).

The extraction of fluid inclusions employs equipment developed at the University of East Anglia Isotope Lab (Dennis et al. 2001). The crushing cell consists of the crushing chamber and a piston that is moved using an electromagnet. The base and tower of the cell are fitted with heaters for the removal of water before the sample is crushed to remove any atmospheric water vapor that may be present.

Slices of calcite were taken along growth layers with a maximum thickness of 5mm using a low speed Isomet diamond wafer saw. At least two samples were cut from each growth layer for repeat analyses. A portion of the slice weighing approximately 500 - 1000 milligrams is loaded into the cell and evacuated to a high vacuum. After the sample had been evacuated and heated at 100 °C for 15 minutes, it was gently crushed for 15 minutes by repetitive motion of the piston. During this time the crushing cell was closed off from the high vacuum pumps and opened to the U-trap. A dewar of

liquid nitrogen was placed under the U-trap to collect the water and CO_2 released during crushing. After crushing, the cell was heated to 150°C under vacuum to remove all adsorbed water. After heating is complete the U-trap temperature is increased to -120°C to release any CO_2 which is pumped away. The cold trap is then warmed to room temperature and water is trapped in a Pyrex tube together with 50 mg of zinc shavings ("Indiana Zn"). The water is later reduced by reaction with zinc at 500°C for 1 h and the hydrogen gas is analyzed on a SIRA II mass spectrometer against H_2 from a laboratory standard (DTAP). The absolute δD values are calculated using the VSMOW and VSLAP reference waters for calibration. The precision of measurements of the standard is 0.11 ‰. A portion of the crushed calcite was reserved for analysis of $\delta^{18}\text{O}_{\text{ct}}$.

The volume of water in each calcite sample was estimated from the intensity of the major beam (^2H signal). Capillaries containing known masses of water were used to create a calibration curve. Samples that gave an intensity of less than 5.0×10^{-5} indicated less than 0.5 ml of water; these data were not used because they were most likely fractionated during extraction (Dennis et al. 2001).

Samples

Samples were prepared for fluid inclusion analysis to evaluate δD and temperature variability during the Wisconsin glacial period from Reed's Cave, South Dakota. In an attempt to produce high resolution records, sample size was reduced to ~1 g or less. Speleothems 99902 (RC2) and 20000 (RC20) are two samples from Reed's Cave, South Dakota that partly grew at the same time, from 62 to 49 ka BP. These speleothems have partly divergent $\delta^{18}\text{O}_{\text{ct}}$ records but each appears to be recording climate, (Serefidin 2002). The analysis of the δD and paleotemperature calculations can test whether similar temperatures are being recorded by these two speleothems. Time resolution for each measurement ranges from 200 years during fast growth to 6300 years during slow growth for sample 99902. The faster growing speleothem 20000 has a time resolution ranging from 50 years to 690 years.

Results:

Tests of the procedure

Calibration of the crushing cell and vacuum line was done by measurements of DTAP standard water in glass capillaries alone and with Iceland spar following the procedure of Dennis et al. (2001). The reproducibility of samples was tested by analyzing replicates of the laboratory standard water, DTAP, in capillaries, together with 500 to 1000 mg pieces of

Iceland Spar (MEXIS). Fourteen MEXIS samples were prepared but 3 samples produced transducer readings that indicated they were fractionated during transfer due to incomplete recovery or desorption. The 11 remaining samples gave an average δD value of $-61 \pm 9\text{‰}$ with a range of -49 to -77‰ . The difference from the mean ranges from 2‰ to 14‰. The average δD agrees with δD value for DTAP (laboratory standard) of $-58 \pm 4\text{‰}$. The slightly depleted average value of $-61 \pm 9\text{‰}$ may result from fractionation effects from incomplete desorption of water from the calcite powder.

As another test of reproducibility of the method, sixteen growth layers of speleothems from Reed's Cave were analyzed in replicate, by analysis of slices taken as close as possible to the same level in the stalagmite. From the eleven layers which had sufficient water for isotopic analyses, four of these results agreed within the typical analytical error of 3 ‰. Groups of replicates are identified in the tables by color. Sample codes begin with the abbreviation for the speleothem (RC2 for sample 99902 and RC20 for sample 20000) and followed by an identification number for the layer number or height from base. Overall, the difference between replicate analyses ranges from 1 to 27 ‰. Two possible reasons for this are: a) incomplete recovery of water, resulting in isotopic fractionation; b) non-equivalence of the supposed replicates such that different growth periods are being averaged. Samples taken near the outer perimeter of the stalagmite may contain thousands more years of growth than a sample from the main growth axis. Results from adjacent growth layers show average differences which is comparable to estimate of reproducibility from analyses of crushed capillaries of water of less than 10‰.

To determine if leaks of atmospheric water vapor would contaminate samples, we attempted to collect water from the line without bringing the crushing cell and pyrex line down to vacuum. Three attempts failed to result in a measurable amount of water. We conclude that any small leaks had no effect on the isotopic values of collected water.

δD analyses can be offset if the proper zinc:water ratio is not used: the recommended ratio is of 50 mg Zn to 1 mL of water. We assume that the maximum water content of the speleothem is 0.1 wt %, and with a yield close to 100%, the sample sizes averaging 500 mg to 1 g will give us extracted water volumes from 0.5 to 1.0 mL. We ran capillaries filled with 0.5 mL and 1.0 mL of DTAP water with 40 mg, 50 mg and 60 mg of zinc. These quantities gave reproducible and accurate results using standards of DTAP as small as 0.5 ml in capillaries with Iceland spar.

Analyses of speleothems

Sample weights ranged from 0.27 to 1.48 g. The number and volume of fluid inclusions varied between the growth layers so the wt % of water varied somewhat with sample size. The results of δD analyses for the crushed calcite samples includes only the samples that were large enough to run on the mass spectrometer. Typically, samples less than 0.5 ml in size were too small for isotopic analysis. Of the 78 samples that were crushed and transferred to the zinc tubes, only 62 had enough water to collect δD data.

Reed's Cave, South Dakota

Cave dripwaters were sampled to determine spatial variation throughout the cave and whether there was a distinct seasonal signal in the isotopic composition of these waters. Results from oxygen and hydrogen analyses show a variation of up to 36‰ in the δD values and 5‰ in the $\delta^{18}O$ for drips. This seasonal variation is well within the range expected for mid-continental precipitation (Rozanski et al. 1993). The range from -75 to -117‰ generally agrees with range of -70 to -102‰ (estimated from GNIP maps) of modern precipitation in this area, with cave drips slightly more depleted than the minimum of ~-102‰ for precipitation. The more 2H enriched waters in the range from -81‰ to -90‰ are found in samples that were collected from cave popcorn, an evaporative speleothem feature. These areas of the cave likely have less than 100 % humidity, which makes the waters unsuitable for study of equilibrium deposits. The modern drip water samples collected from the location of Wisconsin age speleothem samples 99902 and 20000 have a range of δD from -97 to -117‰ and $d^{18}O$ of -10.3 to -15.3‰ and falls slightly below the global meteoric water line (MWL). The local MWL calculated from drip water at the sample sites in the cave is $\delta D = 8.0 d^{18}O + 6.7$. This is within the expected range for mid-continental site in North America.

Forty-five samples from the two speleothems were crushed. Of these, 34 gave δD values, while 11 failed due to insufficient quantities of water. The average δD for the 34 samples is -97 ± 4 ‰ with a minimum value of -150‰ and a maximum value of -35‰. $\delta^{18}O$ values were calculated using the modern MWL and a hypothetical glacial age MWL with $\delta_0 = 0$. Five samples with volumes less than 0.5 mL may have been fractionated during transfer of water from crushing cell to the zinc-filled pyrex tube.

Variation in δD

The δD results clearly show that extraction and measurement of fluid inclusion water is very difficult. Preliminary results give some reproducible data and result in calculated temperature shifts that can be correlated with other proxy records. Analysis of small samples may also lead to unaccountable errors in δD values.

Atmospheric circulation patterns control relative contributions of moisture sources of different isotopic signatures to different regions (Charles et al. 1994, Nativ and Riggio 1990). The isotopic compositions of storm tracks in the Black Hills are determined by the relative contribution of Pacific and Gulf of Mexico air masses; the position of these air masses differs seasonally as well over long-term periods. There appears to be a good connection between the trajectory of these air masses and the isotopic composition of precipitation. Measured δD values from fluid inclusions can give information on how the position of these air masses may have been different in the late Pleistocene although it may be difficult to distinguish these from temperature effects. The seasonal bias in the isotopic composition of recharge feeding different drip sites is likely controlled by some combination of both variables. More depleted values of δD may indicate a dominance of more depleted air masses as well as lower temperatures.

The δD values for the Reed's Cave speleothems show a range of values less than the estimated range for seasonal variation in $\delta^{18}O_{ppt}$. The average δD value for sample 20000 is consistently lower than for sample 99902, even during coeval periods of growth. A previous paper (Serefidin et al., submitted) showed a similar difference in average $\delta^{18}O_{ct}$ values for these two samples and attributed this difference to seasonality of recharge of drip waters. Sample 20000 was likely formed from drips biased to winter precipitation. This also explains the lower δD values. The range of δD values for sample 20000 is -65 to -150‰, more depleted than range of δD for sample 99902 of -40 to -129‰. There appears to be a slight enrichment of 10‰ in sample 20000 between 59 and 55 ka BP. This could indicate a short-term increase in the influence of Gulf of Mexico storm tracks. There is a similar enrichment of δD values in sample 99902 beginning at about 57 ka BP. The $\delta^{18}O_{ct}$ and δD values for these two speleothems agree at this point as well, which would explain the similar calculated temperatures. There is also evidence of warming in the $\delta^{13}C$ record at Crevice Cave in Missouri at this time (Dorale et al. 1998). The chronology for the change in 99902 is less certain due to weaker age control and lower resolution resulting from extremely slow growth rates over this interval.

Paleotemperatures

Temperatures were calculated using the estimated $\delta^{18}\text{O}$ of fluid inclusions ($\delta^{18}\text{O}_{\text{fi}}$) and measured $\delta^{18}\text{O}_{\text{ct}}$ from the powders collected after crushing. The range of temperatures calculated for Reed's Cave use the modern MWL and estimated glacial age MWL relationship (Harmon and Schwarcz 1981). Temperatures are calculated for Reed's Cave with $\delta_0 = 0$ (glacial age estimate) and $\delta_0 = 6.7$ (modern). Temperatures that are less than zero and greater than modern are assumed incorrect. It is unlikely that samples in the glacial and cooler MIS 3 interglacial are greater than modern temperatures. The range of acceptable temperatures is 0 to 8 °C using the modern MWL and 1 to 11 °C using the glacial age MWL.

We expected all temperatures from Reed's Cave samples 99902 and 20000 to be lower than the modern value of 10 °C. Temperatures higher than modern or below zero may be due to fractionation as a result of incomplete water recovery. Incomplete recovery of water gave both positive and negative offsets in replicate samples. Samples with very low yields, usually less than 0.5 ml, also gave negative offset of up to 40 % in analysis of capillary + Iceland spar. This would lead to lower apparent temperatures of deposition.

As noted above, the $\delta^{18}\text{O}_{\text{ct}}$ records from the coeval period of growth in samples 99902 and 20000 show an offset in average $\delta^{18}\text{O}_{\text{ct}}$ and difference in magnitude of isotopic variation. In a previous paper (Serefiddin et al., submitted) we show how differences in seasonality and flow-paths of recharge can cause such differences.

Minor evaporative effects can also cause an enrichment in record with respect to the other, but because the deposits were formed in equilibrium (as proved by Hendy test), it is unlikely that evaporative/kinetic fractionation has occurred. Paleotemperatures for these records give similar values and similar direction of change (Figure 1).

Temperatures were calculated using both the global MWL relationship and the modified glacial age MWL. The coeval part of the record shows a similar change in temperature, but the magnitude of increase is higher for sample 20000 (Figure 1). We observe a temperature increase of 7 °C in sample 99902 and 8 °C in sample 20000 from 62 to 57 ka BP (Figure 1). After 57 ka BP temperatures decrease by 8 °C at ~ 54 ka BP. The agreement in magnitude of temperature shift in the two coeval deposits is in striking contrast to the difference in their $\delta^{18}\text{O}_{\text{ct}}$ records. The magnitude of this temperature shift may, however, be somewhat exaggerated. For comparison, however, Anderson et al. (2000) observed cooling of up to 10 °C in the Colorado Plateau at the LGM, suggesting that

temperature shifts of this magnitude may have occurred during the last glacial cycle.

Conclusions

Variations in δD values over time as preserved in speleothem fluid inclusions are powerful recorders of past air mass composition and position and possibly of climate change. Late Pleistocene deposits from Reed's Cave, South Dakota show consistent depletion in ^2H in fluid inclusion waters. This is evidence of cooler temperatures and increased precipitation that may be due to changes in atmospheric circulation from ice sheet fluctuations or global ocean temperature gradients. Maximum δD values and a possible corresponding temperature increase in both Reed's Cave speleothems is seen at 57 ka BP. A trough in δD values at 54 ka BP correlates with a cooling event in the Mediterranean and in the Devil's Hole calcite record (Bar-Matthews et al. 1999, Winograd et al. 1997). Although the δD records from Reed's Cave appear to be recording some component of global climate change, it is more useful to apply them towards understanding local or regional climate. Higher resolution records will be developed following more sample analyses and may give better insight into local climates.

We have analyzed two coeval stalagmites from Reed's Cave whose $\delta^{18}\text{O}_{\text{ct}}$ values differed by up to 3 ‰. If they had been deposited from water of identical isotopic composition, this would have implied a difference of at least 12 °C between their temperature of deposition, even though they were formed only a few meters apart in the same chamber. The analysis of fluid inclusions from these two deposits confirms there was a corresponding difference in hydrogen isotopic composition of drip waters feeding these deposits, which we assume to have been correlated to corresponding differences in $\delta^{18}\text{O}$, and which was the reason for the difference in $\delta^{18}\text{O}_{\text{ct}}$ between the samples.

There is evidence from the paleotemperature calculations that there were variations in the local relationship between $\delta^{18}\text{O}$ and δD (meteoric water line) during the late Pleistocene. Subzero temperatures and extreme magnitude of temperature change are calculated using the modern MWL for the Reed's Cave samples; these can only be resolved if the local MWL was changing throughout the period of these records. It may not be reasonable to use a constant MWL relationship for all fluid inclusion samples in the Pleistocene. Assumptions about past MWL relationships must be made to calculate $\delta^{18}\text{O}$ values for included waters until the $\delta^{18}\text{O}$ of waters can be measured directly.

We have also assumed that δD values are preserved over time and it remains a faithful record of δD of paleoprecipitation. Unless alternative proxy records for absolute

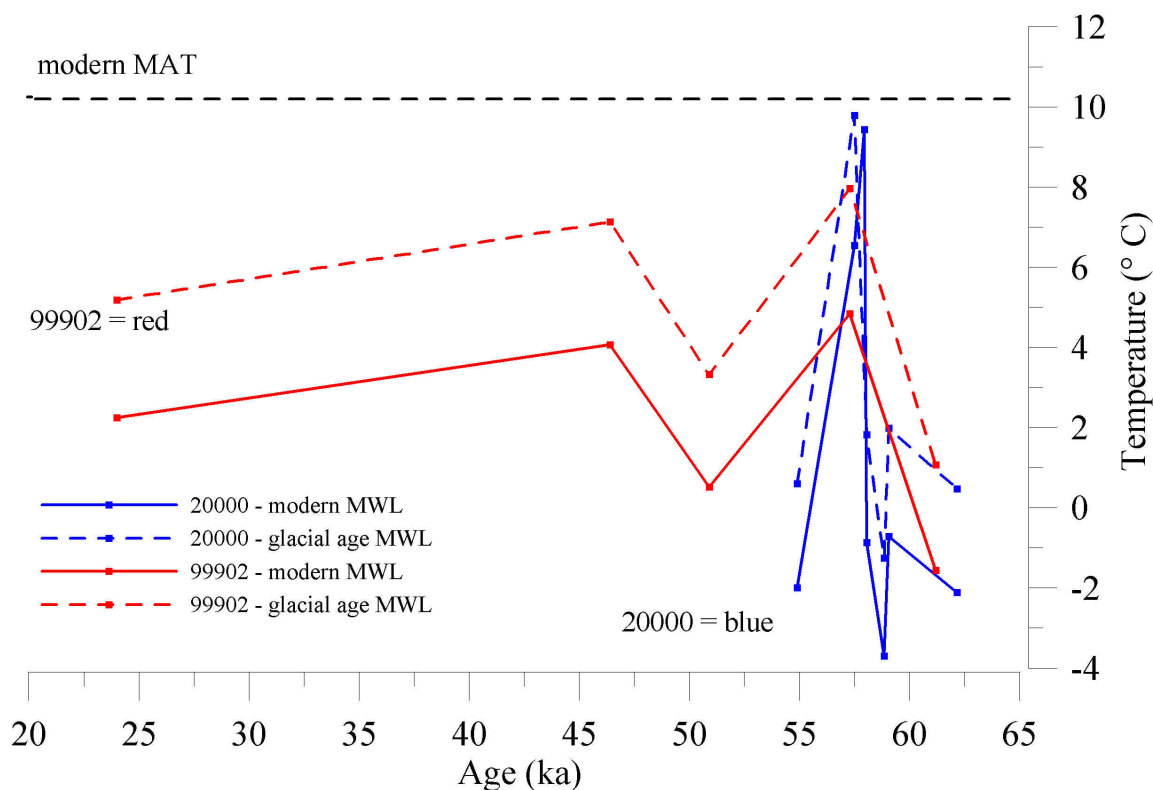


Figure 1. Paleotemperatures for Reed's Cave speleothems 99902 and 20000. The solid line uses the modern MWL relationship and the broken line uses the glacial MWL relationship.

paleotemperatures are developed to test these models, it will be difficult to ascertain the accuracy of this assumption. The results do show promise because we see correlation between direction of temperature change in coeval deposits and with other global proxy records.

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the Black Hills assisted with speleothem sample collection and collected all cave water samples.

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(Footnotes)

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Cave Research Foundation Activities 2003

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*Terraced karst landscape, Hunan Province, China
photo: Pat Kambesis*

2003 Highlights

The 69th Meeting of the Board of Directors of the Cave Research Foundation took place on October 31, 2003 at Sequoia National Park, California.

Personnel changes: Chuck Pease has resigned as a director of the Foundation and of the International Program. He has served for eight years on the Board and the Foundation appreciates his efforts.

