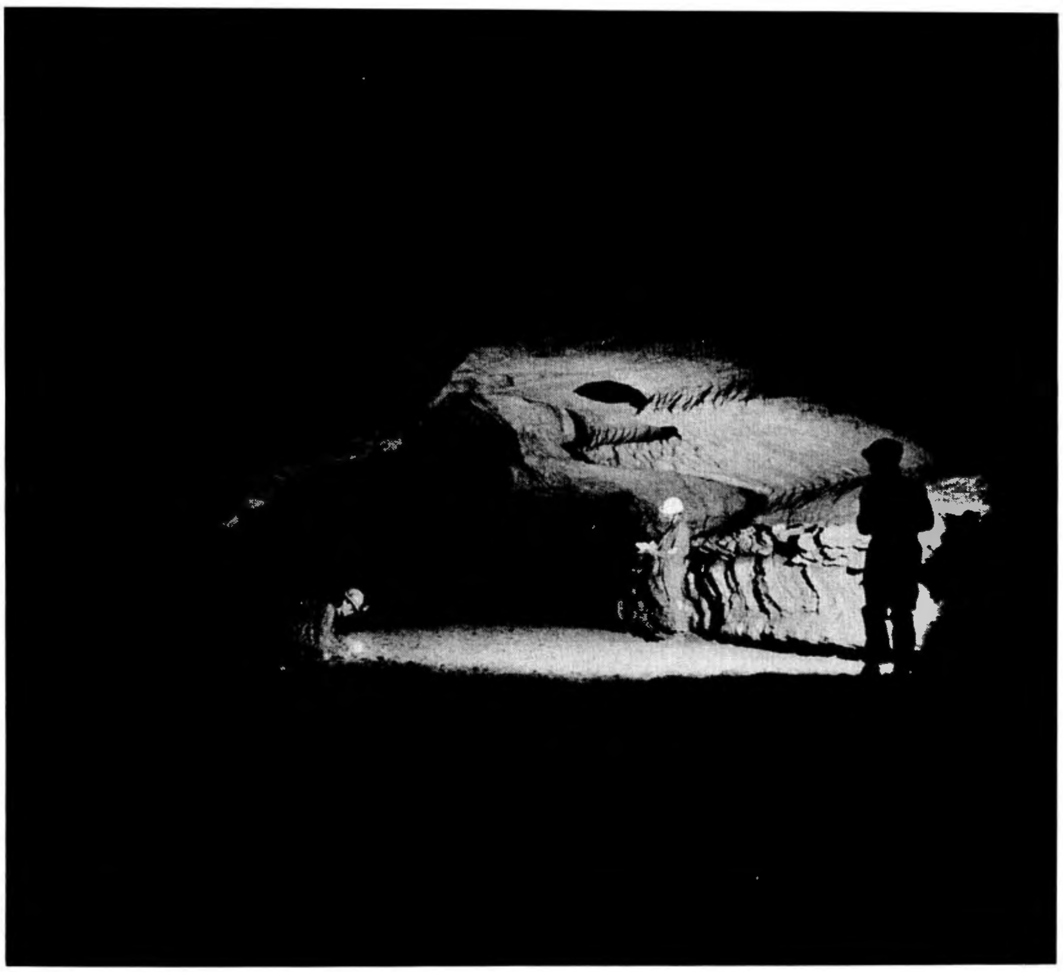
1988 ANNUAL REPORT



Cave Research Foundation

Cave Research Foundation Annual Report for 1988

Cave Research Foundation
1019 Maplewood Dr., No. 211
Cedar Falls, IA 50613
USA

The Cave Research Foundation (CRF) is a nonprofit corporation formed in 1957 under the laws of the Commonwealth of Kentucky. Its purpose is to support scientific research related to caves and karst, to aid in the conservation of cave karst wilderness features, and to assist in the interpretation of caves through education.

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Cover Photo: A CRF survey crew working in the Lost Passage, Fitton Cave, Arkansas. (*Photo by Pete Lindsley*).

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CAVE CONSERVATION

The caves in which we carry out our scientific work and exploration are natural, living laboratories. Without these laboratories, little of what is described in this Annual Report could be studied. The Cave Research Foundation is committed to the preservation of all underground resources.

Caves are fragile in many ways. We take considerable care that we do not destroy that which we study because many of the cave features take hundreds of thousands of years to form. Also, many of the processes that formed the cave passages we travel are no longer active in these areas. People who unthinkingly take or break stalactites and other cave formations cause great and irreparable damage. Cave life, such as blind fish, live in precarious ecological balance in their isolated underground environment. Disturbances, such as causing bats to fly during winter hibernation, can be as fatal to them as shooting them.

Caves are wonderful places for research, recreation and adventure. But before you enter a cave, we urge you to first learn how to be a careful and conservation-minded caver by contacting the National Speleological Society, Cave Avenue, Huntsville, AL 35810, USA, for excellent advice and guidance for novice and experienced alike.

Highlights of 1988

As you read through this report, the vitality of the Foundation's research, education, and interpretation programs will be readily apparent. The CRF is extremely happy to have funded five karst fellowships in 1988 with grants totalling $6,500.

The Foundation's long term projects in Kentucky, Missouri, New Mexico, and California continue to produce results of interest to speleologists as well as to the National Park Service and U. S. Forest Service managers. Of note are the completion of two Mammoth Cave tour trail maps and the publication of a booklet containing thirteen preliminary quadrangles which detail the latest map of Carlbad Cavern.

This year saw the CRF enter into a cooperative venture with two speleological organizations within the People's Republic of China, the Institute of Karst Geology and the Speleological Society of South China Normal University, to exchange information and investigate caves in three southern provinces. The success of the China expedition should mean future expeditions to this country as well as other CRF sponsored foreign caving expeditions.

Two new projects were started during 1988, one at Guadalupe Mountains National Park, Texas, and the other at Lava Beds National Monument, California. Operating agreements between the National Park Service and CRF were signed in February and November respectively. The Capitan reef within Texas has tremendous potential for large caves which to date have not been tapped. The use of the luxurious "Ship-on-the Desert" as a field facility within the Park should greatly enhance our efforts here. Lava Beds contains 112 named caves and many more may exist in the remoter areas of the Monument. Future efforts by the Foundation here will be inventory and monitoring of the cave resource to assist the National Park Service in their management and protection efforts.

The CRF Board agreed to provide assistance to Arizona Conservation Projects, Inc. (ACPI), in their baseline environmental study of Kartchner Cavern, Arizona. This essentially pristine cave was purchased by the State of Arizona and will be developed as the state's newest state park. This represents the first time that a cave and its surroundings will be studied in detail *prior* to development. Three members of the ACPI board are CRF members. CRF's assistance will primarily be in the form of review of the draft reports prepared by ACPI's scientific team.