CRF was a co-sponsor of the conference "Karst Hydrology and Ecosystems" which was held at Western Kentucky University in August 2003 in Bowling Green, Kentucky. CRF hosted a mid-meeting luncheon at the Hamilton Valley Research Station and also co-sponsored field trips out of Hamilton Valley.

President Rick Toomey represented CRF at a joint visioning meeting on the National Cave and Karst Research Institute. Those in attendance included federal, state and university representatives, NSS, ACCA and the Karst Waters Institute. The meeting covered review of management models and discussion on the focus of NCKRI.

Operation Area Reports:

Scott House, Ozark Operation Manager, reported that they have both funded and unfunded projects. The funded projects are from the Forest Service and the National Park Service. The Forest Service agreement funding is probably going to be increased over 50%. House explained that CRF worked with rangers (especially law enforcement), office personnel, maintenance etc. CRF trains rangers in recognizing bat species, are responsible for monitoring cave species, and take care of other cave management-related tasks.

John Tinsley, Sequoia Kings Canyon Operation Manager, reported that CRF help host the 2003 NSS convention and Tinsley led some of the field trips. The Lilburn Cave atlas was published. 20.5 miles mapped. Greg Stock published a field guide to the Sierran landscape geology. There is a pending proposal to look at nutrient cycling and proscribed burns in the area. Despain, Tinsley assisting in this project. There is also a potential fire ecology grant project to which Despain and Tinsley may apply. The objective of the project is to provide baseline data before a real burn. Protecting the cabin may be an issue. The last controlled burn was in 1978, but the fire got too hot and burned everything up except the giant sequoias, so there are thousands of them coming up.

The cave diving program by Bill Farr may be on hold. The Park Services policy on cave diving is that another diver and full equipment (32 tanks) must be on site. This exploration effort has been difficult because involves diving above 5000 feet but to depths of many hundreds of feet, so the diver must make several trips in just to leave tanks to get to the bottom and then several hours of decompression coming up. Though the results of the effort have been worthwhile, this part of the exploration may not continue for much longer.

Dave West, Eastern Operation Manager reported that there has been an addition of another project outside of Mammoth Cave National Park. The project is at Cumberland Gap National Monument in Kentucky. The project coordinator will be Mike Crockett. Pat Kambesis has taken over for Mike Yocum in serving as the liaison for the Mammoth Cave Control Point Project. Elizabeth Winkler continues to work on the Trip Report Database project with great success.

Cindy Heazlit reported on the Lava Beds Operation on behalf of Janet Sowers who could not attend the Board meeting. CRF personnel continue to monitor ice levels, locate and record cave entrances with GPS and place brass markers, 4) Lava Beds and Crater Lake Heazlit: We've continued doing ice levels and brass markers. Survey work is on hold until the cartography is caught up for various caves of this project. Lots of the Park Service positions have been cut due lack of federal funding, so they have lost two positions at Lava Beds that are not being replaced. Dave Larsen is the resource management person who is going to have to cover their work. The new visitors center is completed - it is no longer over the cave.

John Tinsley reported that they are very close to signing a contract to build the Lava Beds research center. However, building costs have increase three-fold because of the war in Iraq. The first bid had to be rejected. About \$50,000 worth of masonry work was cut from the budget and its anticipated that building could start in five to six months. CRF now has a building permit for the 1600 square foot research center. If all goes on schedule, it is possible that the new center will be complete and opened by June 12, 2004.

The Southwest Operation Area report was presented by Rick Toomey on behalf of Barbe Barker who could not attend the meeting. CRF is continuing to work on loop closure problems in various parts of Carlsbad Cavern. They conducted three classes to teach CRF personnel how to do resource

inventories. Restoration work continues in Lake of the Clouds, The Guadalupe Room, and Rock of Ages. CRF has received funding from a cost share agreement to conduct restoration in Ft. Stanton.

Rick Toomey reported on CRF's GIS Program. Bernie Szukalski and Aaron Addison have taken over the GIS program started by Mike Yocum, and they are taking it in new directions. They have been doing a lot of teaching to various CRF areas how to use the programs. In addition, they are doing program development. They are working on a palm pilot version of GIS, so one could work in cave on it for inventory.

The 2004 Annual Meeting will be held at our Hamilton Valley facility at Mammoth Cave National Park.

Hamilton Valley Research Station Report -2003

Pat Kambesis: Hamilton Valley Directo and ,On-site operations

Janice Tucker: Scheduling, collecting fees

Joyce Hoffmaster: Maintenance

Roger McClure: Land Maintenance

General Projects:

The management team continue to keep the facilities/bunk-houses and Hoffmaster House clean and in good repair; keep the trailer in good repair; maintain our roads and parking areas, keep our utility building and storage barn (in the valley), clean and organized.

There is now a perimeter trail in the valley which is maintained. Mowing is done on the access roads and around the barn (to keep it easily accessible), around the main facility/bunkhouses, trailer and Hoffmaster House.

We are working on a digging plan for the sinkholes located in the valley. Various inventory projects are being done by CRF and other volunteers (flora inventory, general cave biology, bat count at Adwell Cave.)

Science and Resource Management at Mammoth Cave National park has set up a a weather and Soil Chemical Analysis Monitoring and an ozone bio garden near the Hoffmaster House.

A rain gauge has been installed near the cistern for atrazine monitoring by Hoffman Environmental Research Institute Project of Western Kentucky University.

Building maintenance included work on roof, plumbing system, bunk houses and rest rooms. Two work weekends that

concentrated on major housecleaning and land maintenance.

This past year we have bought in \$3000 from Conservation Reserve Program, Corn Program, tobacco allotment, & hunting lease.

Future Plans:

Continue to increase use of HV by researchers, educators, universities and others who share our commitment to cave. We are looking into the possibility of an Agreement with The Nature Conservancy. They are very interested in helping CRF establish a burn program that would help restore pre-settlement plant communities on our land.

Lilburn Cartography Summary for 2003

Peter Bosted

There were six cartography expeditions to Lilburn Cave in 2003. Survey activity was somewhat curtailed compared to 2002 due to preparations for the NSS Convention which was held in nearby Porterville, CA in July. During 20 survey trips, 3067 feet of new passage was surveyed using 391 stations. There was also 600 feet of re-survey using 47 stations. The most new survey was in the Canyonlands and Low Hanging Fruit areas that were the main focus of last year's surveys. There are only very tight crawls and one difficult climbing lead (with air) remaining in the area.

Another major area of survey activity was near the Triangular ladder, where previously known passage had accidentally not been surveyed by CRF. The two leads remaining in the Outback were surveyed. Surveys were also done in the River Pit area, and more remains to be done by those willing to get cold feet. A very tight maze near the Enchanted River was surveyed for 300 feet, and the leads in Meso America (near the Attic) were polished off yielding a similar total. Four passages were found during NSS Convention -related tourist trips, and these passages were promptly surveyed during the Labor Day and Columbus Day expeditions netting another 300 feet of new survey.

The quadrangle maps of the cave were brought up to date for the first time, and a quadrangle map book was published for release at the NSS Convention. In addition to the 90 quadrangle maps, drawn at a scale of 20 feet per inch, and printed on 11 by 17 inch paper, the Atlas contains a list of all the principal surveyors (more than 200 stations, a list of symbols, a list of statistics, a brief history of exploration, a

visual guide to the quadrangle locations, and an index of place names. The present length of Lilburn Cave is approximately 20.5 miles, or 33.0 km.

Certificates of Merit

The following individuals and groups were presented with a Certificate of Merit:

Jim Baichtal, geologist for Tongass National Forest, for years of extensive work to understand and protect globally significant karst resources in southeast Alaska.

Yuan Daoxian, director of the Karst Dynamics Laboratory of the Institute of Karst Geology, Chinese Academy of Geological Sciences in Guilin. He was a founder of the Karst Institute, and has done as much as anyone in China to understand and protect karst resources, and to develop connections with karst scientists in the west, starting with the first western expedition in the late 1970s when the British surveyed Crown Cave on the Li River. He is a great ally to CRF for China work.

Mike Crockett has been the spark plug at the Gap Cave project at Cumberland Gap National Historic Park, and is serving as the Project Coordinator. He has expended enormous energy (and not a little expense) to ensure the projects success. Mike's conduct has been extraordinarily professional throughout the transition from "grotto project" to CRF project

Members of the Hamilton Valley Land Management Committee including Dave Hanson Joyce Hoffmaster and Janice Tucker.

Donna Mosesmann for serving in a leadership position at the annual Restoration Field Camp at Carlsbad Caverns National Park. Donna has taken a week of her vacation for over 10 years to devote to volunteer work for CRF during Restoration Field Camp.

Lilburn Mapping Team. For completing the quad map book and which won a gold medal at Cartographic Salon at the National Speleological Society annual meeting of 2003.

John Corcoran for his years of diligence in leading the Fort Stanton Cave Project. In the past two years John has worked closely with Mike Bilbo and others at the BLM to work out the techniques and process for exploration and survey of Snowy River: a pristine virgin area. John has led numerous expeditions and coordinated the survey of the new areas, including publishing up to date GIS maps.

Mark Scott has been very involved at Lilburn Cave for more than 7 years. He is known for leading climbs, pushing tight leads and always maintaining a jovial attitude. Mark is a generous member who regularly provides homemade beer and other alcoholic treats to CRF cavers. Mark will be the new P.I. for a CRF digging projects in the park. He has helped to set nearly 400 survey stations in Lilburn.

Kelly Fuhrmann, NPS Cave Specialist. Kelly Fuhrmann came to Lava Beds as a Wildlife Biologist Seasonal. From the beginning, he supported CRF research efforts to study caves, bats, magnetic anomalies, insects, moss, ferns, and ice formations. Kelly recently revised and updated (from 1988) the Lava Beds Cave Management Plan to bring it into the 21st Century. He recently wrote a photographic history of Lava Beds from 1873 to 2003 using photos taken a long time ago and juxtaposed on each page photos he took this last year. It clearly shows changes in vegetation since the Modoc War and through the 30's, 30's and since. He has proposed to expand our work in the ice caves with studies to be funded and conducted by the Monument in core drilling and time dating of ice. He has actively supported our efforts to build a Research Center in the Monument. Kelly is an enthusiastic, hardworking individual who has kept the well-being of the caves at the center of his efforts. We are honored to call him colleague, friend, and fellow caver. We wish him well at Carlsbad.

CRF Fellows:

The following individuals were elected to be CRF Fellows:

Jed Mosenfelder is an active Lilburn caver known for enduring long survey trips to the remote southern areas of the cave. He has been involved at Lilburn for more than 10 years and through several moves, including overseas. Jed has worked on climbs, hauled tanks for diving, and worked to maintain the CRF infrastructure on-site at Lilburn. Jed has surveyed more than 700 stations in Lilburn

Merrilee Proffitt has been active at the cave for many years. Her specialties have been tight leads, cave restoration, and clean-up, hauling diving tanks, and offering to baby-sit other cavers' children. She has surveyed more than 410 stations in Lilburn. Merrilee has also been active in Mineral King and worked on the maps and inventories for Cirque and White Chief caves.

Lynne Jesaitis has been a person to be counted on at Lilburn through the years. She makes a large percentage of expeditions and often shows for spontaneous. She thrives on long trips and always maintains a smile and great attitude. She has also helped with restoration projects,

climbs and dives. She has worked throughout the cave and has set more than 550 survey stations.

Art Fortini has also been an active Lilburn caver for many years. His specialty is climbs and he has completed many, including the lead that led to the fall 2002 Canyonlands and Low Hanging Fruit extensions. He has surveyed more than 250 stations in Lilburn.

Ray Mansfield of Shepton Mallet, UK, has been a long term, major collaborator on a CRF project, the compilation of a Mammoth Cave bibliography. Ray is an internationally known cave bibliographer, and was for many years the editor and publisher of *Current Titles in Speleology*. He has a long-term fascination with Mammoth Cave and had assembled a card-index Mammoth Cave bibliography of more than 1600 references. In 1993, Ray learned that Sue

Hagan and Mick Sutton were compiling a Mammoth Cave bibliography and gazetteer, and he donated his entire card index to CRF. At the time, this was the most comprehensive Mammoth Cave bibliography, incorporating all earlier bibliographies as well as a great deal of Ray's bibliographic research. That card index has been incorporated into the current 5900+ entry Mammoth Cave bibliographic database, to which Ray has continued to make substantial contributions. Recognition of Ray's role would be especially appropriate at this point, as we are about to put the bibliography up as a searchable/ sortable database on CRF's web site. Ray will co-author that work.

Bernie Szukalski has worked with the CRF GIS project for more than 6 years. He has assisted most, if not all, of our operations areas providing GIS consultation and expertise and software that he created.



Clean-up crew at Fort Stanton Cave, New Mexico

Hamilton Valley Research Station

Hamilton Valley Land Management Symposium

Sue Hagan & Mick Sutton

On November 9, 2002, in conjunction with the Cave Research Foundation's Annual Meeting, an all-day symposium was held on the topic of Hamilton Valley Land Management. This was the first formal symposium to be held at CRF's Research Center at Hamilton Valley.

The Research Center and property are the result of more than a decade of fund-raising, land acquisition, and construction. This is the culmination of dreams going back almost to CRF's founding in the 1950s. Connecting the Flint Ridge cave system to Mammoth Cave was not the only pursuit of the organization; many saw the caves as an opportunity for new karst research. From this mix of scientists and cavers, a vision grew of an organization that promoted, funded, and conducted world-class cave research, not just in the world's longest cave but everywhere—all places karstic could be a suitable laboratory.

In 1990, an era in CRF history ended when the National Park Service at Mammoth Cave decided to close the original but deteriorating facilities above Crystal Cave. But another era began almost simultaneously as CRF committed to finding its own place to call home. Two years later, that place was found – the approximately 160 acres that have retained the name, Hamilton Valley. A worn-out tobacco farm with several dilapidated buildings, it had a view cavers fell in love with on first sight.

The "Valley" is actually a large, complex sinkhole, or, more technically, a polje. It is known that passages of the Mammoth system run deep under the ground, but these are not accessible from the surface—yet. A small (by Mammoth standards) cave is located within the Valley, and several inner sinks, or ponors, in the Valley bottom, as well as potential entrances at the sandstone/ limestone contact, raise hopes for a future entrance into the big cave.

The Research Center and bunkhouses on the rim of this grand sinkhole provide an operations base for ongoing CRF research and exploration activities, as well as for other groups needing a base for cave related activities—caving, courses,

or simply contemplation. The expansive windows and outside balcony focus attention on the karst landscape. The Research Center is a place where ideas about karst abound. Naturally enough, some of those ideas are about how the karst should be managed.

How will a major caving organization manage its own karst property, both those features on the surface and those underneath? That was the question that went out to solicit participants to the 2002 Symposium. Early on, Dr. Tom Poulson responded to the invitation by asking some questions and throwing out some provocative statements for affirmation or rebuttal:

1. Should CRF manage the valley to make money (perhaps income from raising crops or hay) or are we more interested in restoring the native vegetation?
2. We can never restore a system but can revitalize it. But then, we have no accurate records of what it used to be like. So, perhaps we need to ask what we would like (e.g. keep the karst valley view).
3. Do we want to save the rare and endangered species of plants that have suffered from allowing succession toward forest to occur by suppressing fire? If so, are we willing to assume the dangers that come with fires? Do we need to acquire more property to protect the integrity of the landscape and to make a fire management plan feasible?
4. Should we leave HV alone and let nature take its course? No management amounts to mismanagement.
5. What we do about exploration, cave entrance ecology, and archeology has no bearing on management of HV.

The symposium did not answer these questions, but they did surface periodically. An oft-recurring theme was that data collection and interdisciplinary communication is essential for planning landscape management and for future research purposes. Before we clear areas or conduct prescribed burns, do we know if there are rare or endangered species already struggling for survival? Removing trash from a sinkhole may seem a good idea but what if some of the detritus consists of important historical artifacts? In our haste to gain entry into a promising lead, we may not only permanently alter, say, the biology, but we may also fail to record important paleontological data. Above all, are we certain that our actions will cause no harm to the cave system.

The following synopsis will give a glimpse of what went on that November day, but even the full-length versions of the talks (some still in the works) cannot convey the excitement that filled the air of the crowded room. One by one, each of the presenters conveyed something important not just about Hamilton Valley, but about managing karst landscapes everywhere. As a caver-run organization, as an organization dedicated to cave research, there is a special obligation for managing our own property: CRF ought to get it right. Karst land management for Hamilton Valley can and should be a model of landscape management with applicability beyond CRF's borders, beyond the borders of Mammoth Cave—it can and should be a demonstration of karst management with implications for any place in the world. Clearly, caring for the surface and all that lies beneath it is important to anyone who cares about caves.

Synopsis of Presentations

Sue Hagan opened the proceedings with an introductory talk (“Research is our Middle Name”), then introduced the first speaker, Gene Hargrove. Gene, a professor of environmental ethics and founder of the *Journal of Environmental Ethics*, was a CRF member in the 1960s. He has not been involved with CRF activities since, but connections still exist - e.g., Gene had dedicated his 1989 book to Red Watson and gives Red mention in his most recent writing. It's also Gene's doing that Turner Avenue (Benington Grotto) has become a kind of paradigm within the environmental ethics community for voluntary restraint in the visitation of fragile areas. Gene's touch-stone presentation was an abstract treatise drawing to the conclusion that arguing for conservation using principles of environmental esthetics is probably more effective than using economic arguments.

From the abstract to the concrete, Roger McClure, current Land Management Director at Hamilton Valley, used a thorough slide show to summarize events leading to the pur-

chase of Hamilton Valley and what's been done there since. His talk covered the various agricultural and leasing arrangements that have brought in money, the volunteer labor that built buildings and cleaned up trash, and the ongoing maintenance projects. Following was Stan Sides, former CRF President and now a neighboring landowner, who gave a well-researched history on land-management politics in the Mammoth Cave area and a synopsis of Hamilton Valley property owners and neighbors. One especially pertinent piece of information was that all of Hamilton Valley falls within the first proposed boundaries for Mammoth Cave National Park—and of course CRF's property is well within the boundaries of the International Biosphere Reserve.