Ronald Bridgemon
CRF President

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SCIENCE PROGRAMS

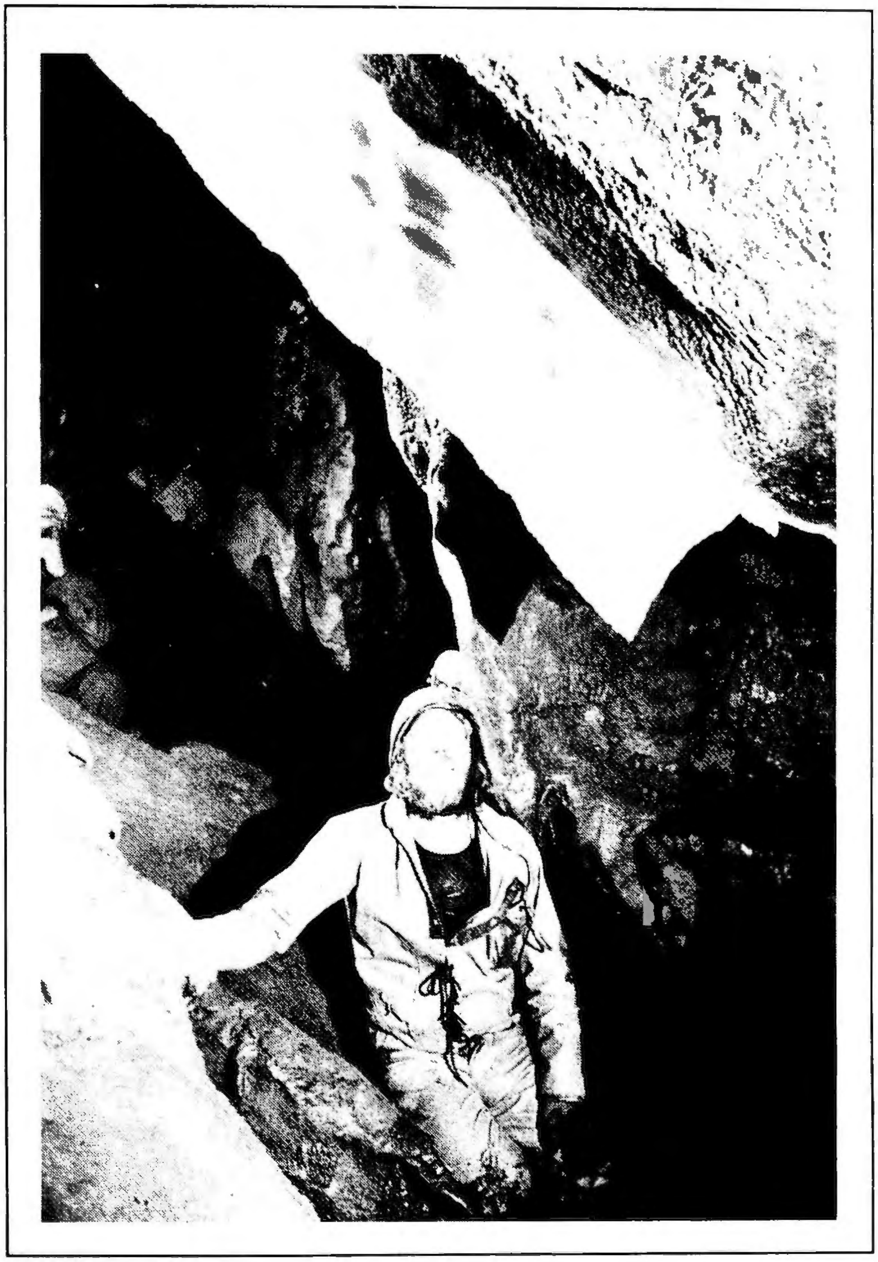

Figure 1: Peter Bosted examines a bacon rind formation in Lilburn Cave, Kings Canyon National Park, California. (*Photo by Pete Lindsley*).

Cartography Program

Lilburn Cave 1988 Cartography Report

Peter Bosted

Progress on the survey of Lilburn Cave and other features of Redwood Canyon continued at a good pace in 1988. There were seven expeditions to the area between late April and early October. There were 26 survey trips into Lilburn Cave, netting a total of 6260 feet using 567 stations. This brings the total length to 10.3 Miles (16.6 km). This is now the second cave in California to pass the ten mile mark. The principal areas that were surveyed were the Yellow Floored Domes area (6 trips), the Crystal Crawl, the Lake room, the Schreiber complex, the Alto stream and the Attic-Attic area (each with 2 trips). There remains approximately one mile of known cave left to survey, mainly in the more difficult-to-get-to areas of the cave. Careful checking of crawls and climbs may well reveal additional passages. There were two survey trips into Cedar Cave bringing its length to 715 feet. More trips will be required in this cave to follow the strong air flow. Finally, there were three surface surveys made, one to tie in features close to Cedar Cave, and two to pinpoint the location of a new large sinkhole that opened up above the south end of Lilburn Cave and dumped significant amounts of sand into the passages below.

Work continued on updating the large map which contains all passages surveyed to date. Quadrangle maps showing different levels of Lilburn Cave in more detail were begun. A map showing all of the surface features and their relationship to the caves was also drafted.

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New Lilburn Instrumentation

Mike Spiess

Reliable data collection has been a goal for the Lilburn hydrology project for some time. The Stevens A35 chart recorder installed at Big Spring has not functioned for more than a week for several seasons. Beginning in October 1988 new data logging equipment was installed.

At Big Spring a Campbell Scientific 21X data logger was installed in the housing that contained the Stevens. The 21X is a micro-processor controlled unit powered by eight D cells. Expected battery life for the unit is 4-6 months. Connected to the Campbell are temperature, conductivity, and stage (pressure) sensors. The sensors are sampled every 15 seconds. Data is recorded in RAM when any of the three sensors record a significant change and once an hour. Since data logging frequency is controlled by change, readings will be denser during the "flushing" events that occur at Lilburn. Data is written to cassette tape when RAM is full.

At the upper end of the Redwood Canyon watershed, about 1/2 km from Quail Flat, a tipping bucket rain gauge has been installed. The site is designated wilderness area, so the installation was designed to be totally removable when the project is completed. The rain gauge is installed on a 2.5 m tower. Propane heating is required during the winter months (elevation approximately 2200 m). Data logging at this site is accomplished by using a custom unit designed and built by Gary Mele. The data logger records the date and time of each tipping event in RAM. A portable computer is used to download the data through a standard serial interface. Monthly replacement of the propane tank will be required from December through April. The data logger must be downloaded twice a season.

The benefits of this instrumentation are:

1) A continuous reliable record with accurate timing
2) Additional data on temperature and Ec
3) Data in digital form for easier analysis.

Analysis of the data recorded during the 1988-89 winter/spring should show a correlation of rainfall events and stage. Additionally, the data may suggest logging of other factors in future seasons.

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Highlights from the California Area

John Tinsley

The California area boasts a significant new project at Lava Beds National Monument in addition to the established activities in Sequoia and Kings Canyon National Parks. The new project, under the direction of Janet M. Sowers, will emphasize resource inventory, a cave management plan, and research opportunities concerning the extensive system of lava tubes located on the northeasterly flank of the Medicine Lake volcano in northern California. A working agreement has been concluded between CRF and Lava Beds National Monument, a draft cave management plan has been readied for review, and plans for the fledgling research program are scheduled for early 1989.