Cave exploration and cave management policy was a recurrent theme. Current CRF President Rick Toomey discussed paleontology, and the ramifications of surface disturbance and cave exploration on paleontology (watch out not only for mastodon tusks, but the small stuff as well). Rick opined that persons digging entrances could be trained to watch for artifacts. Kurt Helf (a former Tom Poulson student, now an ecologist at MCNP) discussed entrance-area ecosystems and the effect on them of altered airflow. If entrances are to be protected from human-made disruptions to the natural ecology, it is essential that “before” and “during” documentation be conducted during the disruptions. Rick Olson and Tom Poulson kindly presented Kathy Lavoie and Diana Northup's co-authored paper on cave microbiology. The bottom line is that simple steps can be taken to minimize the impact of exploration on previously unentered passages, and data on the native microflora can be obtained easily through following some research protocols during initial entry. Pat Kambesis and Chris Groves outlined the significance of Hamilton Valley with regard to the Mammoth Cave system, and the potential for cave exploration (e.g., the sinkholes in the bottom of the valley are not necessarily the best places to be looking for a breakthrough). Chris strongly supported the theme of careful assessment before commencing disturbance of geological features, asking the tantalizing question, “Why haven't we done this before?”

Archeologist Jan Marie Hemberger (in a talk co-written by Phil DiBlasi) gave a succinct and cogent argument for opening up the land management discussion to a range of input from a variety of disciplines. While an archeological survey was conducted on the site of the Research Center before construction commenced, mistakes have been made. Examples include a drain-field that went in without the benefit of an archeological survey, and similar lost research opportunities during cleanup projects. But Jan and Phil's point was not to belabor lost opportunities, some of which were probably inevitable, but to suggest that we don't lose future opportunities.

Dick Maxey described his ambitions for trying to introduce the federally-listed American burying beetle on the Hamilton Valley property. This would seem to blend well with notions of prairie restoration. Dick also wowed the crowd with his sample collection of miscellaneous insects that call Hamilton Valley home.

Rick Olson, Mammoth Cave ecologist and long-time CRF member, discussed various aspects of NPS surface management, particularly their use of controlled burns. Rick also presented an overview of the greater Mammoth Cave biosphere region's history which suggests that burning was used by the indigenous inhabitants prior to the arrival of European settlers in the late 1700s. Having once, as a private land owner, experienced a semi-controlled burn, Rick urged caution in the use of fire and noted that some objectives can be achieved more simply by appropriate mowing protocols.

The fire-management theme was taken up again by Tom Poulson, who is of a mind that, ultimately, fire will be essential to achieve prairie, should that be a desired end (e.g., mowing tends to promote grasses over forbs), or simply to promote biodiversity. Tom entertained the crowd with a demonstration of the (hypothetical) sex-linked PYRO gene, and tried to get people to eat rabbit droppings. All of this was a practical demonstration that current land-management practices are having an effect, e.g., the timing and extent of mowing can have an effect on the diversity of both plants and wildlife. Any management plan should aim to revitalize the historic mosaic of forest, savanna, and prairie. Fire of different frequencies, intensities, and timing will be a central management tool.

Ending the symposium as it began, on a philosophical note, Red Watson gave some wide-ranging comments on fund raising, and future organizational goals.

Selected Papers presented at the Hamilton Valley Symposium

History of the Cave Research Foundation and Hamilton Valley

Stanley D. Sides, M.D.

The Cave Research Foundation (CRF) has developed a wonderful base and research facility on Flint Ridge overlooking Hamilton Valley. The Foundation has a long interest and involvement in this portion of Flint Ridge, the history of which is little known to most Foundation participants. The goal of this paper is to make Hamilton Valley come alive from the standpoint of its people, and how they have interacted with the natural features of Hart County and Mammoth Cave National Park.

Dr. Patty Jo Watson and her many investigators have well documented the early prehistoric activities of native Americans in Mammoth Cave, Salts Cave, natural shelters, and shell mounds in the region. The first recorded historic inhabitant of the region was James Sturgeon, a Revolutionary War soldier who took a military claim on 200 acres one and one-half miles from Northtown in the fall of 1790, probably becoming the first settler in the vicinity of Hamilton Valley.

The area around Hamilton Valley was transformed into cleared farms by the mid 1800's. In the 1850's Henry Sell and his wife, Sarah, moved to Flint Ridge near Colossal Cavern. He ran one of the first water mills in the area. His son, Joseph G. Sell married Sarah Thomas in 1876 and bought land near Salts Cave sink. Just west of nearby Ice Cave, Joe and his

wife opened Sell Store. Everyone had gardens and butchered their own meat. Many had orchards. The store was chiefly a source of dry goods, kerosene, vinegar, spices for curing meat, stick candy for children, and farm materials. For many years the general store also served as the local post office and as a tourist information center for those going to Colossal Cave, Great Onyx Cave, Floyd Collins Crystal Cave (FCCC), and nearby Salts Cave.

Joe Sell and his son, L. Melvin, operated a steam powered sawmill east of the store, near the Park Ridge Road. Water was obtained from the dammed creek draining into Ice Cave. Sawdust from the sawmill ran under the present Park Ridge Road to disappear underground into Ice Cave. CRF surveyors in the S and R surveys of Salts Cave years ago reported sawdust in the passages, and the maps show a close proximity to Ice Cave.

The Sells also operated a steam powered grist mill for making corn meal, an important part of the diet of the people of the area. In the days long before refrigeration, once corn was ground, it was easily attacked by insects or became

moldy, so local people returned to the store to have their corn ground every week or two.

Joseph Sell ran the store with his son, Melvin, and Melvin's wife, Nellie, until their land was purchased by the Park in 1936. Joe and Melvin owned extensive Flint Ridge acreage extending to Hamilton Valley, including land now owned by CRF. This included 150 acres immediately east of Ice Cave on Flint Ridge, just outside the eventual Park boundary. Here Mel and Nellie raised three sons, Marvin, Clifton, and Mitchell. Mitchell lived in the Melvin Sell house with his mother until her death in 1966. After Mitchell's death in 1969, the farm was sold to Larry Yadon, a hunter from Louisville. Marvin and Edna Sell received part of the land his grandfather, Joseph, had owned along the Park Ridge Road near Salts Cave, later increasing the size of their farm to 110 acres by inheritance of land from his father's estate.

Hamilton Valley School was along the Hamilton Valley Road in the bottom of the valley until the mid 1920's. With school consolidation, students of the area attended Chestnut Grove School at the junction of the Flint Ridge Road and Park Ridge Road. Wade Highbaugh, the famed cave photographer, was the first teacher at the school. The school term ran from July to the first of the year, and all grades were taught in one room. The NPS closed the school in the 1930's, and students were transferred to the larger school at Northtown.

As the developing Park became a reality, displaced local residents bought land just outside the Park, as did the Sells, or left Flint Ridge. The Mammoth Cave Operating Committee allowed landowners outside the Park to move abandoned homes off Park property. Arthur Adwell was the progenitor of the large Adwell family of Hamilton Valley. His second marriage was to Virgie Dennison, daughter of Eddings Dennison, the owner of Dennison Ferry on Green River. Oscar "Pete" Adwell told the story of how his family, including 8 children, lived for a summer in a small wooden barn that exists today in Hamilton Valley, while his father, Arthur, moved an abandoned house from near Dennison Ferry to the family farm. This house still exists on CRF's property in the valley today, near the road just west of the original site of the Hamilton Valley School. Water for the family was obtained from a spring that still flows, located just east of the house.

Floyd Collins Crystal Cave and Great Onyx Cave on Flint Ridge were closed in 1961. CRF was allowed to remain on Flint Ridge using the Back House, the guide residence behind the Collins House, and the Spelee Hut built by Central Ohio Grotto for its Flint Ridge Reconnaissance project. Jerry Hobbs and his wife, Ida Mae, lived in the Austin House used by the National Park Service as the Flint Ridge Ranger Station. Marvin and Edna Sell lived near Salts Cave. His

brother, Mitchell, lived with his mother on the adjoining farm. Hershell Adwell, Pete's younger brother, lived on the Adwell family farm at Hamilton Valley.

The Great Onyx Job Corps camp opened near Unknown Cave in June, 1965. A trailer camp for faculty developed around the site of the fire tower on Flint Ridge. Soon, the buildings CRF leased were being vandalized, and Floyd Collins Crystal Cave, longest in the world, was broken into and vandalized many times. CRF no longer had a peaceful existence surveying and doing research on the Ridge. In 1967, Joe Davidson succeeded Red Watson as the third CRF president. Superintendent Robert H. Bendt became Park Superintendent. CRF was still not allowed to survey in Mammoth Cave or Mammoth Cave Ridge. Nevertheless, CRF had copies of Quinlan's tracing of the 1908 Kämper map of Mammoth Cave. The map led to much speculation about the possibility of a connection between the Flint Ridge Cave System and Mammoth Cave.

CRF's area of study in the Park suddenly expanded when Gordon and Judy Smith discovered Lee Cave on Joppa Ridge, Thanksgiving, 1968. CRF expanded west in the Park and began surveying important virgin cave on the far side of Mammoth Cave Ridge.

As conditions worsened on Flint Ridge, the inactivity of the NPS regarding the Jobs Corps Camp—the cave pollution, noise, and continued vandalism—made reluctant environmental and political activists out of CRF cavers. The proposed Park Master Plan and wilderness designation proposals brought heightened interest from the Sierra Club and the National Parks and Conservation Association. CRF's relationship with Superintendent Bendt continued to deteriorate as anger over the obvious cave pollution increased. A special concern for CRF was whether the NPS would force us off Flint Ridge if we prevailed in having the Job Corps leave the ridge.

CRF began looking for another home away from its FCCC base. Joe Davidson, with CRF's attorney Harry Wilson from Munfordville, attempted to secure enough contributions from CRF joint venturers to purchase the Marvin Sell farm in 1969. Despite initial promises, adequate donations to purchase the \$22,000 property were not received.

Kay (my wife) and I were frequently visiting Harry Wilson to discuss the history of the Thomas family and their caves. Harry was interested in caving; he had taken photos for Dr. H. B. Thomas on the second trip to Floyd's Lost Passage after it was "refound" in the 1940's. Harry was estate attorney for the Ada Bell Hunter Estate, and an auction of her farm along the Park Ridge and Hamilton Valley Roads was

scheduled on October 25, 1969. Harry called Kay and me in Lexington and suggested we bid on the 19 acre tract at the road corner as potential property for CRF's use if forced out of the Park. On a cold rainy Saturday, we drove to Flint Ridge for the auction. Sight unseen, we bid and bought the 19 acre tract of woods and a deep sinkhole valley. We already knew that passages from Salts Cave ran under or very close to the property.

Despite CRF's opposition to many Park policies, the Foundation was finally granted permission to survey Mammoth Cave in 1969. Red Watson led the Memorial Day expedition, and fielded 10 parties to the Albert's Domes area of Mammoth Cave, shown on the Kämper Map as being near Q87, the closest penetration of Flint Ridge passages to Mammoth Cave. Now CRF was surveying under all three ridges in the Park.

CRF was still looking to move outside the Park in 1970, as expeditions were fielded with difficulty from the Spelee Hut and the Back House. In November, the Austin House was added to the CRF Use Permit. The Austin House and Collins House were initially used for German researchers Franz-Dieter Miotke and Hans Papenberg, and then Jack and Tish Hess. We had better facilities and more room, but the Job Corps Camp was still running full tilt. CRF furthered the concept of underground wilderness, as Flint Ridge, protecting the world's longest cave, was nearly becoming a suburban environment. Sewage pollution of the cave and cave break-ins continued.

Superintendent Bendt was replaced by Joe Kulesza in February, 1971. Joe had served in the Mammoth Cave CCC camps, and was a ranger at Mammoth Cave many years before his career moved him elsewhere. Despite arresting Louisville Grotto members in the 1950's for breaking into the caves in the Park, Joe had a native liking for cavers. He was the first superintendent to recognize that cavers and their activities were important resources to manage for the good of the Park. He told us CRF could plan on remaining on Flint Ridge about another 10 years, but we would eventually be forced to leave. He underestimated by 10 years, as events unfolded.

In July, 1970, I left my Internal Medicine residency at the University of Kentucky Medical Center to enter the Navy, ending up in Vietnam. When I returned to Flint Ridge after my tour of duty, Gordon and Judy Smith helped Kay and I build a small frame cabin on our 19 acres of Flint Ridge. I resumed caving with CRF while completing my active duty at Naval Hospital, Memphis. On July 1, 1972, Kay and I moved our family of two sons back to Lexington, to complete an Internal Medicine residency and begin a Hematology and

Medical Oncology fellowship. I took over the reins of the Foundation from Joe Davidson, becoming CRF's 4th president. I no longer needed to stay at our shack on the 19 acres on Hamilton Valley Road, since I had keys to the buildings CRF leased at Crystal Cave!

Two months later, on September 9, 1972, CRF realized its dream of integrating the cave systems by connecting to Mammoth Cave. As recorded in *The Longest Cave* and *Beyond Mammoth Cave*, CRF continued its work in the Central Kentucky Karst both inside and outside the Park. The Job Corps Camp remained active on Flint Ridge for ten more years. On June 9, 1982, a District Court Judge ordered the Great Onyx Job Corps Center closed, and the slow process began to transfer the camp to its present location near the far northwest corner of the Park.

In 1990, Superintendent David Mihalic notified CRF that our use permit would not be renewed on Flint Ridge, and we must move across the Green River to Maple Springs Research Center. The Thanksgiving 1990 Expedition was the final CRF expedition at Floyd Collins Crystal Cave. We moved equipment and supplies to Maple Springs, and began 1991 expeditions from our new base shared with many other groups.

Kay and I felt Maple Springs, on the "wrong" side of the river, would never please us, given our love for Flint Ridge. I wrote a local realtor, Tony Dady, asking her to notify me if land became available near our 19 acres. In June, 1991, she wrote that the Mitchell Sell farm, currently owned by Larry Yadon, had been put on the market for potential purchase by the Amish moving into the area. After several months the farm had not been purchased, so we expressed interest in the neglected farm with decrepit buildings. During the Labor Day CRF expedition, Mel Park, Jim Borden, Tom Brucker, and Richard Zopf examined the farm with me, and I later met briefly with the realtor.

Kay and I favored purchasing the property as it shared a boundary with our original 19 acre property. We attended the October, 1991, CRF Columbus Day Expedition at Maple Springs. Rather than caving, we met Larry Yadon at Tony Dady's house and closed on the property on October 12. We now owned the property and house previously owned by the proprietors of Sell Store.

Yadon had promised to show me the location of survey markers along the relocated Flint Ridge road. He and I hiked in the woods, but he could find none of the markers. He had not visited his farm in 7 years due to poor health. He wanted to show me a spring he felt was valuable. We struggled

through the brush, wearing suit clothes, to a karst window I had never seen, one not shown on the topographic map. A stream emerged from a low cave, with a well worn animal trail to the water. Thirty feet away, the water fell over a waterfall, and entered a low, brush-filled hole. I asked Yadon what he knew about the cave entrance. He said, "Oh, that's nothing. The spring over here is what is important!" He knew of nobody ever entering the low entrance, and did not consider it a cave.

Returning to Maple Springs, we celebrated our purchase with those in camp. Sunday morning, Richard Zopf and I went back to the karst window, Richard removing some of the logs and limbs from the downstream hole. We then hiked much of the property I had never seen. James Wells and Alan Canon were at Maple Springs and knew of our activities. They returned the next weekend to enter the cave and found difficult virgin cave passages leading on. We invited many friends to return, and on the cold wet weekend of November 23, began cleaning up the property around the buildings. Alan Canon, James Wells, Howard Kalnitz, and Richard Zopf surveyed nearly 1400 feet of wet entrance passage into the larger passages of the cave, now named Sides Cave.

We examined the buildings and decided to refurbish an unfinished utility building. The old Melvin Sell house was irreparable. In the spring of 1992, we allowed the Cave City fire department to burn the house for training.

In January, 1992, new CRF president Ron Bridgemon, Richard Zopf, Mel Park, and Scott House met with Kay and me at Cape Girardeau, Missouri, to determine a method by which CRF would lease part of the property for a field station. In October, Kay and I agreed with Pete Adwell that we would continue to sharecrop the tobacco base, and CRF's land needs conflicted with the best land for growing the tobacco allotment. Pete had been born on the adjacent farm in Hamilton Valley, but Hershell had owned the family farm. Pete had sharecropped our new farm, adjacent to his brother's farm, since our farm was purchased by Yadon in 1970.

Roger McClure found that the Hershell Adwell farm was also on the market. In 1992, the property was purchased from Hershell's widow, Maydell, by Roger McClure and Red and Pat Watson on behalf of the Cave Research Foundation. A small tract along the Hamilton Valley Road had been sold by the Sells to the Allen family twenty years earlier. Red and Roger later purchased this tract as an addition to the property the Foundation owns today. The Ohio CRF cavers moved the Spelee Hut to Hamilton Valley, and refurbished the Tenant House for expedition use. Mick Sutton and Sue

Hagan began leading expeditions from the Tenant House rather than Maple Springs, beginning with the Easter, 1996 Expedition.

Appeals for contributions for construction of a home research base overlooking Hamilton Valley began in earnest. Ground was broken for the Hamilton Valley utility building on May 21, 1998. In September, 1999, Alliance Construction of Glasgow, Kentucky began construction of the main building and dormitories. Dick Maxey and his building committee exhausted themselves overseeing construction details, but their dedication has resulted in the fine facility we enjoy today.

Bob Osburn ran the final CRF expedition at Maple Springs over Labor Day, 2000. A month later, we celebrated the opening of CRF's new home with the dedication on Saturday, October 7, 2000. The Foundation had come full circle, returning to the eastern edge of Flint Ridge through the strength of the commitment of its members to recapture the dream of exploring the caves beyond the upper levels of Floyd Collins Crystal Cave.

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Acknowledgement:

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Hamilton Valley Cultural Resource Management: What's the Point?

Jan Marie Hemberger & Philip DiBlasi

Hamilton Valley, located within a biosphere reserve, is owned by the Cave Research Foundation (CRF). This ownership provides some protection to all the resource categories located in and on the property but much remains to be done before CFR can credit itself with managing Hamilton Valley even in the spirit of a biosphere reserve. There needs to be unified commitment to manage Hamilton Valley resources or the point is there is no point. Without such a commitment CRF does little more than pay lip service to conservation principles. Let's review one resource category – cultural resources.