At Kings Canyon National Park, Chief Cartographer Peter Bosted reports that the surveyed length of Lilburn Cave presently exceeds 10 miles—truly a milestone for a California cave. More than 30 unsurveyed leads, many in the southern portion of the cave system will entice joint venturers during 1989. Color graphics continues to find applications to the Lilburn cartographic program. The hydrology studies program received a shot in the arm when digital logging equipment was installed at Big Spring and a rain gauge, featuring a data logger crafted by Gary Mele, was installed in the Redwood Canyon drainage basin. The combination of the two instruments will enable studies to be completed relating precipitation events to hydrologic response at Big Spring. The sedimentology studies continue to bear fruit. Numerous localities of radiocarbon-bearing sediment have been mapped and the sections described. Selected collecting of radiocarbon samples will continue during 1989.

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Carlsbad Caverns National Park Survey and Cartography

Ron Lipinski

A major goal of the cartography effort in Carlsbad Cavern is to produce inked 1:600 (1"=50') maps of Carlsbad Cavern in plan view, profile and cross sections. One of these maps would be a complete map with details on formations and structure; the other would be one with walls and major features only, plus all survey stations. These maps would be based on a set of survey data in which blunders have been identified and corrected and random errors in loops distributed appropriately. A complete list of survey point coordinates, and an updated length, area and volume of the cave would be additional products. A large step toward this goal was made this year with the publication of a complete set of updated plan-view quadrangle maps in a convenient book at a scale of 1:1200 (1"=100').

Quadrangle Update Project

Over the last several years, the enthusiastic surveyors in Carlsbad had far outpaced the cartographers. By October 1986 about 25% of the 450 survey books from Carlsbad Cavern were not represented on 1:600-scale penciled-vellum quadrangle maps. Ron Lipinski volunteered to coordinate an effort to update the quadrangles and publish the results in rough form.

The quadrangle update project was organized by assigning one or more quadrangles (or "quads") to various quad bosses. Gerry Atkinson took the New Mexico Room quad, Ron Bridgemon took the Left-Hand Tunnel and Lake of the Clouds quads, Dave Dell took the New Section and East Bat Cave quads, Ron Lipinski took the Lunch Room and the four Big Room quads, Laura Reeves took the Guadalupe Room quad and Dick Venters took the Mystery Room quad. Each quad boss took copies of all of the survey books in his or her quad and checked whether the information in that book was included on the quad at the appropriate level of detail. If not, the data was reduced and added to the quad. A new quad was added to the system for the portion of Lower Cave that lies below the Lunch Room quad at the start of the Big Room. This was done to allow detail of that portion of Lower Cave to be shown. Alan Williams had typed into a computer file a complete index of the Carlsbad Cavern survey books listing accession number, date, area of cave, section within the area, instrument type, survey letters used and survey length for each book. This list could be sorted by area, date or accession number as the need arose and was very useful in managing the project.

Areas added to the quads include the Entrance area, Remarkable Crack and Lower Pit Series in the New Section, the Music Room and the Cave Pearl Room in the Main Corridor area, the Western Lower Maze and the Sand Room in the New Mexico Room, the Green Lake Room, the west end of the Papoose Room, the west end of the Mystery Room, Painted Canyon and the Grape Arbor by the Lunch Room, Pickle Alley and assorted boneyard at the entrance to Left Hand Tunnel, a lower level area and Quintessential Right in Left Hand Tunnel, the Storm Cloud Chamber and the Bifrost Room near the Lake of the Clouds, Lower Isolation below Jim White Tunnel, Middle Earth and Spirit World in the Big Room, East Lower Cave and the Naturalist Room in Lower Cave, Texas Pit Room and Koorees Recess and the Rookery near the Trapdoor entrance to Lower Cave, and the National Geographic Tunnel near the Jumping Off Place. In addition, most of the cave was field checked and much detail was added to the map. Throughout this effort, the 1976 NSS Standard Map Symbols were predominantly used (Hedges *et al.*, 1979). The notable exception was the retention of solid triangle for stalactites and stalagmites.

By June 1988, all of the quads except the Mystery Room quad were completely updated. The Mystery Room itself and the scenic rooms were finished, but the portions of Lower Cave on that quad were not updated and checked. Since this area would take considerable time to complete, it was decided to publish what we had in a limited edition. The format chosen was an 11" x 17" soft-covered book of quad maps reduced down to a scale of 1:1200 (1"=100'). This format would be more easily accessible and reproducible than full-scale copies of the 1:600 quads. The pencilled vellums were copied onto 50%-reduced blackline masters for the book. A reduced copy of Bill Wilson's and Bob Buecher's profile of the major east-west joints forming Carlsbad were also included in the book (at a scale of 1:4800, or 1"=400'). One hundred copies were made for distribution to the Park Service and other interested personnel. Figure 2 shows the 1:1200 scale section of the Big Room near Fairyland from the book as an example.

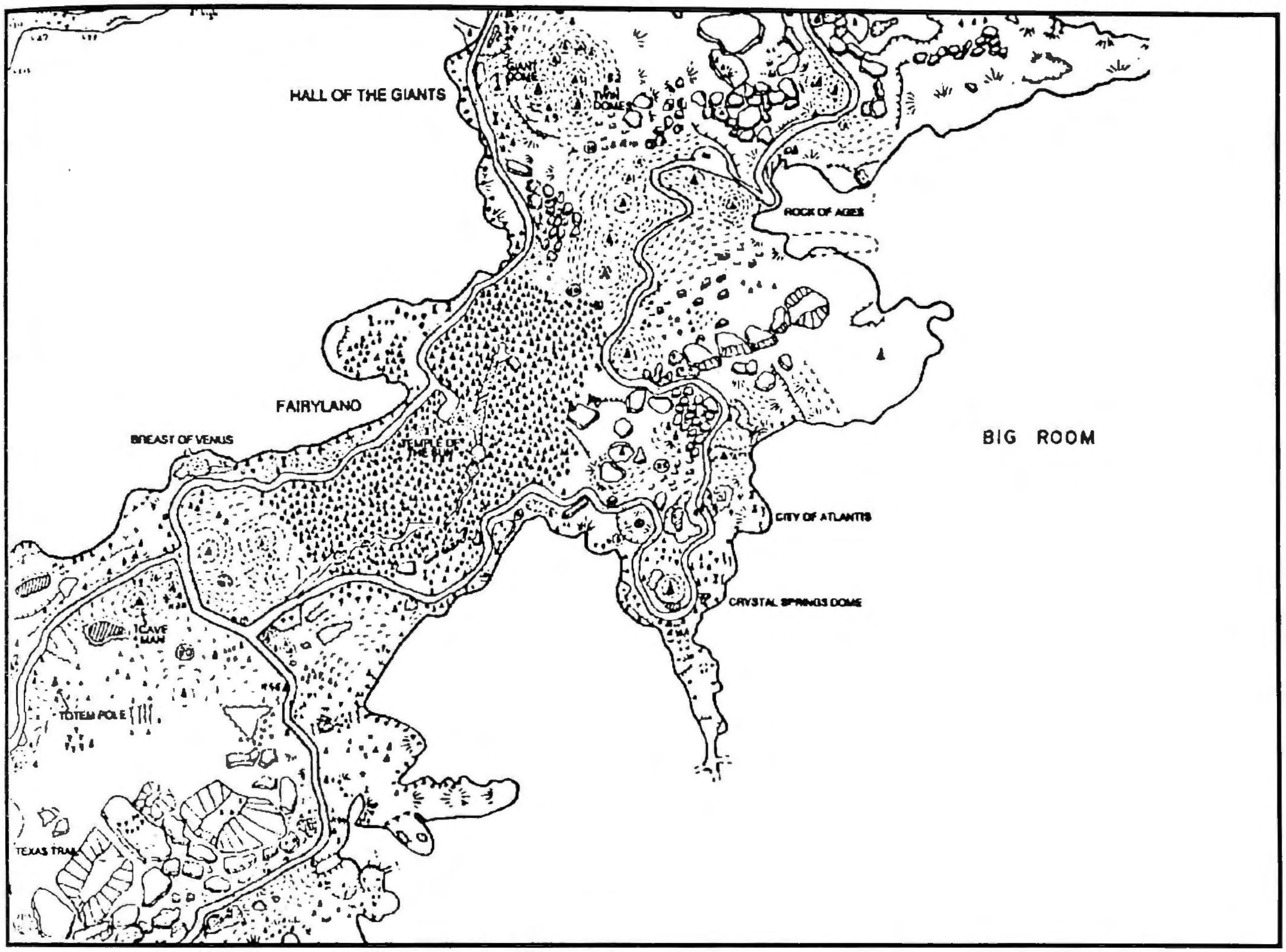

Figure 2: The Big Room near Fairyland in Carlsbad Cavern shown at the 1:1200 scale used in the 11in. x 17 in. book of quad maps.

The passages shown in the book of quads are relationally correct. However, since loop closures and corrections were not performed on the added areas, they are not as precisely placed as possible. Nonetheless, since they all stem from accurately-placed theodolite points, the error in position should be small. The next steps are (1) systematically close loops and distribute random errors throughout the cave, (2) distort the existing map to match the reassigned point locations and (3) ink and publish a final version (along with profiles and cross sections). We are now proceeding in that direction.

Computerized Data Reduction and Loop Closure

The first step in a comprehensive data reduction is typing the survey data into computer files. As of January 1989, we have Brunton and Suunto data from 264 survey books form Carlsbad Cavern typed into 304 computer files. (Some of the books had surveys from different parts of the cave; these surveys were split into separate files). Only about one third of the files have the left, right, up, down (LRUD) information. There were 87 files typed in by Bob Buecher and Debbie Buecher (all with LRUD information), 146 were typed in by Dave Dell and 75 were typed in by Ron Lipinski. There are 355 survey books with Brunton and Suunto data, so we are about 74% complete with that data entry. In addition, the files recently retrieved from John Corcoran's old computer cards (typed in by himself and Fritzi Hardy and Jim Hardy) comprise over 50% of the precision (theodolite) data.

Jim Hardy and Fritzi Hardy have taken the initiative in reducing and loop-closing the Carlsbad data in a comprehensive computer program and producing a complete list of all survey points, in both tabular and plotted form. An important aspect of this reduction is the identification and correction of blunders in the data. Jim Hardy has written a program over the last several years for multiple loop closure and simultaneous identification of possible blunders. Use of this program will compliment the traditional method of inspection of the data while developing the individual work maps. We will be keeping a list of blunders and these will be corrected in the survey data files.

References

Hedges, J., W. Russell, R. Thrun and W. William, 1979, The 1976 NSS Standard Map Symbols: *NSS Bulletin*, Vol. 41, No. 2, p. 35-47.

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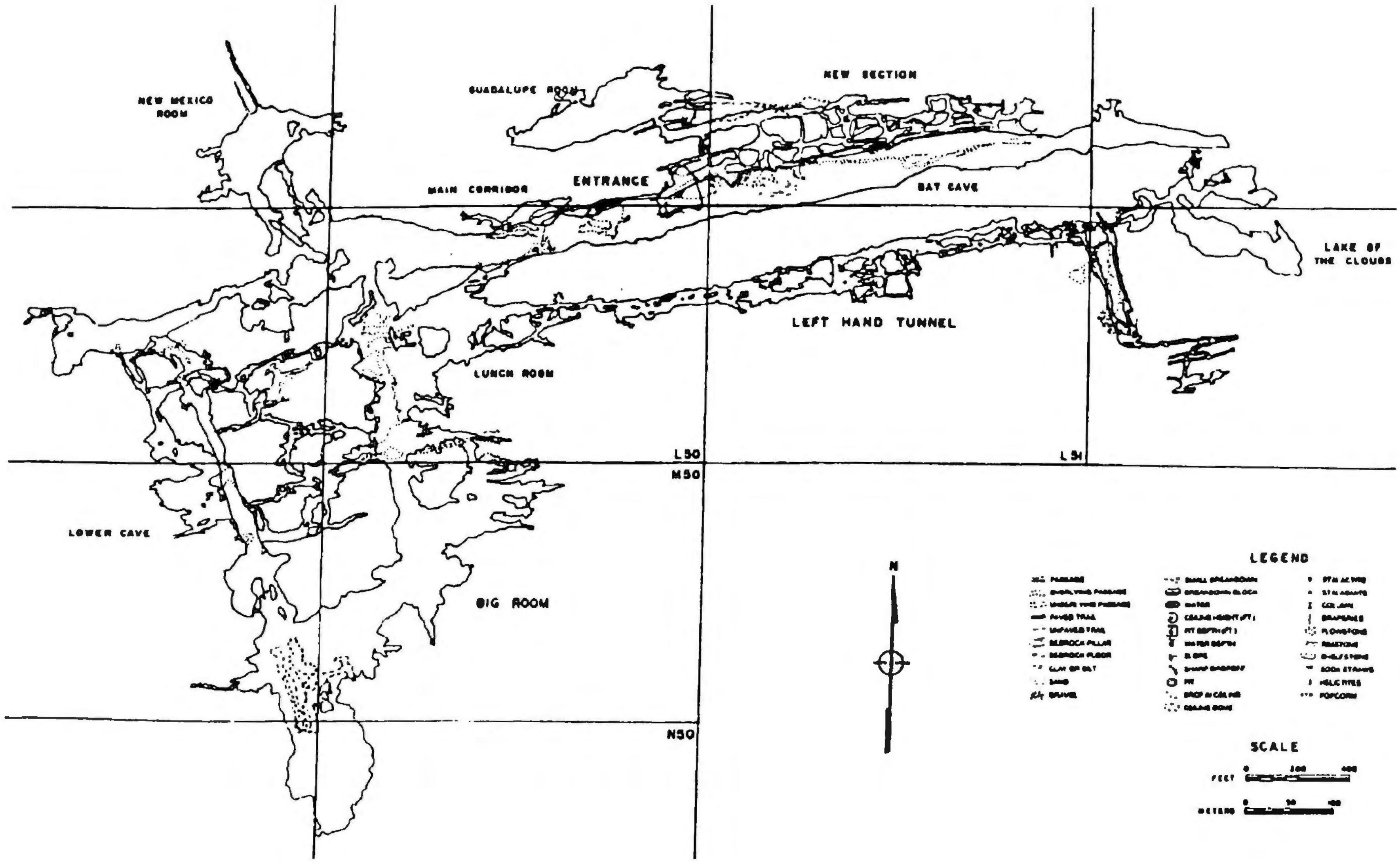

Figure 3: Quad system of maps drawn up for Carlsbad Cavern, New Mexico.