What is known about cultural resources at Hamilton Valley? Actually there is very little known because there has been no comprehensive cultural resource study undertaken. The only areas archaeologically investigated have been the proposed entrance road, parking lot, septic field and building site. The latter three areas were proposed for the ridge top and do not include the ultimate location of the septic field. This work was accomplished by CRF archaeologists DiBlasi and Carstens with the help of student volunteers. The study involved the excavation of shovel tests every five meters along the proposed road and on a five by five meter grid in the area of the proposed parking lot and building site. The results of this investigation were less than remarkable. The results pointed to the fact that there were no resources found in the areas where two researchers most expected to find at least some evidence of prehistoric use of the property. Several standing farm structures were noted by the investigators but their efforts were focused exclusively on the proposed ground disturbing activities. The balance of Hamilton Valley has not been examined for cultural resources.

From cultural resource work within Mammoth Cave National Park (MCNP), and the surrounding area, we know that there is an abundance of both prehistoric and historic cultural resources in the region. Watson's efforts concentrated on cave entrances and interiors. Carstens examined rockshelters. DiBlasi investigated historic signatures in MCNP, aboriginal drawings in the region, and the location of the Floyd Collin's home. Prentis undertook a systematic sample of part of MCNP, looking for both prehistoric and historic cultural resources. Crothers detailed in-cave cultural resource remains and their implications and Hemberger explored the necessity and implications of cave cultural resource management.

Armed with this information CFR should expect, until proven otherwise, to find cultural resource sites at Hamilton Valley. Look around – there are plenty of examples of human utilization of Hamilton Valley - farm structures, Adwell Cave, the sinks, and even our new facilities. CRF should outline management principles for looking for cultural resources and mechanisms for addressing them. We would like to present some ideas for consideration.

What are the legal and ethical responsibilities of the Foundation to the cultural resources of the property? Legally archaeology in this country is driven by Section 106 of the National Historic Preservation Act of 1966 (as amended). Essentially, this law states that the federal government will consider the effects of its actions on the cultural resources for federally funded, licensed or permitted activity. Since the Foundation is a private not-for-profit corporation that has not directly used federal funds for our activities on the property, we have no legal obligation, to the cultural resources present, under this law.

There is also a state law, the Kentucky Cave Protection Act, which requires consideration of cultural resources. This law was enacted to protect archaeological, biological, speleological and paleontological cave resources and it is applicable to privately held property, such as Hamilton Valley. Crothers points out, in his capacity as the state archaeologist, that this law requires a permit for archaeological excavation. While a permit is not required for "minor scientific exploration" such as digging in sinkholes to open a cave entrance, he notes the potential to damage cultural resources. He suggests that an archeologist assess any suspected cultural remains exposed through such activity.

Our ethical responsibility as a leading karst and cave research organization obligates us to integrate all aspects of karst research and conservation in an effort to minimize impacts to the environment and cultural resources. In fact, our ethical responsibility was the motivating factor behind Carstens' and DiBlasi's examination of those portions of the property to be affected by initially proposed construction.

For CRF and Hamilton Valley, it is imperative that cultural resources not be addressed within a vacuum. The approach needs to be integrated but flexible. CRF needs to develop a vision for Hamilton Valley and set reasonable timeframes for both short- and long-term goals. Next a comprehensive land

management plan for Hamilton Valley that outlines strategies to attain these goals should be developed. This document needs to integrate discussion of all planned activities and all resource categories at Hamilton Valley. Neither the vision nor the land management plan can be static. CRF needs and goals continually change, biological species come and go from the threatened and endangered list and the 1970s trash pile or the CRF national headquarters reaches 50 years of age and deserves consideration as a cultural resource.

A primary management principle is to know what you are managing. A comprehensive inventory for all resource categories needs to be accomplished across the entire property. This should be done before any other land altering activities are proposed or completed. This is because some of our activities have already impacted cultural resources and may have impacted other resource categories. Cultural resources have been impacted by our efforts to clean the property of trash. We may have possibly impacted resources during construction of our septic field, because this area was not examined for cultural resources we may never know.

This is not to say we shouldn't have removed the trash or constructed the septic field but it should have been done within the context of a management plan and with clear consideration of the consequences of the actions on the resource. Being good stewards of the land doesn't mean you need to, or that you can, save everything but that land altering actions are fully considered.

Another key element to management is to know what activities are conducted on the property and to identify their ben-

eficial, benign or adverse effects. Examples of activities would include, but not be limited to, agricultural practices, hunting, vegetative clearing or planting, demolition and construction. Examples of effects would include, but not be limited to, the removal of artifacts important to understanding trade networks, food preferences and preparation and regional technologies, population control and introduction of a non-native species.

How do we address the issue of cultural resource management? CRF needs to produce an integrated land management plan that addresses the needs and goals of the Foundation while considering affects to all categories of resources.

To develop a cultural resource management plan as an integral part of a land management plan, CRF can approach our active archaeologists (DiBlasi, Carstens, Crothers, Hemberger, Wagner and Watson) and regional professionals such as Darlene Applegate at WKU. To implement the actual study (or studies) any or all of these professionals can direct students in the completion of the necessary field activities.

Without a comprehensive land management plan any examination of the property by archaeologists would be nothing more than an exercise in futility. The end result of such an unguided study would result in nothing more than a laundry list of cultural resources.

So what's the point? We need a cultural resource management plan within the context of a land management plan. The vision and goals of the Foundation need to be the basis of a Hamilton Valley Land Management Plan.



A view into Hamilton Valley from the front window of the Hamilton Valley Research Station, photo: Pat Kambesis

Hamilton Valley Research Station Report

Pat Kambesis

The Hamilton Valley Committe consists of:

Pat Kambesis: Hamilton Valley Director, On-site operations

Janice Tucker: Scheduling, collecting fees

Joyce Hoffmaster: Maintenance

Roger McClure: Land Maintenance

General Projects:

Continue to keep the facilities/bunkhouses and Hoffmaster House clean and in good repair; keep the trailer in good repair; maintain our roads and parking areas, keep our utility building and storage barn (in the valley), clean and organized.

There is now a perimeter trail in the valley which is maintained. Mowing is done on the access roads and around the barn (to keep it easily accessible), around the main facility/bunkhouses, trailer and Hoffmaster House.

We are working on a digging plan for the sinkholes located in the valley. Various inventory projects are being done by CRF and other volunteers (flora inventory, general cave biology, bat count at Adwell Cave.)

Science and Resource Management at Mammoth Cave National park has set up a weather and Soil Chemical Analysis Monitoring and an ozone bio garden near the Hoffmaster House

Simple rain gauge has been set up near the cistern for atrazine monitoring by Hoffman Environmental Research Institute Project of Western Kentucky University.

Hamilton Valley was used by the following groups during the course of the year.

Eastern Operations Expeditions

Central Kentucky Karst Coalition

University Field trips (geology, hydrogeology):

University of Mississippi,

University of Tennessee

Eastern Kentucky University

Purdue University

Mammoth Cave Resource Management Seminar

WKU-MACA University in the Park Classes (History of Exploration, Survey/Cartography, Karst Geology)

Kentucky Speleological Survey meeting

Hoffman Institute Karst Conference

June 2003 Anthropology Retreat

Upward Bound

Toomey/Winkler Wedding

Various research working both inside and outside of the Park Various international cavers/researchers who were in the area

Building maintenance included work on roof, plumbing system, bunk houses and rest rooms. Two work weekends that concentrated on major housecleaning and land maintenance including:

installing/maintaining the boundary trail,

installing fencing

cutting trees/cedars

trailer maintenance

tenant house/spele-hut area work,

trimming fence rows, field rows

shelving & lights in utility building

keeping erosion in check

maintaining roadways & parking lot

mowing.

maintaining the "viewshed" of the valley

This past year we have bought in \$3000 from Conservation Reserve Program, Corn Program, tobacco allotment, & hunting lease.

Future Plans:

Kambesis plans to move into the trailer next spring. The bedroom in the main facility will be converted to an office dedicated to Eastern Operations.

Continue to increase use of HV by researchers, educators, universities and others who share our commitment to cave and karst.

We are looking into the possibility of an Agreement with The Nature Conservancy. They are very interested in helping CRF establish a burn program that would help restore pre-settlement plant communities on our land.

Biology

The Pink Planarians of Devils Icebox Cave – a population study proposal

Michael R. Sutton

PREAMBLE

Research Problem: Devil's Icebox Cave, Boone County, Missouri, contains the only known population of a large stygobitic planarian, *Macrocotyla glandulosa*. The federal and state conservation status of the species is S1, G1, G3, defined as critically imperiled (both within Missouri and globally) and found only within a restricted range (Missouri Department of Conservation, 2001). While there is existing information on the planarians' population density (Campbell, 2002), there has been no systematic documentation of population density, seasonal variation, or population trends under controlled and reproducible conditions.

Structure and taxonomy: The planarian was first collected by P. W. Frank. It was described by Hyman (1956), and redescribed by Kenk (1975). Specimens have also been collected by Gardner (1986). The flatworm is eyeless, pallid in color, with variable amounts of reddish-orange pigment, has a prominent adhesive organ, and has been reported as large as 3 cm in length.

The pink planarian's systematic place is: phylum Platyhelminthes, class Turbellaria (flatworms), order (or suborder) Tricladida (characterized as flatworms with a three-segmented intestinal tract), family Kenkiidae. *M. glandulosa* is the type species for the genus. It has two congeners, *M. lewisi* from Perry County, Missouri and *M. hoffmasteri* from West Virginia. The Missouri species are widely separated by 200 miles through which flows the Missouri River, so all three species appear to be thoroughly isolated populations of what presumably was once a much more continuous group of related species. There are references to a population of *M. glandulosa* from Iowa, but this was spurious, and the Iowa flatworm has since been assigned to a different genus, *Sphalloplana speophila*. Species boundaries may be more firmly established than family boundaries.

Ecology: The planarian probably has a mid-chain place in the cave's food web. The species appears to be primarily a predator on crustaceans (amphipods and isopods). There is no evidence of predation upon the flatworm, but a reasonable hypothesis is that it is preyed upon by crayfish. The planarian shares its habitat with a diverse stream fauna which includes a number of epigeal species as well as a troglomorphic isopod (*Caecidotea brevicauda*) and a phreatobitic amphipod

(*Baetiscus brachicaudus*) (Gardner, 1986, Elliott, 2002). The crayfish is a common epigeal species, *Orconectes virilis* (Northern crayfish), with a widespread distribution.

Conservation: The continued existence of *M. glandulosa* has been a matter of concern to the conservation community and to land managers. The primary threat to the flatworms' existence and the cave's biological community in general, is the potential for deterioration of the water quality. Devil's Icebox is especially vulnerable to water pollution and siltation, as the cave stream is fed by relatively open sinkholes within a broad sinkhole plain, as well as by a losing stream. Moreover, the cave's watershed adjoins the City of Columbia, and the expanding population of that city is putting considerable developmental pressure on the sinkhole plain. The portion of the watershed protected within Rock Bridge State Park is relatively minor. Cave streams in this kind of setting have had an unfortunate propensity to turn into open sewers, with severely detrimental consequences for the stream ecosystem, unless development occurs with careful attention to the karst landscape.

PROJECT AIMS

There are two related aims:

- 1) Collect initial data on the population density, habitat preferences, aquatic community makeup, seasonality, and as time permits, behavior.
- 2) Develop protocols for quantitative inventories of *Macrocotyla glandulosa*, such that minimally trained workers can produce systematically comparable counts in semi-permanent representative census areas.

TIMEFRAME

The fieldwork will take place from late July 2002 to July 2003. The final report is due December, 2003. Approximately six field trips will be scheduled within this time frame, omitting the mid May to late July period in order to minimize disturbance to a gray bat maternity colony, but otherwise more or less evenly distributed. The initial trip will be con-

cerned primarily with the selection of suitable census plots; a minimum of two days should be committed for this trip. The final trip may be delayed past the nominal termination date in the event of unfavorable weather. All scheduled trips are subject to postponement owing to inclement weather.

PROTOCOL

Protocols will be developed and revised during the course of the project. Optimizing the number, size, and location of census plots together with the thoroughness of data collection at each plot, will be balanced with the practicalities of available person-hours. In general, thorough data collection at a limited number of sites will be the preferred method, but at least one trip for a preliminary assessment of the remainder of the cave would be useful for comparative purposes.

Census plots will be established in a variety of habitats—e.g., downstream (surface) from the cave entrance, heavily vs. lightly traveled cave-stream passages, silt vs. rock strata and pools vs. riffles. Secondary census plots with approximately the same parameters as the primary sites will be set aside to survey only at the beginning and end of the project, to attempt establishing whether census procedures are themselves influencing the population. Counts will consist of thorough searching in an upstream direction while recording the amount of search effort (number of rocks searched, time spent, area searched, type of light used).

Parameters to be recorded include (a) water temperature, stage and turbidity and other parameters; (b) nature of the substrate within the census plots; (c) water depth; (d) microhabitat context of each specimen; (e) approximate length of each planarian and whether it is extended or contracted; (f) other fauna within a smaller sample area for each census plot; samples of invertebrate fauna may be taken for identification if necessary.

Field Trips will take place only in settled weather, and will have a minimum of four participants.

Data management will require field notes to be copied immediately after each trip. Biological parameters will be entered into the Missouri Biospeleological Database, and a trip report will be written closely following each trip. A final report will be completed following the completion of the project.

DELIVERABLES

Copies of the raw field data will be deposited at Rock Bridge State Park immediately following each field trip. A progress report will be delivered by the end of 2002. The final report, due by the end of December 2003, will consist of a summary of the data collected over the course of the

project, together with any conclusions, suppositions, and/or recommendations, and a protocol for continuing inventory of the planarians using minimally trained volunteers.

RESPONSIBILITIES

The **Cave Research Foundation (CRF)** will: be responsible for carrying out the field work and writing the required summaries and protocols; will consult and collaborate with other researchers studying the cave (especially with regard to hydrological research), with Department of Natural Resources staff, and with the Missouri Department of Conservation.

The **Missouri Department of Natural Resources** will provide access to Devils Icebox Cave, will provide personnel for field assistance and advice, and will provide partial funding.

The **Missouri Department of Conservation** will provide technical consultation, will provide periodically updated copies of the Missouri Biospeleological Database, and will provide partial funding.

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Systematics Of The North American Subterranean Amphipod Genus *Batrurus* (Crangonyctidae)

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ABSTRACT

Batrurus Hay is a relatively small generic group that inhabits caves and related groundwater habitats in parts of eastern and central USA. Two field trips, conducted in the spring of 1999, yielded important new locality records that give us a better knowledge of the distribution of the genus. The examination of fresh samples as well as older collection material has resulted in descriptions of four new species. Based on these descriptions and redescrptions of three previously known species, the taxonomy of the genus is revised. In addition, a phylogenetic analysis using morphological data is employed to examine the relationship of *Batrurus* to 12 selected crangonyctid taxa, including its potential sister genus *Stygobromus* Cope. Five epigean and hypogean amphipod taxa were chosen as outgroups for the analysis. For interspecific and intergeneric comparisons, pairwise sequence differences of the 18S (small subunit) rDNA gene are given for three species of *Batrurus* and three of the outgroup taxa. Based on an updated, detailed distribution map the biogeography of *Batrurus* is discussed with regard to possible dispersal and vicariant events. The evaluation of new data obtained during this study contributes to a more complete understanding of the evolutionary history of the genus.

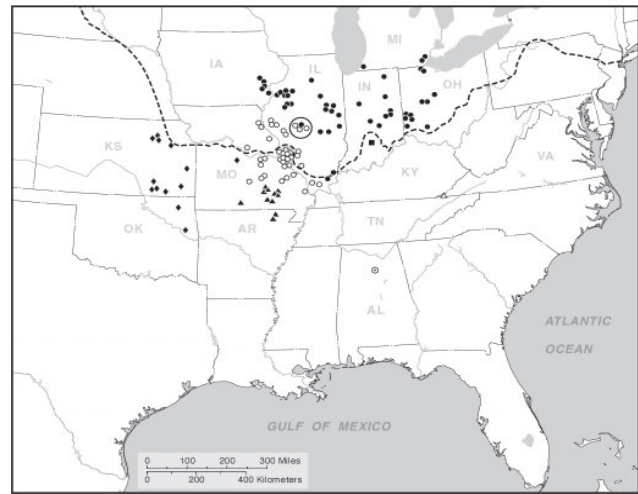


Fig. 1. Geographic distribution of *Batrurus* in eastern and central North America. Each symbol represents approximately one locality record (the actual number of records may be slightly higher in some of the densely clustered areas). Open circles: *B. brachycaudus*; filled diamonds: *B. hubrichti*; filled circles: *B. mucronatus*; filled triangles: *B. pseudomucronatus*; dot surrounded by circle: *B. wilsoni*; filled square: *B. cellulanus*; open triangle: *B. angulus*. The large open circle in the glacial drift area (Illinois) surrounds several localities: three are the first records for *B. brachycaudus* from glacial drift habitats; one is a locality occupied by both *B. brachycaudus* and *B. mucronatus*.

I went on 2 excursions in 1999. From March 6-13, I visited potential localities of *Batrurus* in several areas in Virginia, northeastern Tennessee, and northern Alabama. A second, longer field trip took place from May 3-30. Together with a German PhD student, I sampled approximately 120 localities of *Batrurus* in karst regions of northern Arkansas, southern Illinois, southern Indiana, Missouri, and northern Oklahoma, and selected drain tile outlets in glacial drift fields in Illinois, Iowa, and Ohio (Figure 1). *Batrurus* is a small genus of the amphipod family Crangonyctidae known exclusively from North America. The main objective of this study

was to re-investigate the distribution and abundance of *Batrurus*, and collect fresh specimens for DNA analyses.

Both excursions were funded by the CRF and CCV (Cave Conservancy of the Virginias). The collection trips resulted in 3 publications (Englisch & Koenemann, 2000; Koenemann, S. & Holsinger, J.R. 2001a & b). The main paper contains descriptions of four new species, *Batrurus angulus*, *B. pseudomucronatus*, *B. wilsoni* and *B. cellulanus* (Koenemann & Holsinger, 2001a & b). Furthermore, new hypotheses regarding the biogeography and evolutionary

history of the crangonyctid genus *Batrurus* are discussed. Based on our investigations we think that *Batrurus mucronatus*, a relatively abundant and wide-spread species in the Central Lowland area, outlived the Pleistocene glaciations in deep groundwater aquifers. Two additional papers provide the first DNA sequence analyses of subterranean amphipods, probably even subterranean crustaceans (Englisch & Koenemann, 2000; Koenemann & Holsinger, 2000 a & b).

The second, 3-week excursion during May was evidently successful. Specimens of *Batrurus* were found in localities of sampled regions in Ohio, Indiana, Illinois and Missouri. We were generally able to collect *Batrurus* from localities from which it was reported in the past. Some of these localities had not been re-sampled as long as 50 years. Furthermore, new *Batrurus* localities can be reported for each region visited. Altogether, 29 localities have been successfully sampled. The ratio of productive sites and "empty" localities was approximately 3:1, so that a total of ca. 90 sites were visited and sampled. In addition to *Batrurus*, the following peracarid crustaceans were also collected from several of these localities: *Crangonyx forbesi*, *Gammarus troglophilus*, *Synurella dentata*, and several species of the isopod genera *Caecidotea* and *Lirceus*. Some of these genera were included in the sequence analyses that we carried out at Ruhr-University Bochum, Germany, directly after the May field trip.

Because the realization of the proposed project had to be modified according to available funding, we decided to focus on regions where potentially new species could be expected or where the overlap of distribution zones of two or more species needed special investigation. For this reason, we did not visit regions in Arkansas, Kansas, Michigan and Oklahoma. Some localities in Ohio seemed to be identical with Hubricht's sample sites from the 40s. These sites were re-sampled for the first time in over 50 years. The fact that they are still inhabited by *B. mucronatus* is very encouraging and indicates a stable population of *Batrurus* in the glaciated farm field areas. However, in areas with increasing urbanization we were mostly unable to find any animals in typical habitats. These urban areas were either characterized by a general loss of habitats (Marion, Marion Co., OH) or by the loss of a single habitat of a previously reported endemic species, suggesting extirpation (local extinction) in these areas (Bloomington, Monroe Co., IN).

Surprisingly, two species of *Batrurus*, *B. brachycaudus* and *B. mucronatus*, could be found closely co-occurring in glaciated farm field areas in central-western Illinois (Figure 2). The two species were collected from drainage catchment basins less than 1 mile apart. These results certainly render a more complete picture of the biogeography of *Batrurus*,

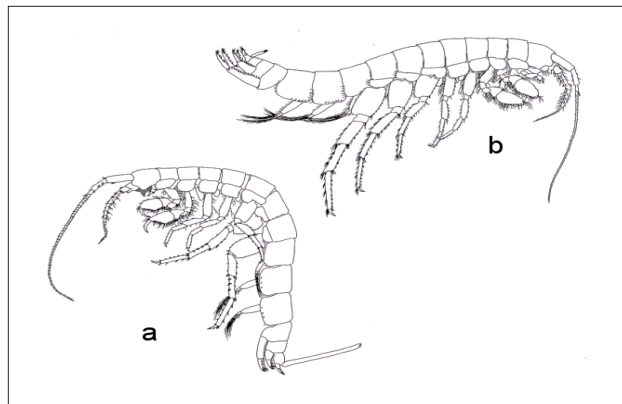


Fig. 2. Two relatively abundant species of *Batrurus* with widespread geographic distributions. **a:** *Batrurus mucronatus* (15.5 mm male) from an old well near Champaign, Champaign County, Illinois. **b:** *Batrurus brachycaudus* (19.0 mm syntype female) from Keifer Creek, St. Louis County, Missouri (from Koenemann & Holsinger, 2001).

and will assist in a better understanding of the evolutionary history of this group.

The occurrence of *Batrurus* in karst areas (Illinois and Missouri) as opposed to glaciated farm field areas is characterized by less abundant and often isolated populations. Fortunately, *Batrurus* could be re-collected not only from previously reported caves (Equality Cave, Saline Co., IL, and Kelly Hollow Cave, Oregon Co. MO) but also from new cave habitats (Forester Cave, Shannon Co., MO). Thanks to the initiative of Dr. Bill Elliott, we had the opportunity to attend a meeting of cavers at the U.S. Geological Survey (Div. of Geology and Land Survey), Rolla, MO. Here we were also permitted to study the comprehensive archive with cave files. A brief inspection revealed several dozens of Missouri caves with potential habitats for stygobiont crustaceans, promising substantial discoveries for future projects.

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Brief Overview of Coleopteran Fauna at Hamilton Valley

Richard Maxey

This paper was presented at the Hamilton Valley Symposium in November 2002.

Being an entomologist, Hamilton Valley provides an opportunity to do long term research into the present day insect fauna on the two hundred acre property, in Hart County, Kentucky, that the Cave Research Foundation owns. I have set pitfall traps baited with various items including pig dung, human dung, a combination of pig/human dung, "aged" raw chicken wings, "aged" dead mice and a combination of the chicken and mice. These traps consisted of a one quart plastic container buried in the ground with a suspended cup of one of the previously mentioned "cocktails." They were covered with a six by six inch Masonite board as a rain shield and then protected from four-legged predators with eighteen by eighteen inch chicken wire secured with four aluminum gutter spikes. When traps were left for an extended period of time, antifreeze was added to preserve the captures. Quinine and hot pepper sauce were added to the antifreeze to prevent any animal that breached the chicken wire from being poisoned by the preservative. Animals will not eat items containing quinine and/or hot pepper sauce. The extended trapping was not done until I had established that the Federally endangered American burying beetle (*Nicrophorus americanus* Olivier) was not present at this time.

It is a long term goal to attempt to reintroduce the American burying beetle to Hamilton Valley if the U. S. Fish and Wildlife Service agree to the idea. The Service does not have a reintroduced population of American burying beetles in the southern region at this time. Ohio State University, by which I am employed, has a captive breeding program that could possibly be the source for introduction. It is not possible to determine from old records if *N. americanus* was ever found in Hart County, Kentucky. It never was collected in large numbers, which may account for the current lack of records. Hamilton Valley, with its varied habitat, certainly could provide favorable niches for the beetle. My trapping has confirmed very high populations of the congeneric species *N. orbicollis* Say and smaller numbers of *N. tomentosus* Weber, *N. sayi* Laporte and *N. marginatus* Fabricius. This would indicate that possible reintroduction of *N. americanus* is feasible. Experimental trials (per communication with George Keeney at the OSU Insectory) have shown that when both *N. americanus* beetle and *N. orbicollis* beetles were placed on a carcass, *N. americanus* successfully defended the car-

cass. Based on that, it is assumed that the larger *N. americanus* would do so in a natural setting as well. Therefore, interspecific competition is not a factor and the high numbers of the congeneric species *N. orbicollis* indicate a favorable habitat for burying beetles and other carrion beetles.

The other carrion beetle species present at Hamilton Valley such as *Oiceoptoma noveboracense*(Forster), *O. inaequale*(Fabricius), *Necrophilis americana*(Fabricius) and *Necrodes surinamensis*(Fabricius) were taken in large numbers in pitfall traps as well as coming to lights at night. A few *N. orbicollis* were taken at night at black lights as well as the building lights.

Speculation as to the demise of *N. americanus* includes increase in artificial lighting (which disrupts navigation), increase in edges and fence rows due to rise in agriculture-which leads to the increase of scavengers such as raccoons, skunks, etc. that compete for carrion, and increase in urbanization and habitat fragmentation. Other possible factors are past deforestation, leading to the extirpation or decline of various birds and rodents including the passenger pigeon, *Ecotopistes migratorius*, the wild turkey, *Meleagris gallopavo*, and the ruffed grouse, *Bonasa umbellus* which provided food sources as carrion. An additional problem was the use of pesticides. DDT in particular may have led to the beetles decline in the 1960s and would correspond well with when the last *N. americanus* was collected in Kentucky and in Ohio (1974).

Thanks to the rebounding of wild turkey and ruffed grouse both in Ohio and Kentucky, the banning of DDT, and the increase in forested lands in both states, the chances are good for establishing viable populations of *N. americanus* in both states. In Ohio, we have introduced *N. americanus* for the last three years and have found at least one F1 generation. Their range of up to five miles makes recovery difficult. The vision of the reintroduction of *N. americanus* exists because it is part of the historical fauna that should be part of the natural biosphere at Hamilton Valley.

Additional goals of this project have been to inventory all insects at Hamilton Valley. Methods of collection include:

using the above-mentioned pitfall traps as well as sugar traps. (Sugar traps consist of gallon containers hung from trees with a large cut-out in the side to admit insects and filled with a mixture of fermented brown sugar, water, yeast and a handful of soil). We have also used light trapping with sheets hung out on clothes lines with black lights and mercury vapor lights to draw in a variety of night flying insects (many terrestrial insectivorous insects are attracted to the lights for a meal!), and field collecting off flower heads and under rocks, logs, and bark. The lights of the facility itself are a great attractant for the rich variety of moths and beetles that so far have been found there.

I am preparing a species list, in some cases only to the genus or family for insects I cannot key out to species, as it will take a long time to enter it into a database. If anyone is interested in a particular species found in Hamilton Valley or has collected something unusual, let me know. Please just put the specimen in a vial with 70% alcohol (Rubbing Alcohol) with the following information written **in pencil** on paper and put in a vial, not taped to the vial. On the paper, record the State, County, location of the specific area of collection, (if Hamilton Valley, just put HV) date of collection, the name of the person who collected it and the habitat it was found in or on (porch, tree, a sidewalk, a path, grass, scrub, etc.) and host plant association, if known. This last information is not necessary, but it is helpful if you can take the time. These vials can be left at HV with my name on them. You will receive credit in the database as well as on specimen labels. I am always interested in insects from different localities (states, countries) for my own collection, which I use to identify insects collected.

I will be doing an intensive base line survey this coming year in the prairie (the main open parts of the valley) to determine what is there before and during any changes we may make in vegetation cover or following burns. Insects are not impacted by burns and most benefit from them. The previous grazing of cattle probably helped to maintain a quasi prairie as well as the small tobacco plots that were in the valley. The cattle acted in the same way as bison to maintain open areas by grazing and adding dung for the dung beetles. I have not collected in the valley areas and will undoubtedly find many more insects to add to the data base. One arthropod that should be at Hamilton Valley is the Carolina scorpion, *Vaejovis caroliniensis*. I have found it at Sloan's Valley, Pulaski County, Kentucky in rock ledges. I would appreciate anyone who finds one at Hamilton Valley to notify me. Their sting is similar to a bee sting and they are not considered dangerous or aggressive.

I have tried to collect in almost every month of the year because many beetles emerge at different times and can be plentiful at one time and totally absent at another. It is an ongoing survey that will hopefully never end even after I have hung up my nets and traps. I will update my progress in the newsletter when I find a really noteworthy beetle or other insect and will give updates on the possible reintroduction of the American burying beetle.

I wish to thank George Keeney, The Ohio State University Insectory and Greenhouses, for his help in writing this article. I also wish to thank George Keeney, Nancy Shapiro and Cheryl Early for proofreading.

Appendix: Insect list

The following are the Orders and representative members of those Orders I have collected or observed in the past three years:

Numerous species of the following Orders of insects: Thysanura: bristletails; Diplura: diplurans; Collembola: springtails; Ephemeroptera: mayflies; Odonata: dragonflies and damselflies; Orthoptera: grasshoppers, katydids, crickets, Dictyoptera: mantids, wood roaches; Phasmida: walkingsticks; Isoptera: termites; Plecoptera: stoneflies; Dermaptera: earwigs; Psocoptera: booklice and barklice; Thysanoptera: thrips; Hemiptera: water boatmen, backswimmers, negro bugs, ambush bugs, plant bugs, stink bugs, assassin bugs, leaf-footed bugs and seed bugs; Homoptera: treehoppers, froghoppers, spittlebugs, aphids, leafhoppers, planthoppers and cicadas; Neuroptera: antlions, lacewings, dobsonflies, mantidflies and owlflies; Coleoptera: sap beetles, ladybird beetles, flat bark beetles, handsome fungus beetles, blister beetles, pleasing fungus beetles, June beetles, chafers, rhinoceros beetles, Hercules beetles, flower beetles, shining leaf chafers, dung beetles, long-horned beetles, snout beetles, leaf beetles, tiger beetles, ground beetles, hister beetles, carrion beetles, shining fungus beetles, rove beetles, soldier beetles, lightning bugs, net-winged beetles, dermestid beetles, bark-gnawing beetles, checkered beetles, click beetles, metallic wood-boring beetles, darkling beetles, stag beetles and bessbugs; Lepidoptera: butterflies and moths - many of which I need help in identifying, there are very large numbers of moth species at Hamilton Valley and a number of them are hard to key out; Diptera: flies, again a large number that I have not worked on collecting, spending most of my time and efforts on Coleoptera; Siphonaptera: fleas, at some point, I will try to obtain a few bat fleas which may be on the bats

Ecology

The Ecological Foundation for Prescribed Fire in the Mammoth Cave Area with Special Reference to Hamilton Valley

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Abstract

Prescribed fire is a resource tool being used at Mammoth Cave National Park, and experience there is applicable to management concerns at Hamilton Valley. Justification is based upon study of regional historical accounts, paleobotanical remains in Park caves, and pollen analysis from Jackson Pond. It is also recognized that fire can have a decided effect on the terrestrial cave ecosystem. Prescribed fire areas in the Park were selected based upon habitat modeling, current vegetation types, and proximity of sensitive cultural resources. Approximately 75% of the Park is composed of habitat types that would naturally support fire dependent or fire tolerant vegetation communities. The remaining 25% of the Park supports moist habitat types with vegetation that would be damaged by fire. Hamilton Valley vegetation types include open area/prairie, mesic slope forest, and mesic upland, mixed, and coniferous forest. Some mixed stands are naturally glade-like. Prescribed fire areas should be selected on the basis of habitat type and current vegetation. Fire should be applied to successional vegetation with great care, and the advice of a fire ecologist sought.

Karst Landscape Overview

Hamilton Valley falls within the International Biosphere of the Mammoth Cave region, a karst landscape which is characterized by subterranean drainage. The Green River runs east to west through Mammoth Cave National Park, and is the hydrologic base level for any cave(s) underlying Hamilton Valley.

Within the regional karst landscape, there are two historical and three functioning ecosystems. Historically, barrens bordered by savanna covered large portions of the Sinkhole Plain located south of the Park. Barrens are similar to prairie,

but there is evidence that these grasslands originated from fires set by Native Americans (Baskin *et al.* 1999), and were not part of the tall grass prairies (Baskin *et al.* 1994). Karst "valleys" within the dissected upland of the Mammoth Cave Plateau offer a similar habitat type to the Sinkhole Plain, but no historical descriptions of pre-settlement vegetation have been found. Soon after settlement in the late 1700s, the grasslands described were largely converted to agriculture. Within the Park, barrens and savanna have been lost due to fire suppression. Other ecological components of the karst landscape are comparatively intact even though seriously distorted.

Though impaired by dams, the river ecosystem supports a highly diverse fish and invertebrate fauna (82 and 250 species, respectively) of which over 50 species are freshwater mussels. The cave ecosystem, containing both aquatic and terrestrial components, is one of the most diverse in the world with over 130 regularly occurring species. Finally, the forest ecosystem has exceptional diversity with 82 species of trees in a variety of riparian and upland communities. An unknown percentage of currently forested land in the Park would have been maintained as savanna and possibly some prairie via natural and Native American set fire. Diversity of plant species in the Park has almost certainly suffered due to forest succession in the absence of fire, yet over 1100 kinds of plants have been identified to date. Sorted among terrestrial communities according to habitat preferences, 203 species of birds, 43 species of mammals, 29 species of amphibians, and 38 species of reptiles have been reported from the Park. Data on other taxa, such as terrestrial invertebrates and fungi, are lacking. The species data for Mammoth Cave National Park is maintained in NPSpecies, a database developed by

the National Park Service's Inventory and Monitoring Program in 1999.

Functionally, since sinking streams and cave streams are tributaries of base-level rivers by way of springs, they are all part of the river continuum, with the important distinction that the middle section is underground. These distinct but connected aquatic ecosystems are energetically supported by in-washed organic debris from the forest/savanna and former barrens ecosystems. Food transport is usually down gradient, but natural back flooding from the river through springs into the lower cave streams is also important. As base level rivers lower their channels, cave streams follow and leave dry upper levels. These passages become habitat for the terrestrial cave ecosystem, which is also dependent upon the forest/savanna and former barrens ecosystems for its food base. The import of food is mostly accomplished by cave crickets, bats, and packrats which feed in the forest/savanna above, and use caves for refuge where their guano accumulates.

Clearly, all of the component ecosystems within the karst landscape are functionally connected and must be managed holistically in order to realize our restoration goals. Fire is obviously a powerful determining force in vegetation communities. Whether a given area is prairie, savanna, or forest is governed largely by fire regime, and these vegetation types define habitats, including food supply, for a broad spectrum of wildlife. For the river and connected aquatic cave ecosystem, vegetation determines the amounts and quality of water, sediment, and organic matter that enter. For the terrestrial cave ecosystem, the types and quantities of insects, fungi and plants available to bats, woodrats, and cave crickets are largely determined by major vegetation types sculpted, in part, by fire.

Surface Habitat Types in Mammoth Cave National Park

Taking regional geography and hydrology into account, a vegetation habitat classification has been developed for Mammoth Cave National Park (Olson and Franz, 1998). This habitat classification combines bedrock geology, slope, and aspect in the Park's Geographic Information System (GIS) with a spatial resolution of 30 meters. The rationale is that for a given climate, bedrock geology largely determines soil type, and whether surface or subsurface (karst) drainage prevails. Soils on calcareous bedrock are pH buffered as the underlying rock is dissolved; soils on non-calcareous rocks tend to be more acid due to the lack of buffering. Because of this, the Kentucky State Nature Preserves Commission classifies habitats as "calcareous" or "acid" based upon bedrock type, and this plan follows their convention. Due to the tendency for subsurface drainage to develop in

calcareous bedrock such as limestone, virtually any site will be more xeric (dry) than an equivalent site underlain by insoluble rocks such as sandstone or shale. The magnitude of this general difference appears to be minimized on the steepest exposures due to rapid surface drainage.

One significant attribute of the habitat map is that natural physical influences on vegetation types are made clear, and in a quantitative way that is not attainable by direct study of geological quadrangle maps (see Table 1). This is especially important given the complex history of cultural disturbance over the past two centuries since settlement, and the profound impact on vegetation patterns seen today. For example, the vast majority of coniferous forest stands in the Park today are linked to pre-Park agriculture. Local environmental conditions amenable or inimical to fire are controlled directly and indirectly by the factors that determine habitat type. About half of the habitat types in the Park are variously prone to fire; habitat types not prone to fire are the Calcareous Mesic, Floodplain Alluvium, and the two Supra-Mesic classes. At over 9000 acres, the Calcareous Mesic habitat type is important for two reasons: the change in fuel type on these shaded slopes (Tim Sexton pers. com.), and the great linear extent of these habitat patches will impede the progress of fire across the landscape. The major habitat type at Hamilton Valley is calcareous subxeric, which is fire prone. Small areas of acid mesic habitat support fire tolerant species, but calcareous mesic habitats do not.