Guadalupe Escarpment Area

Rich Wolfert

1988 has been an exciting year for the Guadalupe Escarpment area. Accomplishments include new projects as well as continued work on existing programs.

This year CRF added a new area of operations at Guadalupe Mountains National Park. This park, located in Texas near the New Mexico border, includes the beautiful and rugged southern end of the Guadalupe Mountains. Much limestone is exposed and the cave potential of the area has barely been tapped. Great opportunities exist for finding new caves and for expanding scientific research in the Guadalupes. CRF has the use of deluxe field facilities at "Ship on the Desert" which was formerly Wallace Pratt's vacation lodge.

A video project has been completed at Lechuguilla Cave. Video equipment, including camera, recorder, lights and battery packs, was transported through various parts of the cave. The Denver Museum of Natural History has used the resulting footage to produce a video feature of Lechuguilla for interpretive use by Carlsbad Cavern National Park as well as for museum use. This program, entitled "Lechuguilla Cave, the Hidden Giant", is also being made available to public television for broadcast.

Another highly successful CRF-NSS Carlsbad Cavern restoration field camp was conducted this year. These week-long projects have become an annual event each summer. Participation is by both CRF and NSS cavers from across the country. Much of the restoration work is done during normal daytime hours within sight of the cave visitors and also serves as an action interpretive exhibit.

Cartography efforts have continued for several years on the production of a set of detailed quadrangle maps of Carlsbad Cavern (see the article in this Annual Report on Carlsbad Cavern National Park Survey and Cartography by Ron Lipinsky). A milestone has been reached this year with the publication of the preliminary edition of these quadrangle maps.

Minor extensions of Carlsbad Cavern continue to be found in various part of the cave such as Middle Earth, Restoration Pit and the New Section. Science projects include work in biology, mineralogy and geology. Carlsbad back-country caves continue to receive attention with mapping and production of step logs to the caves. The 1988 Guadalupe Escarpment accomplishments are many and have been made possible by the dedication and hard work of everyone involved.

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Missouri Cave Survey and Inventory

Scott House

Projects on state and federal lands began in 1980 and are continuing as a joint project in cooperation with the Missouri Speleological Survey, a statewide affiliation of caving groups. Maps, reports, photographs and other data are reposited with the Missouri Department of Natural Resources, Division of Geology and Land Survey, for storage, data processing and duplication.

Most of the project sites are in the south-central part of the state in the Ozark Plateau karst area. Host rocks for the caves are typically Ordovician or Cambrian dolomites with occasional beds of sandstone.

Ozark National Scenic Riverways

Several trips were taken to extend the length of Allen's Branch Cave, a fairly long, low, wet cave, to 1219 m (4000 ft). Several smaller caves in the vicinity were also mapped. The Allen's Branch area lies outside of the park boundary but hopefully may be included in some future land purchases. Several trips were taken to the upper reaches of the Jacks Fork River; some of these were by canoe. A number of smaller caves and shelters were found and mapped in these areas. Several caves in the Pulltite area along the Current River were also mapped; several more await completion. Numerous trips were also taken to Powder Mill Creek Cave, a project done in conjunction with the Missouri Department of Conservation. Although the cave lies within Riverways boundaries it is actually owned by the Department.

Missouri Department on Conservation

Five trips were taken to Powder Mill Creek Cave, a large wet cave near the Current River in Shannon County. Mapping is ongoing in three area: Hellhole, a major side passage discovery; the Windy Crawl, a large and mostly dry extension, and the continuation of the main stream up the Third Water Crawl. By the year's end the length of the cave was approximately 5487 m (18,000 ft).

One two-day expedition, an annual one, was to Great Scott Cave in Washington County, an important bat cave in the Meramec River basin. Both new and resurvey were done in this long term attempt to update and extend the old map. Currently, the length stands at about 3658 m (12000 ft).

Two small caves, which are located in the Clifty Hollow Natural area in Maries County, were also surveyed.

Missouri Department of Natural Resources, State Parks

Two parks received work during 1988. The DNR requested that CRF map additional side passages in the Devil's Icebox, a large cave in Rockbridge State Park, Boone County.

During a March expedition three survey crews surveyed approximately 458 m (1500 ft) of side passages bringing the length to 9084 m (29801 ft). Two additional trips were taken to the park to complete a topographic overlay of the cave and park environs as well as to search for reported but missing caves. Three trips were taken to Grand Gulf State Park in Oregon County to complete a detailed topographic map with profiles and cave overlays.

Mark Twain National Forest

Three large caves received most of the work on Forest Service lands in 1988. Three trips were taken to Oregon County's Kelly Hollow Cave, a mostly dry Ozark cave with two sections of trunk passage. By the end of the year the length of the cave was 1006 m (3300 ft).

Four trips were taken to Still Spring cave in Douglas County, the largest in the Forest. Small side passages and extensions of the main stream crawl accounted for most of the survey. The length of this grueling cave is now 2500 m (8200 ft).

Four trips were also taken to Iron County's Cave Hollow Cave which is now over 610 m(2000 ft) long. It was determined that hibernating bats in the cave are the federally-endangered Indiana bats (*Myotis sodalis*) and the cave is now closed for the winter.

Indian Creek Cave in Howell County was mapped and determined not to be on Forest Service land. Surface work in Ripley County failed to turn up any new caves and previously-reported Panther Cave was found to be filled. One trip was taken into the Rock Pile Mountain Wilderness in Madison County on a reconnaissance of the Marsh Creek Caves. One new cave was discovered along the Trace Creek section of the Ozark Trail in Washington County. A trip was made to sort out and map the Peter Cave area in Iron County; the caves turned out to be very small. A surface check was done of an area in Iron County where a tailings pond has been proposed; no caves were found. At the request of the Forest Service two pits within the Irish Wilderness area were mapped; neither went far but the USFS personnel were impressed with how little surface indication there can be for karst development. Nearby areas have been proposed for lead development and much more work will have to be done to determine what sort of environmental impacts will be created.

Private Lands

In addition to privately-owned Allen's Branch Cave several more Missouri projects involved CRF members. Mick Sutton and Sue Hagan continue working on a variety of smaller caves in the Reynolds and Iron County areas as part of a long-term project to map all of the caves in that area. Paul Hauck took one trip to do some work on the now-dormant Meramec Caverns project. This show-cave's length stands at about 6706 m (22000 ft).

Personnel

Most of the above work was coordinated by Doug Baker and Mick Sutton, particularly the Forest Service work. Scott House coordinated the Riverways and Rockbridge trips. Sue Hagan coordinated the Grand Gulf project.

CRF Joint Venturers worked in 16 different counties in Missouri, mapping 47 caves and taking approximately 60 work trips. Over 70 reports, photographs and locations were submitted to the state files. Also completed and turned in were 19 maps depicting 33 caves.

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Cartographic Delineation of the Caves of Mammoth Cave National Park

Scott House

1988 was a very good year for cartography at Mammoth Cave National Park. In particular, much was accomplished on the 1:600 series base maps of Mammoth Cave. Most of this work was concentrated in Mammoth Cave Ridge due to recurring surface survey problems elsewhere. By the end of the year, however, new theodolite surveys were being run by CRF personnel and hopes are high that 1989 will see these problems solved.