Condensed Vegetation Map of the Park

Vegetation in the Park has been classified into seven categories, and mapped based upon individual sorting of 200 Landsat satellite spectral data channels using the habitat map as a guide (Olson *et al.*, 2000). This vegetation classification is condensed in order to facilitate designation of fuel types for fire management. Not all categories occur at Hamilton Valley.

In subxeric deciduous forest, chestnut oak and chinkapin oak sort very distinctly with sandstone and limestone substrates respectively, whereas blackjack and post oaks are less selective. With periodic fire, these forest stands may have been a more open woodland or savanna in the past. Much of the relatively level plateau fragments, (locally called ridges) which will someday support oak-hickory forest and savanna, were in agricultural use prior to Park establishment. Within these mesic upland oak-hickory forests, the chemical and hydrological influence of relatively thin limestone units (calcareous subxeric habitat) interbedded with sandstone on the ridges is muted in comparison with the thick limestone beneath karst valleys. This is due to weathered sandstone

Habitat Type	Acreage	Percent of Park
Calcareous Xeric*	150	<1
Calcareous Sub-Xeric*	15,400	30
Calcareous Mesic	9,050	18
Calcareous Supra-Mesic	130	<1
Acid Xeric*	60	<1
Acid Sub-Xeric*	2,500	5
Acid Mesic*	20,000	40
Acid Supra-Mesic	1,000	2

Table 1. Areal Extent of Habitat Classes in the Park. Habitat types in with * are capable of carrying fire during the spring and fall fire seasons. These habitat types account for approximately three fourths of

residuum on top of the limestone, and the limited degree of karst development possible.

Mesic forests are most prominent in ravines directly connected with the Green and Nolin River Valleys, but outliers exist in karst valleys and in the bottoms of large sinkholes. In addition to beech and maple, black cherry and black walnut can be locally prevalent. Floodplain forests are characterized by sycamore, silver maple, and river birch on river banks, and box elder slightly further from the water. Being superbly adapted to the highly disturbance-prone gravel bar habitat, sycamore trees are also found wherever significant disturbance has occurred, such as along roads.

Mixed deciduous/coniferous (and vice versa) forests in the Park are overwhelmingly successional after pre-Park pasture and row crop use. These old fields are generally located in acid mesic habitats on relatively level uplands, in calcareous subxeric habitat found in karst valleys such as Hamilton Valley, and on floodplain alluvium. In mixed xeric communities/habitat types, Virginia pine is typically associated with chestnut oak, and eastern red cedar with chinkapin oak. Many of these stands appear to be virgin in contrast to the profoundly disturbed old fields. On xeric limestone sites, solutional features called rillenkarren indicate that the thin soil and exposed bedrock is not due to post-settlement erosion. The successional trajectory for old field forests is reasonably clear on the uplands (oak-hickory forest/savanna), and the floodplain (sycamore-box elder-elm), but in the karst valleys pre-settlement vegetation types are not known. Shingle oak is largely restricted to karst valleys, so this species may have been prevalent.

Coniferous forests in the Park, like the mixed stands previously discussed, are overwhelmingly successional after pre-Park agriculture. Stands in karst valleys are dominated by eastern red cedar, and those on sandstone uplands are mostly Virginia pine, but considerable mixing occurs. Commonly on the uplands around a nucleus of coniferous forest, a zone of coniferous/

deciduous forest is found, which is followed by a zone of deciduous/coniferous vegetation, transitional to oak-hickory forest. All elements are not present in each case, but forest succession is clearly documented. In the big karst valleys, the current successional trajectory is less clear. In the absence of fire, the karst valleys could easily become a subxeric oak-hickory forest with mesic hollow species in the sink bottoms.

Prairie in the Park is limited to small areas each no greater than 40 acres, and none can be considered actual remnants from pre-settlement times. Even so, these areas are rich in prairie grasses and forbs such as big bluestem, Indian grass, goldenrod, and tall coreopsis. They serve as refuges for species marginalized by conversion of former prairie on the sinkhole plain to agriculture, and by fire suppression within and beyond Park boundaries (Seymour 1997). Other open areas in the Park are largely mown roadsides, cemeteries, and lawns around developments maintained in fescue. Hamilton Valley vegetation types include open area/prairie, mesic slope forest, plus mesic upland, mixed, and coniferous forest. Some mixed stands are natural glade-like stands.

Brief Descriptions of Vegetation Communities

Cedar-Oak Stands - In the driest limestone habitat types (calcareous xeric and sub-xeric), especially on south to west facing slopes, cedar-oak stands prevail. These are sites where eastern red cedar is not successional, and where the inherent dryness of the site is an important factor in limiting growth of deciduous trees other than drought tolerant species such as chinkapin oak and blue ash. Based upon field observation of scars, fire is also a factor in limiting the invasion of more mesic species. However, given the vulnerability of eastern red cedar, fire intensity must be typically low, and the ability of cedars to grow right out of exposed limestone benches puts some distance between them and the meager fuel available.

Ridgetop Pine-Oak Stands – Located on the dry edges of sandstone cliffs facing south to west, acid xeric habitats support nearly pure but narrow stands of Virginia pine and chestnut oak. Analogous to the cedar-oak glades, these sites are where Virginia pine is not successional. Droughty conditions are clearly a factor in the maintenance of these stands, but the role of fire is not known. Observations in the field have failed to detect fire scars on either pines or oaks, so until the role of fire is better understood, these stands should remain low on the list of priorities.

Oak-Hickory Forest/Savanna – On broad uplands in the Park separated by large karst valleys south of Green River, oak-hickory forest covers relatively large areas of acid mesic-subxeric and calcareous sub-xeric habitat types which have been minimally disturbed. For now, the goal for prescribed fire in oak-hickory forest is to reduce the invasion of fire intolerant species such as beech and maple.

Karst Valley Forest/Savanna/Prairie

Pre-settlement vegetation types in karst valleys south of Green River, including Hamilton Valley, are unknown, and most of these large expanses of calcareous sub-xeric habitat were farmed prior to Park establishment. Research on stable isotopes of carbon and oxygen (Doral *et al.*, 1998) are needed to determine pre-settlement vegetation patterns back through time. Until these data are acquired, the goal for prescribed fire in karst valleys should be limited to maintenance of isolated prairie patches, and small-scale experiments in successional stands of cedar/pine.

Mesic Slope Forests – In some instances, portions of these steep, north-facing very moist habitat types could be included within a prescribed fire unit to make the fire line safer and easier to manage, but this fire-intolerant vegetation should not be forced to burn. Fire intolerant species such as American elm and butternut, which are put at risk by exotic diseases, may become more vulnerable to infection via fire scars.

Archaeological Indicators of Pre-settlement Fire

Miles of cave passages within the Park contain abundant artifacts left by Native Americans, mostly between 2000 and 3000 years ago. Much of this ancient material consists of plant remains from various uses, and these artifacts provide insight into some pre-settlement vegetation characteristics under similar climatic conditions. Data on pollen, recovered during archaeological investigation of Salts Cave in the Park, (Watson *et al.* 1974) indicate an abundance of lambs quarters in samples dated between 3000 to 3500 years before present (BP), followed by peaks in grasses and ragweed in strata above (still probably ca. 3000 years BP). The same study revealed an

increase in the occurrence of edible annual weed seeds in human paleofeces, including much lambs quarters, sunflower, sumpweed, amaranth, panic grass and maygrass. These plant remains indicate that vegetation conditions other than closed canopy forest existed since light intensity on the ground would have been inadequate. Use of fire to maintain openings in the forest would be consistent with practices elsewhere in eastern North America (Olson 1996). Prentice (1993) acknowledged a heavy emphasis on horticulture by prehistoric populations, but did not discuss fire.

Three types of plant stems were primarily used for torch fuels in local caves by Native Americans: cane, false foxglove, and goldenrod (Watson 1969, 1974). Olson (1998) noted that false foxglove was used dominantly in some Park caves, and that false foxglove is partially parasitic on the roots of oak trees (Pennell 1935). Musselman and Mann (1978) induced root parasitism with other tree species, but noted that large natural populations are found at the margins of oak stands. Given this parasitic relationship and the simultaneous requirement for adequate light if plant stems are to grow tall enough for use as torch material, oak savanna or openings bordering oak stands must have been much more prevalent than today since false foxglove is very infrequent in the Park (Seymour 1997). Oak savanna is a largely fire-dependent community, and the presence of this community type would be consistent with observations on the probable prehistoric slash and burn plant cultivation documented in the vicinity of Salts Cave. In Lawrence County, Ohio, ecological restoration via prescribed fire has resulted in significant increases in the abundance of false foxglove and other herbaceous species (Hutchinson 2000). This is consistent with the archaeological evidence at Mammoth Cave National Park.

Cane is primarily a lowland species in the region today, being largely confined to the Green River corridor and major tributaries. Watson (1969) noted cane torch remnants up to one inch in diameter, and that modern cane this size could not be found. She concluded that this cane likely came from bottomland sites under cultivation for edible species. Olson (1998) pointed out that cane was once much more widespread based upon the Filson Map of Kentucky (1784), and that the growth of large cane in a variety of habitats would simply require less competition; especially more light. The same situation would apply to goldenrod since it can only grow to a size useable for torches with adequate sunlight.

Archeological remains of slippers worn by Native American miners and explorers in portions of the Mammoth Cave System (Watson 1969; King 1974) were often manufactured from leaves of rattlesnake master. This species is restricted to savanna and prairie communities, and is currently very limited within the Park. Though it is possible that rattlesnake master was

harvested on the Sinkhole Plain and transported up to the Mammoth Cave Plateau, this species would have been much more abundant in savannas and glades on the plateau than it is today.

All of the food plants described above, the large plant stems used for torch materials while exploring and mining in caves, and the plants used for slipper material require more light than what is available in Park forests today. In the tiny areas within the Park where these species are currently found (some actual habitat remnants and others artificial, such as roadsides), their populations are severely limited. This scarcity compared with past abundance indicates that much less closed-canopy forest existed then compared with now, and modern suppression of fire is the most probable explanation.

A full inventory of Hamilton Valley plants might provide site-specific evidence of pre-settlement fire. A small patch of rattlesnake master, was found growing in the valley soon after CRF acquisition of the land; the patch has been sectioned off for protection. Current management of the plot prescribes periodic mowing.

Historical Vegetation Descriptions Relevant to Fire

The earliest historical description of vegetation on the Mammoth Cave Plateau was by Botanist Francois Michaux (1805) in 1802, and this was limited only to the view up from the Sinkhole Plain, most likely near Dripping Springs in Edmonson County, which is just southwest of the Park and Hamilton Valley: "The surface of these meadows is very even; towards Dripping Spring I observed a lofty eminence, slightly adorned with trees, and bestrewed with enormous rocks, which hang over the road..." The maintenance of prairie vegetation on the Sinkhole Plain by fire is very well documented, and Michaux stated: "Every year, in the course of the months of March or April, the inhabitants set fire to the grass, which at that time is dried up... The custom of burning the meadows was formerly practiced by the natives, who came to this part of the country to hunt." Michaux's description of savanna on the Mammoth Cave Plateau at the Chester Escarpment is further supported by place names on USGS Quadrangles in the Park City and Cave City vicinity such as Bald Knob, Brushy Knob, and Huckleberry Knob.

The earliest description of vegetation on the plateau away from the Chester Escarpment is by Alexander Bullitt. In the introductory chapter of an 1844 visitors' guide to Mammoth Cave he wrote: "For a distance of two miles from the Cave, as you approach it from the South-East, the country is level. It was, until recently, a prairie, on which, however, the oak, chestnut and hickory are now growing; and having no underbrush, its smooth, verdant openings present, here and there, no unapt resemblance to the Parks of the English

nobility." The two mile distance from the cave corresponds closely to the southern boundary of the Mammoth Cave Estate, which indicates land-use rather than a natural ecological origin for the former putative prairie become savanna, which is today a dense oak-hickory forest in mid to late succession. Other factors to bear in mind are that 1) this description is approximately 50 years post settlement, and 2) Mammoth Cave was intensively mined for saltpeter during the War of 1812. The process required a steady supply of firewood for the boiling furnaces, and yet more wood for production of fixed alkali (potassium hydroxide) used in the manufacturing process. Consequently, trees were cut from many acres of land for miles around in order to meet the demand (Faust 1967).

Hussey (1876) conducted a survey of plants in Barren and Edmonson Counties, and observed that Buffalo Clover (*Trifolium reflexum*) "occurs in several localities between the railroad and Mammoth Cave... I mention it because I have never found so many specimens in any one locality before, and also to make note of the fine rose-pink color it everywhere had."

DeFries (1880) reported in his 1878 timber survey across Kentucky: "On leaving Glasgow Junction [now Park City], toward Mammoth Cave, plenty of white oak is found in the sinks; post oak, black oak, scarlet oak, and red oak are found on the higher grounds, and as soon as the Chester sandstone, which caps the so-called hills, is reached, chestnut is found in great abundance. This is the first chestnut worthy of note found, and all that has been found, so far [from the Mississippi River to here], if a few bushes on the silicious limestone, near the Tennessee river, be excepted; though doubtless all this Chester sandstone, from Hopkinsville to Glasgow Junction, would have been covered with it, but for the fires that long ago swept over this richly timbered country, year after year, and drove its choicest trees from the forests".

"Again, forest fires have not denuded certain portions of the country in the neighborhood of Mammoth Cave. What is known as Doyle [or Doyel] Valley for instance, has been, for some reason, largely protected from the ravages of fire, even if the entire district has not been. From the growth of chestnut I am inclined to think it has never been continuously burned over... On the hill sides facing Doyle's Valley the trees are magnificent, and white oak, liriiodendron, white hickory, massive chestnut, scarlet oak, red oak, black oak, Spanish oak, chestnut, ashes and redbud &c., abound. The chestnut, however, is limited to the sandstone and stops abruptly when the limestone is reached descending the hill." DeFries's conclusion that Doyel Valley experienced a lower fire frequency based upon the growth of chestnut trees is a bit confusing since he clearly states that the chestnuts were only to be found on or near sandstone substrate which is

Vegetation	Habitat Type	Typical Species
1. Subxeric Deciduous Forest/Savanna	Acid SubxericCalcareous SubXeric	*Chestnut *OakPost *OakChinquapin *OakBlackjack* OakPost Oak
2. Mesic Upland Deciduous	Acid MesicCalcareous Subxeric	*White OakPignut HickoryBlack Oak
3. Mesic Hollow/Floodplain Deciduous Forest	Calcareous MesicAcid MesicAlluvium	***Sugar MapleBeechBox ElderSycamore
4/5. Mixed Deciduous/Coniferous Mixed Coniferous/Deciduous Forest	Acid MesicCalcareous SubxericAlluvium	**Red Maple **Tulip Poplar **Dogwood S**weetgumCedar/pine
6. Coniferous Forest	Acid Xeric to MesicCalcareous Xeric to Subxeric	Virginia PineEastern Red Cedar
7. Prairie/Open Area	Calcareous SubxericAcid Mesic	*Native Grasses and Forbs Mown Grass

Table 2. Vegetation, Habitat Types, and Typical Species. Habitat type nomenclature follows the Kentucky State Nature Preserves Commission system (Evans 1991). “Acid” refers to non-carbonate bedrock, which results in acid soil, and “calcareous” refers to carbonate bedrock, which results in more alkaline soil. Xeric refers to dry areas, mesic to moist, and alluvium to river laid sediments. Fire dependent/tolerant species are shown with *, assemblages (particularly

limited to the valley rim. Another caveat to bear in mind is that these observations were made approximately 90 years post settlement.

The observations of Michaux, Hussey, and DeFries are especially useful. The forest on the Chester Escarpment at Dripping Springs and everywhere else today has a solid canopy, and bears no resemblance to the savanna Michaux described. Buffalo Clover is a savanna or forest edge species, and even though Hussey’s survey was conducted approximately 80 years post settlement, the multiple occurrences indicate that this species, and therefore its habitat, was formerly widespread. Today, buffalo clover is “extremely rare” in the Park (Seymour 1997). In both cases, the observed botanical changes over time are consistent with the effects of fire suppression. DeFries observed the abundance of post oak (among others) in the area where Diamond Caverns is located today. Magnificent specimens of this extremely fire tolerant tree, old enough for DeFries to have seen when he passed through, are still found nearby. As well, he was specific in pointing out where the effects of fire appeared less manifest (Doyel Valley), and in doing so clearly implied that fire effects were more general in the Mammoth Cave vicinity.

Regional Fire Ecology

Study of pollen cores from Jackson Pond, located about 30 miles northeast of Mammoth Cave on the Sinkhole Plain (less than a mile from the Chester Escarpment), indicated

that from about 3900 years before present the region had a mix of prairie and deciduous forest. Whether the prairie had its origins in climatic change, or was the result of human actions is not known (Wilkins *et al.* 1991, pp.236-7). When Michaux described the annual spring fires on the Sinkhole Plain in 1802, a primarily cultural source of ignition was apparent to him. Ray (1997, p.188) acknowledged the role of Native American set fire in the maintenance of prairie and savanna, but also made a convincing argument for the importance of lightning ignited fire as a force affecting vegetation patterns in the Mammoth Cave area. Oak ecosystems in eastern North America have co-evolved with fire (Abrams 1992, Olson 1996), and the relationship between savanna and oak forest has only recently been recognized. Some compilations of the distribution and status of the oak hickory, savanna complex don’t acknowledge that the type occurs in Kentucky, but more recent treatments depict the Mammoth Cave region as having been a mixture of savanna, prairie and forest.

There are two fire seasons in the Mammoth Cave area, one in spring from March 1st to May 15th, and the other in fall from October 1st to December 15th. Given that many herbaceous plants remain alive and even bloom into late October (Seymour 1997), fuels are not as consistently dry in fall as in the spring, and leaves do not typically finish dropping until late October. Other points favoring the spring fire season over fall are that the effects of spring fires are generally more beneficial to many types of wildlife since the seed crop of the previous growing season has already

been consumed and/or dispersed during the winter, and that nutrients from the ash are less likely to be washed away before germinating plants can absorb them. The annual spring fires described on the Sinkhole Plain by Michaux would tend to propagate up the Chester Escarpment, which faces primarily south in the Mammoth Cave area. This southern aspect of the escarpment is conducive to drying fuels, and since the prevailing wind is from the south, the escarpment would function as an excellent fire ladder to the Mammoth Cave Plateau. DeFriese's observation of post oak between Glasgow Junction (Park City) and the escarpment is consistent with frequent fire.

East of Turnhole Spring, the Park is characterized by mature karst which includes the Mammoth Cave System plus other major caves, and very limited perennial surface streams. Large segments of the plateau including Joppa Ridge, Mammoth Cave Ridge, and Flint Ridge are relatively level and well drained except for isolated wetlands with vernal pools, and short spring runs. The only major barriers to northerly propagation of fire in this sector of the Park are the shaded Calcareous Mesic slopes described above which serve as fuel breaks where fire would be required to burn down slope into fuels with greater moisture content. Isolated patches of particularly xeric habitat on slopes with high sun exposure will also retard fire due to low amounts of fuel. Similarly, outside the southern boundary of the Park there are few barriers to fire on this highly dissected portion of the Mammoth Cave Plateau known as "The Knobs" due to lack of surface streams, and also due to extensions of the Sinkhole Plain into the escarpment.

The southern edges of Woolsey and Doyel Valleys are only about two miles from the Chester Escarpment, and therefore close to a reliable annual pre-settlement ignition source. In the Park City area, fingers of the Sinkhole Plain cut into the escarpment and narrow the gap to within a half-mile. These valleys have the same karst hydrogeology that exists on the Sinkhole Plain, therefore, no surface streams are present to inhibit the spread of fire. Based upon the foregoing, it is conceivable that the annual spring fires on the Sinkhole Plain spread into these two valleys with some frequency. Unfortunately, we have no early historical information on vegetation or fire frequency in these or any other karst valley in the Park. DeFriese's conclusions on Doyel Valley did not support frequent fire, but being roughly 90 years post settlement, the appearance at that time could just reflect land use preferences. An attempt to find silica phytoliths and charcoal in soil as indicators of past vegetation type and fire regime had negative results (Kaliz 1997). Carbon and oxygen isotope studies of speleothems in cave passages underlying these karst valleys can provide information on major vegetation type and climate (Dorale et al. 1998), and these will be pursued in the future.

The eastern edges of Houchins Valley (including contiguous Eaton and Strawberry Valleys) and the smaller karst valley leading to Dennison Ferry are both over four miles from the Chester Escarpment, and not directly downwind from the documented annual fires on the Sinkhole Plain. Therefore, it is less likely that fire from the Sinkhole Plain propagated into these valleys when compared with Woolsey and Doyel Valleys. Ignitions in Houchins Valley via cultural or natural sources would easily spread up onto Flint Ridge and propagate north with the prevailing southerly winds. Ignitions from lightning are possible on any of the ridges, and lightning scars on trees are common. Considering the full range of habitats modeled and mapped in Mammoth Cave National Park, over 40,000 acres or about 75% of Park lands are capable of carrying fire under the normal range of weather conditions during the fire seasons.

Fire Management Units and Prescribed Fire Areas

To the greatest extent possible, each Fire Management Unit is designed as a defensible polygon in the event of wildfire. Boundaries consist of rivers, ravines and roads within the Park, and the Park boundary around the outer perimeter. At least one Prescribed Fire Area was selected per Fire Management Unit. The process for selection of Prescribed Fire Areas with ecological criteria was GIS-based. Only habitat types that would naturally support fire dependent or tolerant vegetation communities were included. Next, vegetation was considered, and the overwhelming majority of Prescribed Fire Areas consisted of vegetation mature enough to benefit from fire. Limited areas of successional vegetation were included as part of an adaptive management strategy, and fire should be applied in these areas with caution and careful study.

Conclusion

Consideration of fire management at Hamilton Valley should take into account such factors as current vegetation patterns, expected outcomes, the potential impact on existing structures (e.g., the house in the valley), and certainly safety considerations. Some, though not all, anticipated results can be mimicked by mowing practices which would certainly eliminate the risks inherent with burns. On the other hand, those risks can also be minimized by careful planning. If the Land Management Committee decides to initiate a prescribed fire program for Hamilton Valley, they should start with a small section and work with professionals such as the Kentucky Department of Fish and Wildlife Resources and the Nature Conservancy.

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Geoscience

Microsampling and Isotopic Analysis of Adjacent Fluorescent/Non-Fluorescent Band Couplets in a Midwestern Speleothem

Rhawn F. Denniston

Introduction

Since the 1970s, speleothems (cave deposits such as stalagmites, stalactites, and flowstones) have been used to reconstruct decadal/millennial-scale paleoclimatic changes. More recently, Shopov, Ford, and Schwarcz (1994) and Baker, Smart, Edwards, and Richards (1993) demonstrated the (sub)annual nature of fluorescent banding in speleothems. Microsampling and isotopic analysis of sub-annual speleothem growth bands may, therefore, provide new insight into subannual variability in some continental settings. To test this hypothesis, the uppermost portion of a single calcite stalagmite from Crystal Cave, Wisconsin, was microsampled and analyzed for stable carbon and oxygen isotopic ratios across fluorescent growth horizons (Figure 1).

Origin of Fluorescence in Speleothems

Fluorescence in speleothems originates from organic acids produced by plant activity in soils overlying the cave and which are incorporated into the speleothem by infiltrating meteoric fluids. Fluorescent speleothem bands (typically <200 μm thick) are therefore believed to represent calcite crystallization from drip-waters that infiltrated through the soil zone when plant activity was high (e.g., late spring - early fall) while non-fluorescent zones delineate growth during late fall - early spring. This interpretation is supported by the observation that the uppermost layer of a Midwestern stalagmite, collected in January, 1992, is non-fluorescent and by $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data of individual fluorescent band couplets (see discussion and figures below).

Research Techniques

Mosaics of fluorescent bands were constructed using laser Confocal scanning laser microscope imaging techniques at the University of Iowa Eckstein Medical Research Facility. These images were correlated with reflected light photomicrographs as maps for microsampling. Individual fluorescent and non-fluorescent bands were sampled using the microdrilling apparatus developed and maintained at the

University of Michigan's Stable Isotope Laboratory. Drilling is performed laterally instead of vertically, thereby allowing sampling of zones considerably narrower than the drill bit (Dettmann & Lohman, 1995). The resulting microgram-sized powders were analyzed for carbon and oxygen stable isotopic ratios at the University of Michigan using a Finnigan MAT 252 stable isotope mass spectrometer.

Speleothem $\delta^{13}\text{C}$ & $\delta^{18}\text{O}$ Values as Paleoclimatic Indicators

Since the pioneering work of Schwarcz et al. (1976) and Harmon et al. (1978), the oxygen isotopic composition of speleothems has been examined as a record of changing continental climate. More recently, Dorale, Gonzalez, Reagan, Pickett, and Baker (1992) linked carbon isotopic values to vegetation and attributed a rapid shift in speleothem $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values to changing climate conditions in the upper Midwest at ~5700 ybp. They attributed a gradual shift in $\delta^{13}\text{C}$ values and a concomitant rapid shift in $\delta^{18}\text{O}$ values to rapid climatic change (on the scale of a few decades) and a slower (a few centuries) vegetative response (C_4 to C_3 vegetation).

The oxygen isotopic composition of speleothem calcite reflects the $\delta^{18}\text{O}$ (standardized $^{18}\text{O}/^{16}\text{O}$ ratio) value of precipitation and the temperature at which the carbonate precipitates from cave dripwater. When calcite is precipitated under isotopic equilibrium with dripwater in deep, poorly ventilated caves where temperatures of calcite crystallization are constant throughout the year, the temperature dependence of precipitation $\delta^{18}\text{O}$ values and the correlation for mean annual surface temperature (Dansgaard, 1964) can be combined into the generalized calcite-water fractionation equation (Friedman & O'Neil, 1977) to yield temperature/ $\delta^{18}\text{O}$ relationship of $0.3\text{‰}/^\circ\text{C}$ (Dorale et al., 1992).

The carbon isotopic composition of speleothems is a function of $\delta^{13}\text{C}$ values of carbonate bedrock hosting the cave and of soil CO_2 produced primarily by root respiration and decay of organic matter (Ture, 1986). Plants using the Calvin, or C_3 photosynthetic pathway (e.g., trees, shrubs, forbs), have average $\delta^{13}\text{C}$ values of -26‰ PDB (Pee Dee Belemnite

isotopic standard), while Hatch-Slack, or C_4 pathway plants (e.g., many prairie grasses), have $\delta^{13}C$ values averaging -13‰ PDB (Deines, 1980). Because $\delta^{13}C$ values of soil CO_2 are related to vegetation type, the carbon isotopic composition of speleothem calcite can record vegetation signals (Dorale *et al.*, 1992). Thus, as prairie replaced forest during the mid-Holocene, $\delta^{13}C$ values increased. The thin soils overlying caves in the Ozarks are incapable of significant carbon storage and thus vegetation signals are immediately translated into the subsurface and are not buffered by old, slowly decomposing soil organic material. Stalagmites, therefore, are sensitive to even subtle or short-lived vegetation changes.

Results

Both carbon and oxygen stable isotopic ratios differ between adjacent fluorescent and non-fluorescent zones (Figure 2). Both $\delta^{13}C$ and $\delta^{18}O$ values are $<1\text{‰}$ lower in non-fluorescent bands than in adjacent fluorescent bands. Instrumental precision is capable of clearly defining these differences, however the because these bands are not visible under plain light and because of the moderate limitations of this microsampling system, it is possible, and indeed likely, that at least some of these analyses incorporate more than one individual band. This homogenization would be expected to decrease seasonal differences in stable isotopic signatures.

Seasonal Shifts in $\delta^{18}O$

The seasonal temperature range implied by the shift in $\delta^{18}O$ values between fluorescent and non-fluorescent bands is substantially smaller than actual conditions. Homogenization of infiltrating meteoric waters may be responsible, but this model would require infiltration times on the order of months. Another possibility is that fluorescent bands do not succinctly delineate seasonality. Instead, fall infiltration may flush organic acids from the soil zone thereby a recording in the stalagmite a more depleted isotopic composition than would be expected from summer precipitation. Although overlap of bands during sampling is unlikely, the effect of fluorescent calcite contamination of a nonfluorescent band would be negligible because of the small volume of fluorescent bands relative to non-fluorescent bands. Therefore, any minimizing of the shift between the isotopic values of fluorescent and non-fluorescent bands must be due to artificial lowering of fluorescent $\delta^{13}C$ and $\delta^{18}O$ values in fluorescent bands by non-fluorescent bands.

The two sources of southern Wisconsin precipitation are Gulf and Gulf-Pacific, with Gulf-Pacific of increased

importance during winter months (Simpkins, 1995). Simpkins (1995) reported a range in $\delta^{18}O$ values of -0.14 to -23.87‰ with a weighted mean of -8.02‰ for Iowa precipitation in 1992. Despite this considerable variance, this study identified a strong seasonal relationship between monthly mean surface temperature and $\delta^{18}O$ values. Precipitation $\delta^{18}O = -10\text{‰}$, back-calculated using calcite $\delta^{18}O$ values, falls close to the lighter end of Iowa summer (-9 to -2‰) precipitation values reported by Simpkins (1992). When corrected for latitude, this value may fall well within the range of normal summer precipitation $\delta^{18}O$ values.

Seasonal Shifts in $\delta^{13}C$

The $\delta^{13}C$ value of speleothem calcite is controlled by the compositions and solubility's of soil CO_2 and the carbonate rock hosting the cave. However, assuming infiltrating fluids are restricted to well-developed infiltration pathways, changes in speleothem $\delta^{13}C$ will be related to fluctuations in organic acid productivities in the soil zone overlying the cave. Ode *et al.* (1980) examined seasonal shifts in $\delta^{13}C$ values of a Mixed Prairie (containing both C_3 and C_4 vegetation) in the Northern Great Plains. They report low $\delta^{13}C$ values in spring, increased $\delta^{13}C$ values in summer, and finally a return to low $\delta^{13}C$ values in fall. Although temporal changes in the carbon isotopic composition of infiltrating fluids may be diluted by degradation of pre-existing organic material, rapid infiltration rates or short infiltration pathways (i.e. along conduits) may preserve this $\delta^{13}C$ signal. As discussed above, changes in infiltration pathways might alter water/rock interaction ratios, thereby changing fluid isotopic compositions. In addition, a temperature-related decrease in the solubility of organic acids coupled with an increase in calcite solubility might affect $\delta^{13}C$ values of speleothem calcite. Although the direction and magnitude of the isotopic shift between fluorescent and non-fluorescent bands is similar, evaporation and kinetic effects related to accelerated out-gassing of CO_2 are unlikely because the speleothem is composed of dense, optically clear calcite, suggestive of slow, near-equilibrium crystallization. The enrichment of $\delta^{13}C$ values in fluorescent bands over adjacent non-fluorescent bands may be explained by flushing of organic acids from the soil zone during warmer parts of the year when C_4 productivity is high.

Conclusions

Preliminary isotopic investigations of adjacent fluorescent band couplets reveal a small ($<1\text{‰}$), but apparently significant shift in $\delta^{18}O$ and $\delta^{13}C$ values. For caves with short infiltration paths or rapid infiltration rates, homogenization of infiltrating fluids may be minimized, thereby maximizing the isotopic shift between fluorescent and non-fluorescent

bands and allowing a better estimation of seasonality from speleothem calcite. The shift in oxygen isotopic values may represent seasonal changes in meteoric precipitation and/or cave temperature, although teasing the relative importance of each of these variables from this data set requires a better understanding of cave hydrology and the requisite studies by the cave owners are currently underway. Carbon isotopic shifts may be linked to seasonal differences in soil organic matter decomposition, the activity of C_3 vs. C_4 vegetation over the cave, or cave hydrology (affecting such variables as the degree of calcite saturation of the dripwater, the degree of out-gassing of CO_2 prior to calcium carbonate deposition onto the speleothem, etc.).

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Sedimentology of the Redwood Canyon Karst, Kings Canyon National Park

John C. Tinsley

Monitoring of sediment movement, sinkhole development, and sinkhole evolution in Redwood Canyon, Sequoia, and Kings Canyon continued in 2001-2002. Owing to a cool spring season that limited the rate of snowmelt in the front-country, peak levels of runoff were limited, with spring of 2002 runoff registering about 1 foot greater amplitude in central Lilburn Cave compared to the spring of 2001 season. Sediment scour and fill events in Lilburn Cave were unremarkable. An unusual event was an early winter storm that dumped 12 inches of rain falling on dry ground in about 36 hours into Redwood Canyon. The storm eroded much duff and leaf fall from the channels, but did not seem to cause widespread flooding in the canyon. The discharge was great enough to wash a medium-sized cedar tree across the CRF's stream monitoring station in Redwood Creek, located about 100 m downstream from where the Hart Tree Trail crosses Redwood Creek, effectively destroying the sensors and cables, as well as ripping away the stage-recorder stilling tower from its moorings. Fortunately, the data logger was not damaged. This station will have to be repaired this summer.

The Pebble Pile sinkhole continued to stope headward, and at its nearest point is about 12 feet from the present position of the Redwood Canyon trail that leads to Big Spring, the resurgence of Redwood Creek water from Lilburn Cave. Eventually the trail will have to be relocated, but there is plenty of room to do that. Two new sinkholes were noted in the karst in 2002, and none were noted in 2001.

The National Park Service is planning to conduct a controlled burn, or series of controlled burns in Redwood Canyon beginning in about 4-5 years. This will afford us a great opportunity to install some instrumentation and monitoring points in several sinkholes within the caves and karst, in order to observe the impacts of the burning on the caves and karst features, especially in terms of rates of sediment yield to sinkholes. This will probably be a cooperative study conducted with the cave management folks at SEKI (Joel Despain).

Contaminant Source and Transport in a Karst Groundwater Basin

Patricia Kambesis
Western Kentucky University

Introduction

Agricultural land use in areas that overlie karst aquifers negatively impact groundwater quality because karst terrains provide multiple, direct hydrologic connections from the surface into groundwater aquifers (White, 1988; Quinlan 1989). The connections and rapid velocities associated with surface and subsurface flow in karst aquifers allow for contaminants to move quickly into and through a groundwater system (Vesper *et al.*, 2001.) When karst groundwater returns to the surface via springs, any contaminants within the water become part of surface streams and rivers (Alexander and Lively, 1995). These in turn, affect water quality in areas located downstream of the spring outputs. The purpose of this study was to identify the source and movement of agricultural contaminants in a karst groundwater basin within the context of local climate, hydrogeology and land use.

Study area

The study area is located within the Corn Belt region of the Upper Midwest, in northeast Winneshiek County, Iowa and southeast Fillmore County, Minnesota USA. (Figure 1). The Upper Iowa River is the regional base-level drainage of the area and it flows 60 km east to its confluence with the Mississippi River. Land use in the Upper Iowa River Watershed is predominantly agricultural in nature. Corn (22%) and soybeans (19%) are the most commonly grown crops (UIRW Report 2004). Grassland and forest cover occupy 35% and 19% of the watershed respectively.

The local bedrock consists of Cambrian, Ordovician, and Devonian sandstones, shales, limestones and dolostones that were deposited in a series of transgressive and regressive cycles. The lowermost units are predominantly sandstones with shale and carbonate beds. These strata grade upward into carbonate sequences containing subordinate sandstones and shales. The uppermost sedimentary sequences are composed entirely of carbonates. Locally, the Ordovician Galena Group directly underlies the land surface and in descending order consists of the Dubuque, Wiselake, Dunlieth and the basal unit of the Decorah Formation. The rock units form the Galena aquifer that is one of the major agricultural water sources for most of the region (Hallberg *et al.*, 1983) and to a lesser degree still serves as a water source for some of the residents of the area. The upper unit of the Decorah Forma-

tion is composed of calcareous shale which serves as an aquaclude that prevents shallow groundwater from entering the deeper carbonate aquifers of the region.

The surface watersheds of the study area are formed within a highly karstified landscape that is drained by surface creeks and by conduit flow. A series of three dye traces that were conducted in 1986 (Wheeler 1986) identified the conduit flow route of Coldwater Cave. The cave system, which is formed in the Dunlieth Formation, is part of the the Coldwater Cave groundwater basin which underlies the Pine Creek and Cold Water Creek watersheds. Streams from both of the watersheds lose water to the Coldwater Cave System either via swallets or through stream sieves. During rain events or snow melt, sinkholes in the study area also contribute recharge to the groundwater basin.