Field Work

Mammoth Cave Ridge

Field work concentrated on resurveying major passages in some areas while pushing leads and finishing up other areas. As a result, much was learned about "well-known" passages and new passage was discovered in attempts to "clean up" several map sheets. The clean-up work was mostly focused on the Cathedral Domes and Kentucky Avenue sheets as those areas near completion. New passage turned up during careful examination of the Mammoth River area under and near Kentucky Avenue. A gypsum-laden maze area was found off of the downstream area while a push on the upstream "end" yielded over a thousand feet of canyons and crawlways. Additional new passage was also turned up during careful resurveys of Morrison Avenue. The best "finds" in the Cathedral Domes area were several hundred feet of the continuation of Bishop's Way as well as other passages lying over Cathedral Domes itself.

As the southeastern end of the ridge neared completion the emphasis of work shifted northwestward toward the historic end of the cave. The resurvey line of Belfry Avenue was extended for several thousand feet; the first sections of

Miller Avenue were resurveyed allowing an excellent closure to Bishops Domes and Belfry to be effected; and new surveys were done in the area of Rhoda's Arcade. The main parts of The Pass of El Ghor and Silliman's Avenue were resurveyed; these are shown on at least two different 1:600 map sheets.

In the historic section of the cave new surveys began to replace older and/or lost surveys. Main Cave was resurveyed from St. Catherine City to the Acute Angle. Blackall Avenue was resketched while Blue Spring Branch, Ganter Avenue, Ranshaw Avenue, Lee Way, Pensacola Avenue and Echo River were all resurveyed. Completing these has allowed us to move ahead with maps of the Historic end of the cave.

Hawkins River Area

Much new survey was done in side passages all up and down the river. Most of this was done in the L Survey where a large loop was closed by connecting to the M survey. Other passages were surveyed off of Fritsch Avenue and in a series of passages near the Roppel connection area.

A series of radio stations were established in the fall and theodolite surveys were done to tie these points to USGS benchmarks in the southern end and outside of the park.

Flint Ridge

Surveying was somewhat limited by the need for additional accurate surface surveys to close large underground loops by. Nonetheless a great deal was accomplished in some areas. The greatest amount of work was new and resurvey in Colossal Cave and the Lehrberger Avenue section of Salts (many times considered part of Colossal) as CRF strives to get a new map made of that large section of the ridge. The resurvey line was completed from the Colossal entrance all the way to new survëys at the Salts/Unknown link area. When new surface surveys are run it will be possible to quickly close these large loops and create permanent maps.

Otherwise, virtually all of the work accomplished was in Unknown Cave. New surveys in the Union Shafts area tied together some large loops and clarified that Byzantine area as well. Much new and resurvey was done in crawls and pits off of the Foundation Hall area. A maze of canyons and shafts off of Ingall Way reluctantly gave up new passage to some determined effort. A level survey was extended out to Turner Avenue giving us a new check on clinometer survey accuracy and odds and ends surveys were done here and there. Some additional surveying was done in the Overlook area of Crystal Cave.

Small Caves

A few of the smaller caves in the park were also surveyed. Several trips were taken to a new find north of the river along the Dry Prong of Buffalo Creek. Buffalo Creek Cave has yielded a considerable amount of passage containing a large stream that is possibly hydrologically connected to other caves in the area. Several trips were taken to Running Branch Cave on the north side and that cave is now nearly finished. South of the river one more trip was taken to finish Smith Valley Cave and A. L. Morrison Cave was surveyed.

Data Reduction

Recognizing the need for a standardized system of reducing data, CRF cartographers have begun a detailed examination of present methods and formats with an eye toward coalescing the entire data base into a standard format. Presently, materials exists on magnetic tape, and CP/M, Apple and MS/DOS files on disk as well as a variety of material that exists only on paper. Work will focus on creating programs that can convert all of this material to standard ASCII files that are easily interchanged from system to system so that all computers available to the Foundation can be used. It is hoped that considerable progress can be made on this during 1989. Jim Borden is leading this effort with Mel Park and Pete Lindsley providing additional expertise.

Meanwhile the number of working programs continues to grow. Eric Compas has produced a new ProDOS version of his reliable Cave Recorder program for Apple II computers. Howard Kalnitz has been writing a new survey reduction program for the Macintosh and has it in an advanced stage at present.

Drafting

Great progress has been made in supplying cartographic direction and support to a number of areas of the cave system. More cartographers are involved than ever before and maps are being drafted at a relatively rapid pace. 1:600 maps currently in progress in pencil form are:

Crystal Cave (2 sheets) ....Art Palmer
Unknown Cave, Pohl Avenue ....Paul Hauck
Unknown Cave, Brucker Breakdown ....Scott House
Unknown Cave, Mather Avenue ....Scott House
Unknown Cave, Gravel Avenue ....Michael Sutton
Unknown Cave, Northwest Passage ....Michael Sutton
Hawkins River System (4 sheets)..................Robert Osburn
Mammoth Cave, Frozen Niagara ....Scott House
Mammoth Cave, Kentucky Avenue ....Michael Sutton
Mammoth Cave, Cathedral Domes ....Scott House
Mammoth Cave, Cleaveland Avenue ....Doug Baker
Mammoth Cave, Blue Springs Branch ....Michael Sutton
Mammoth Cave, Main Cave ....Scott House

In advance planning and field work phases are:

Mammoth Cave, Historic ....Doug Baker
Mammoth Cave, Echo River ....Doug Baker
Mammoth Cave, Bishop's Domes ....Scott House
Mammoth Cave, Cocklebur Avenue ....Scott House
Colossal Cave (3 sheets) ....James Borden

Two tour trail maps were completed and inked during 1988: Cathedral Domes Area and Kentucky Avenue Area. These maps are made available in either the original 1:600 scale or at a reduced 1:1200 size. Together they will show virtually all of the tour trails, past and present, in the southeast end of Mammoth Cave. Permanent reproducible copies of the above maps were provided to Mammoth Cave National Park at cost. An updated and improved version of the Frozen Niagara trail map is planned for 1989.

Several maps of smaller caves in the park were produced during 1988. These included Owl Cave and Hickory Flats Cave. Several other small cave maps are in various stages of completion. Some (Palmer Cave, Rebble Rubble Cave, and Little Beauty Cave) have been inked and await lettering, others (Jim Cave, YMCA Cave, and Bluff Cave) have been drawn but not inked, while still others (Running Branch, Buffalo Creek, and Smith Valley) are incompletely surveyed. Preliminary maps of Smith Valley and Running Branch were produced and the final versions are expected to be done in 1989.

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Small Cave Resource Inventory

Philip J. DiBlasi

The small cave resource inventory project (MACA-N-98) progressed slowly during 1988. Much of the efforts revolved around inventory of rock shelters and the discovery of several small caves. Efforts to relocate and identify several caves known from the literature (i.e. records/trip reports) have failed.

Cartography efforts on several of the small caves have continued successfully. Maps are now complete for several small caves, and old surveys are being upgraded and updated. The cartography has progressed primarily through the efforts of Eric Compas.