The stream passage of Coldwater Cave resurges at two spring outlets and an overflow spring. The main spring resurgences are Coldwater Cave Spring which has a dis-

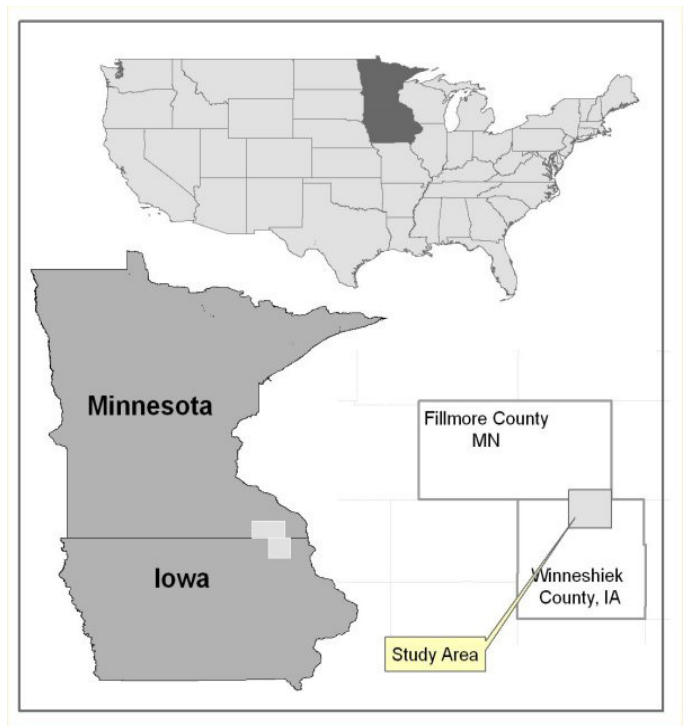


Figure 1. Study Area, Winneshiek County, Iowa and Fillmore County, Minnesota

charge rate of 549 liters/sec during base flow conditions (Koch and Case, 1974) and Carolan Spring with a discharge of 150 liters/sec. Both springs forms runs that flow to the Upper Iowa River located a kilometer to the southeast.

Previous analyses of water quality results documented that both surface streams and groundwater within the basin contain high concentrations of nitrates, bacteria, and pesticides (Upper Iowa RC&D, 2004). Evaluation of water quality data showed that temporary degradation of water quality is significant after storm events. Long-term water quality testing has shown that agricultural contaminants can affect the quality of water supplies from local shallow water wells and can impact the drinking water supplies of the town of Decorah, Iowa, located 6 km downstream of the study area. Both springs were used as monitoring sites during dye traces and for sampling for water quality.

Coldwater Cave Groundwater Basin:

Between June 2002 and August 2003, karst hydrogeologic feature inventories, surface stream inventory, and ten dye traces were conducted that identified four karst groundwater basins in the study area. There are discrete drainage divides between each basin but they can change depending on flow conditions. The Coldwater Cave groundwater basin is the largest of the basins in the study area.

The Coldwater Cave groundwater basin displays allogenic and autogenic recharge. The region is mantled with quaternary sediments, that range in thickness from fifteen to twenty-two meters in the northern reaches of the groundwater basin and thin to as little as two meters or less to the southwest. The mode of recharge in a particular part of the basin is a function of the thickness of the quaternary sediment that mantles it in that area.

Contaminant Source and Transport

Land use in the Coldwater Cave groundwater basin is predominantly agricultural in nature. This is reflected in the constituents of the groundwater. Nitrates, bacteria and pesticides all display levels that are a function of anthropogenic interactions with the landscape.

In the study area, nitrate levels usually don't exceed the 10mg/L standard set by the EPA for drinking water but are well above the natural environmental levels of 2 mg/l. Nitrate concentration is related to land use. Nitrate is soluble in water so nitrate load is a function of stream discharge. Preliminary results from nitrogen isotope sampling indicate that the one of the sources of nitrates are NH_4^+ fertilizers.



Main stream passage of Coldwater Cave
photo: Scott Dankof

Bacteria levels range between 10 and 36 c/100 ml however can spike well into the tens of thousands during storm events. Elevated levels of bacteria also result from annual snow melt events that occur when temperatures begin to fluctuate between freezing and above-freezing. Bacteria is transported to the groundwater system by runoff events.

There are 42 livestock operations in the basin including 4,003 head of beef, 860 hogs, 599 dairy and 290 heads of sheep (Upper Iowa River Watershed Report 2004). According to a farm survey conducted in 2003, over 19,000 tons of waste are generated. Since most operations don't have waste storage structures, it is common practice to scrape and haul manure out to the fields throughout the year. Currently there are 120 homesteads in the study basin. According to the Winneshiek County Sanitarian (2003), over 30% of all septic systems are not functioning properly. This can result in human sewage entering the groundwater basin.

Preliminary results from a ribotyping project indicate that the source of bacteria is cattle and humans (Skopec *et al* 2004). The study also showed that other animals also provide sources of bacteria but the small isolate sampling size did not allow a thorough identification of other bacterial sources.

Atrazine is a man-made substance so there are no "natural" background levels of this material in the environment. Atrazine

zine and metabolite levels tested very low in the study area which seems unusual in an agricultural setting where 32% of row crops are corn. However, it is the location of most corn crops in the basin that can be attributed to the low levels. Most of the corn is located in the allogenic part of the basin where diffuse infiltration (diffuse allogenic flow) into the ground and ultimately to the groundwater is the predominant mode of groundwater recharge. The load of atrazine and its metabolite are a function of application season and discharge.

The ratio of atrazine to its metabolite indicate that atrazine has had a long residence time in the soil allowing it to be degraded to its metabolite (Thurman & Fallon 1996). Despite the low concentrations of both atrazine and metabolite, the pesticide load increases during the application season and periodically spikes after events that produce runoff. Despite the fact that atrazine levels are well below the EPA minimum levels for drinking water (3ppb) little is known about the effects on humans, of long-term exposure to low-level mixtures of pesticide compounds, punctuated with seasonal pulses of high concentrations.

Climate

Climate is the main factor that drives the hydrogeology of the basin, that provides the means for contaminants to get into the groundwater system, and that greatly influences contaminant loads.

The behavior of the aquifer is dictated by storm events and melt water runoff. The velocity of transport of discharge and of contaminants depends on the state of hydrologic base level conditions which is a function of climate.

Conclusions:

The purpose of this study was to identify and quantify the source and movement of agricultural contaminants within an shallow, unconfined karst aquifer. Dye tracing, both qualitative and quantitative, resulted in the delineation of the Coldwater Cave Groundwater basin and determination of hydrologic flow paths within the basin. Investigation of basin and aquifer characteristics, and evaluation of cave map data and karst feature inventories established the relationship between surface and subsurface hydrogeology. Water sampling and analysis documented the quality of the surface water and groundwater within the basin. The sources of pesticides, nitrates and bacterial contaminants were determined using isotopic analysis, ribotyping, and general water quality testing. Review of data collected by other researchers during different flow and climate conditions and integration of that data with the dataset for this study allowed a comparison of groundwater flow in base and high water level conditions. Analysis of cave and surface stream temperatures, hydrograph data, and climate records con-

firmed the relationship between surface climate and cave conditions and illustrated the seasonal nature and event-dependence of groundwater flow and agricultural pollution. Evaluation of land use within the basin quantified the amount and type of agricultural land use within the basin. Integration of this information and data into a Geographic Information System aided in aquifer and basin analysis, allowed further study of aquifer and basin characteristics, and resulted in a better understanding of the relationship of climate, hydrogeology and land use in a fluvio-karst groundwater basin.

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International Programs

The China Karst Environmental Project

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Introduction

An increasingly energetic collaboration between the Western Kentucky University Hoffman Environmental Research Institute, the Cave Research Foundation, and the Institute of Karst Geology in Guilin, China is developing an infrastructure to study environmental problems and solutions in southwest China's karst regions. China has extensive and spectacular karst areas, including an area that covers much of eight provinces of south China, covering 500,000 km² and providing a home to 80 million mostly rural citizens. The beautiful *tower karst* areas of southwest China, typified by the famous landscape paintings and scenes from the Li River and Guilin area, are among the most well known of China's landscapes, providing the scene China's the twenty yuan note. Unfortunately, karst areas provide significant environmental challenges, especially with regard to water resource development. Problems are common with both water quantity and quality. During a research trip to China in early 2002 we became aware of the severe, natural, metal contamination problems in Guizhou, and have started discussions with USGS scientists who have been working on these issues.

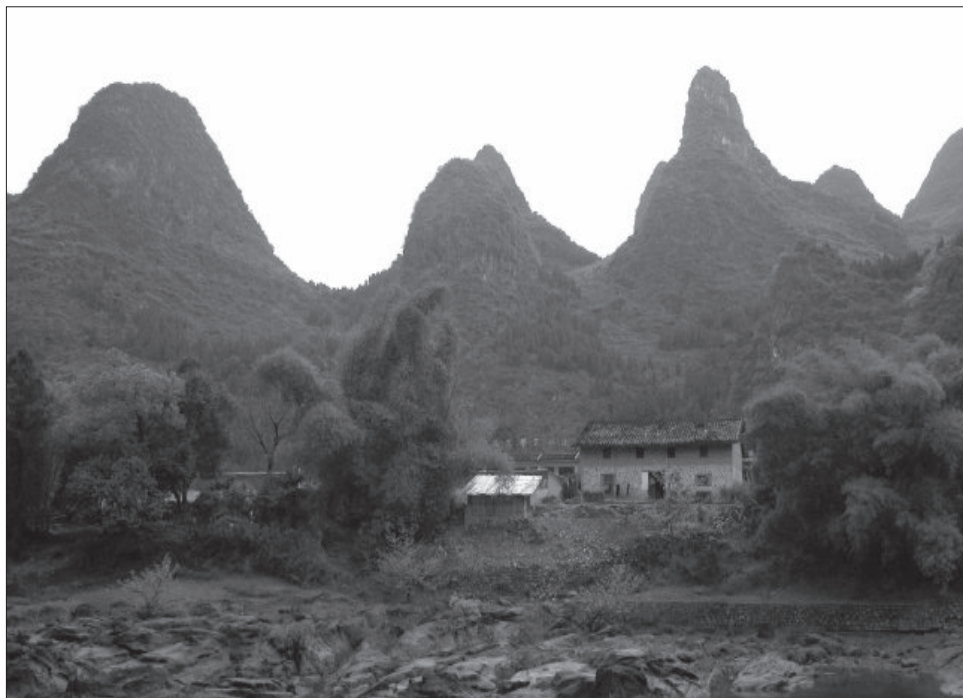
CRF first went to China in

In June, 2000, Chris and Deana Groves, along with Alan Glennon, traveled to Guilin, China, in a cooperative research project between the Hoffman Environmental Research Institute at Western Kentucky University, the Cave Research Foundation, and the Karst Dynamics Laboratory (KDL) of the Institute of Karst Geology of the Chinese Academy of Geological Sciences. With roughly 300 karst geologists, hydrologists, and graduate students in residence, the Institute is the primary karst research center in the China. It is an agency of China's Ministry of Land and Resources (roughly equivalent to a combination of the US Geological Survey and the US Environmental Protection Agency), and is re-

sponsible for karst resource management. The city of Guilin, on the Li River, has a long-standing reputation as a setting of great beauty, and has developed as a significant domestic and international tourist destination. The economic benefits of tourism have led Guilin to become one of the more prosperous regions of southern China. An important aspect of this prosperity is that it has given the region the resources to begin to concentrate on solutions to environmental problems.

Project Background

Hoffman Institute scientists and students, overlapping with CRF personnel, began working with our Chinese partners in 1994, Chris and Deana hosted Professor Zhang Shouyue, a leading karst scientist with the Chinese Academy of Sciences in Beijing, for a week at Mammoth Cave during a US lecture tour. Professor Zhang interacted with numerous students and scientists at WKU and Mammoth Cave National Park, and gave several lectures on research projects in China. In 1995, Chris and Deana visited Guilin and the KDL for the first time, where he presented results of carbonate geochemistry research in the Mammoth Cave area. While in Guilin, he also discussed UNESCO's International Geological Correlation Program (IGCP) Project 379: Karst Processes and the Global Carbon Cycle, with the project's director and Karst Institute founder Professor Yuan Daoxian. This began a period of collaborative work in support of IGCP Project 379. During the trip, they also visited Beijing to meet with Professor Zhang at the Chinese Academy of Sciences. In 1998, a group of organizations including CRF hosted a successful international meeting of IGCP Project 379 in Bowling Green, Kentucky. Three members from the KDL attended the Kentucky meeting along with another 110 scientists and students from a total of 17 countries. Many of those in attendance were among the top karst scientists in their respective countries, and the meeting was very successful in promoting the goals and results of the project. Nearly \$20,000



Karst towers along the Li River, China, photo: Chris Groves

in funding was obtained from WKU, the National Park Service, American Chemical Society, Cave Research Foundation, and the Karst Waters Institute to support travel and registration expenses of students and scientists from around the world.

Project Summaries

The following comes from the China Environmental Series #5, published by the Woodrow Wilson International Center for Scholars in Washington, D.C., and summarizes the organization of the various past and current projects associated with the

UNESCO International Geological Correlation Program (IGCP), Project 448: "Global Correlation of Karst Geology and Relevant Ecosystems"

Partners: Institute of Karst Geology, Guilin, Guangxi (Chinese Academy of Geological Sciences, Ministry of Land and Resources), International Association of Hydrogeologists, International Geographical Union, International Union of Speleology, (US) National Park Service, Cave Research Foundation, Karst Waters Institute

Focus: Interdisciplinary Karst Ecosystem/Hydrogeology/Biogeochemistry Research

Funding: IGCP Project 448, Western Kentucky University, Institute of Karst Geology

Status/Schedule: 2000-2004

Karst landscape/aquifer systems are formed on highly soluble rocks such as limestone, and are characterized by such features as caves, underground rivers, and large springs. One of the world's great karst regions covers a half million square kilometers within eight provinces of southern China. The purpose of IGCP Project #448 is to enhance international communication and cooperation among scientists studying both the physical and biological components of karst ecosystems, including human activities. It is directed by scientists from the Institute of Karst Geology (Guilin, China), the Hoffman Environmental Research Institute (Kentucky, USA), and the Centro di Studio per la Faunistica ed Ecologia Tropicale (Firenze, Italy). A ten-day field excursion was organized through the karst areas of southwest China in September 2001, and international conferences are planned for Spain in 2002 and Kentucky in June 2003, cooperatively with the other three primary international groups investigating karst issues (see *Partners* above).

Workshop on Geographic Information Systems (GIS) for Karst Water Resources in Southwest China

Partners: Institute of Karst Geology, Cave Research Foundation

Focus: Analytical Tools for Water Resource Investigations

Funding: Western Kentucky University, Institute of Karst Geology, Guilin, Cave Research Foundation

Status/Schedule: Initiated 2000, completed with follow-up visit in 2002

Geographic Information Systems (GIS) computer technology provides powerful tools for the analysis of spatial data, and is widely used in environmental, economic, and planning investigations. In 2000 we conducted a three-day workshop at the Institute for Karst Geology in Guilin on the use of GIS for water resource investigations. The workshop focused on analysis and visualization of three-dimensional relationships common in groundwater quality and quantity investigations using Arcview extensions. An outline manual detailing procedures for GIS analysis of karst underground river surveys was translated into Mandarin. A follow up visit to Guilin in 2002 showed that the group had obtained an impressive level of sophistication with the technology, having used it to complete several significant projects, including an extensive structural karst geology analysis at the proposed site of a large airport near Guangzhou, Guangdong.

UNESCO Geological Correlation Program, Project #379: "Karst Processes and the Global Carbon Cycle"

Partners: Institute of Karst Geology, Cave Research Foundation, (US) National Speleological Society, Karst Waters Institute

Focus: Greenhouse Gas Budgets

Funding: Western Kentucky University, (US) National Park Service, Institute of Karst Geology (Guilin), American Chemical Society Petroleum Research Fund, National Speleological Society, Cave Research Foundation, and Karst Waters Institute

Status/Schedule: The original Project period was 1995-1999; collaborative research evolving from the Project is ongoing

Biogeochemical processes within karst areas, which cover some 12% of the Earth's land surface, consume carbon dioxide gas from the atmosphere, but the rates are not well known. Since 1995 our groups have jointly developed new methodologies for the measurement of the karst-associated carbon sink through seven collaborative field excursions (five US to China, two China to US). In 1998 an international conference of the Project in Kentucky attracted 110 scientists from

17 countries. 2002 we installed water monitoring equipment, conducted training on the equipment and data analysis, and began long term monitoring of the carbon sink near Yaji, Guangxi as the fifth field station of a developing global network.

Project on Karst Landscape-based Tourism and Environmental/Economic Development in Guangxi and Guizhou, China, and Kentucky, USA

Partners: Institute of Karst Geology, Guilin Tourism Development Corporation

Focus: Economic Development Through Landscape-Based Tourism

Funding: Western Kentucky University, Karst Research Institute, Guilin Tourism Development Corporation

Status/Schedule: Initiated 1998, ongoing

Guangxi and Guizhou Province of southwest China and south central Kentucky both have globally important karst landscapes where spectacular surface and cave landscapes offer tourism-based economic development opportunities. Seven collaborative study groups (four US to China, three China to US) visited and met with administrators at numerous surface and cave park areas in and around Guilin and Lipu, Guangxi, and in and around Mammoth Cave National Park, Kentucky, to learn about common resource management problems and shared solutions. In 2001 we conducted a three-day English language workshop (spoken and written) at the Karst Institute in Guilin.

Project on Environmental Issues in Guizhou, China

Partners: Cave Research Foundation, Institute of Karst Geology, Guilin, Guizhou Normal University

Focus: Collaborative Research into Environmental Challenges and Solutions in Guizhou

Funding: Institute of Karst Geology, Cave Research Foundation, Western Kentucky University

Status/Schedule: Initiated 1990, ongoing

Ten collaborative study groups (seven US to China, three China to US) have taken place focusing on two interrelated issues in Guizhou: 1) water resources and karst related environmental problems in the areas of Guadalupe and Liupanshui, and 2) cave and underground river survey in Pingba and Duyun. On a 2002 American study trip to western Guizhou, we became aware of the serious natural arsenic and fluorine problems there, and have since met with scientists at the US Geological Survey working there to explore possible collaboration. We also learned about environmental issues in meetings with leaders of two Liupanshui-based scientific institutes.