A locational base map has been produced by Edward Lisowski (Figure 4). This map represents the end result of gridding the "Old Brown Line" topographic map of the Mammoth Cave National Park (1:31680) with the one kilometer Universal Transverse Mercator (UTM) polyconic projection. This newly gridded map now offers the field investigator the use of this map's accurate topography and the ability to plot entrances using the UTM grid system.

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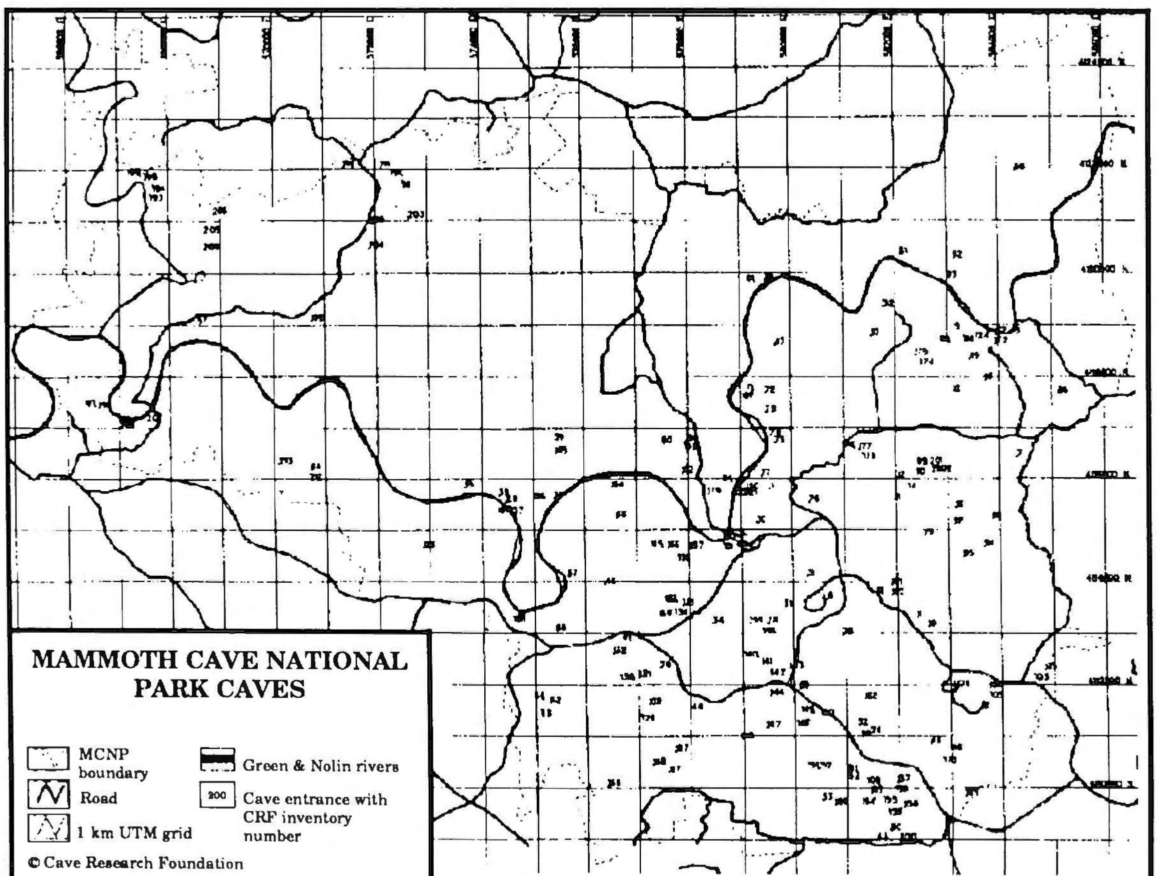

Figure 4: Locational base map produced by Edward Lisowski as part of the small cave resource inventory at Mammoth Cave National Park.

GEOSCIENCE PROGRAM

Cartography, Tephrochronology, and Sinkhole Deposits in the Karst of Redwood Canyon, Kings Canyon National Park, California

John C. Tinsley and Peter Bosted

Introduction

Cartographic efforts to document the karst of Redwood Canyon, Kings Canyon National Park include mapping the three caves of the area (Lilburn Cave, Mays Cave and Cedar Cave) at a scale of 1:240, producing an atlas of the caves, again at a scale of 1:240, emphasizing details of passages, passage gradients, and cross-sections and survey stations, and compiling a map portraying the karst of Redwood Canyon (scale is 1:4800), are progressing well. The cartographic effort at Lilburn Cave is discussed further by Bosted elsewhere in this volume. The 1:4800-scale map, when completed, will show the topography sinkholes, trails, cave entrances and sinking tributary streams. Sources of the map data include poorly-integrated but well-intentioned studies performed prior to Cave Research Foundation's presence in Sequoia and Kings Canyon National Parks as well as CRF surveys designed to portray trails, streamcourses, and developing karst geomorphic features of the Redwood Canyon area. This map will be an integral part of several studies, including the study of rates of soil erosion described below; it should also serve NPS management as an effective documentation of the karst resource that is Redwood Canyon. As this map showing surficial features of the karst will be about 36 x 48 inches when completed, for convenience we offer a generalized, reduced-scale, page-size version in Figure 5.

Figure 5 shows principal topographic elements including Redwood and Big Baldy mountains; the principal tributary streams, the hydrologic input points and the sinkhole distribution, while not yet completely compiled, nevertheless show the potential for new cave in Redwood Canyon, compared to the present mapped extent of Lilburn Cave.

Sinkhole and Sinkhole Sediments

Colluvial and alluvial processes which transport earth materials from slopes to sinkholes and caves are important in the evolution of karst basins' however, opportunities to estimate rates of soil erosion and slope degradation in karsts of the western United States under conditions of natural vegetation are seldom realized. Into the nearly pristine drainage basin of Redwood Canyon, a 700-year old silicic volcanic ash was erupted from the eastern Sierra Nevada and subsequently blanketed the mantled karst; this tephra deposit forms a discrete horizon in selected sinkholes and provides a stratigraphic basis for calibrated, volumetric estimates of post-tephra sediment eroded to the sinkholes. The study includes about 20 of the 60 sinkholes mapped in the karst; the data we present are preliminary but constitute a simple yet effective means to documenting caves and selected karst-related processes.

The sinkhole sediments are composed chiefly of gravel, sand, silt and clay derived from the granitic and metamorphic rocks which frame the canyon, and from alluvial terrace deposits along Redwood Creek and its tributaries. Drainages tributary to redwood Creek typically sink at or near the contact of Redwood Canyon's marble and the adjacent granitic and non-carbonate metamorphic rocks. The white, powdery tephra, identified by its distinctive trace element chemistry as a product of the Deadman Dome vent in the Inyo Craters volcanic chain located south of Mono Lake in eastern California (Wood, 1977), is easily recognized in the field using soil augers or shallow slit trenches.

About 700 radiocarbon years ago, one of California's several volcanic centers erupted explosively in the Mammoth Lakes area in the southern part of the Inyo Craters volcanic chain, south of Mono Lake in east central California. The resulting plume of fine-grained volcanic ejecta, termed tephra or volcanic ash, drifted to the south and west across the Sierran crest, where it blanketed much of the southern Sierra Nevada, including the karst area in Redwood Canyon, then was eroded from hillslopes, rivulets, and gullies and was delivered to the sinkholes. What happened then depended on the nature of the sinkhole in question. Sinkholes containing open conduits in their bottoms apparently transmitted most if not all of the deposits of sediment and ash directly to the cave below, for such sinkholes preserve little if any record of the ash. Sinkholes located on terrain where slopes measure less than about 8 degrees did not receive tephra or sediment rapidly, and processes of bioturbation active on the forest floor commonly have obliterated the tephra layer. Most favorably, sinkholes that are floored with sand and silty sediment lack efficient conduit-related drainage and are permeable to water. Seepage of water through the sediment plug effectively traps air- and water-borne sediment, including tephra; the trapped sediment is accreted vertically to that sinkhole's sedimentary record. In instances where the sinkholes have not developed collapse or stratigraphic leaks into the cave during the post-tephra time, the tephra is isochronous, having been erupted, transported, and deposited within a very short span of geologic time, and establish age

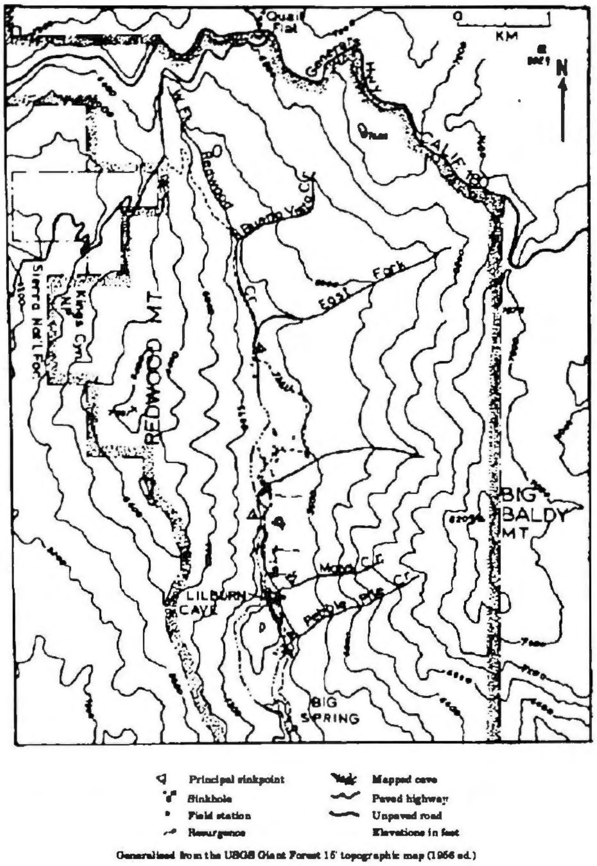

Figure 5: Map showing the Redwood Canyon Karst Area.

equivalence among deposits in widely separated localities. The Redwood Canyon karst is a convenient laboratory wherein rates and processes of slope erosion can be appraised, owing to the tephra "clock" preserved in many sinkholes.

Methods

In each sinkhole, an array of 15 to 30 holes are excavated using a hand-powered soil auger and the respective thicknesses of tephra and post-tephra sediment are measured in each hole. The respective volumes of tephra and post-tephra sediment are estimated using isopach mapping techniques. The quotient of the tephra volume (or post-tephra sediment volume) divided by the area of the drainage basin draining into the sinkhole yields an estimate of the vertical thickness of tephra or post-tephra sediment eroded into the sinkhole from the drainage basin, provided the sinkhole has indeed trapped sediment and has not leaked appreciable tephra or post-tephra sediment to the cave system. Comparing as many sinkhole and drainage basins as possible, the estimated erosion rates among a population of small basins can be studied as functions of basin size, sloped, aspect, vegetation or other parameter of interest. The estimated erosion rates would be applicable to the mixed coniferous forest ecosystem under conditions of present climate which prevailed during the past 700 years. Only by comparing results from a number of well-plugged sinkholes can we obtain stable estimates of sediment yield for further analysis.

Results

Twenty-two sinkholes have been examined and ten sinkholes have been augered as of 12/31/88. Hillslopes of less than 10% tend to retain at least part of the mantle of volcanic ash, which then becomes mixed with the soil owing to biological and physical processes. Slopes steeper than about 10% generally shed their ash mantle readily into the sinkholes and are more efficient contributors of sediment, especially coarse sediment, than their more gently-sloping neighbors. The tephra blanket apparently ranged in thickness from 1 to 5 cm thick in the Redwood Canyon area. Erosion rates of the soil mantle measured in this way range from 0.5 to 1.5 cm/yr during the past 700 radiocarbon years.

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Novel Subaqueous Speleothems in Lechuguilla Cave, New Mexico

Donald G. Davis

Nearly all published interpretations of helictites and stalactites (e.g., Hill & Forti, 1986) have assumed that these grow only in air-filled caves. One exception (Peck, 1979) reported helictites and stalactites interpreted as having grown in phreatic cavities, but they were composed of sulfide minerals and were said to have resulted from unusual conditions that did "not suggest anything other that a rare (but notable) event". Lechuguilla Cave has recently revealed remarkable variants on these speleothems, which closely resemble ordinary helictites and stalactites but which are either actively growing underwater, or are associated with old pool deposits in such a way that subaqueous growth was highly probable. This suggests that basic processes of speleothem growth have not been fully understood, and that unusual decorations in other cave should be reconsidered with the possibility of subaqueous growth in mind.

Subaqueous Helictites

In the WSW branch of Lechuguilla Cave, a climb leads to Pellucidar, a large room about 92 m (300 ft) long by 38 m (125 ft) wide. The floor of the room is divided between gypsum blocks (believed to be residue of limestone reaction with sulfuric acid) and flowstone-crusted breakdown.

Near the room's eastern end, between breakdown blocks, lies a narrow pool, about .6 m (2 ft) by 1.2 m (4 ft) in surface dimensions and 2.4 m (8 ft) deep. The pool is lined with subaqueous mammillary calcite crust and is rimmed by a band of shelfstone up to about 12.7 m (5 in) wide.

Beneath the water of this pool is a spectacular display of several dozen twisting, wormlike white helictites up to about 35.6 cm (14 in) long, emerging from the wall crust from the water level to about .3 m (1 ft) beneath it. On the average, the deeper ones are longer and more downwardly inclined. They are of circular cross-section and of diameters between .15 cm (1/16 in) and .48 cm (3/16 in), any particular one being of rather consistent width; they do not branch except for occasional short "bumps" on the sides. The tips are rounded, and a broken specimen had a tiny oval central canal. Though not as yet analyzed, they appear to be composed of finely-crystalline calcite.

It is certain that these have grown underwater, rather than being subaerial helictites submerged by rising water. Their upper limit is perfectly accordant with the pool's shelfstone rim. Where they rise to the water level, the cross-section becomes flattened along the pool surface, and as much as 7.6 cm (3 in) of the shelfstone's width is made up of a fused, inter-tangled spaghetti of truncated helictites.

A second locality is in a narrower pool filling a crevice in flowstone in Barsoom, a balcony 100 feet above Pellucidar. Helictites here are identical except that they are restricted to about 7.6 cm (3 in). A third occurrence is in the cave's southwest branch, in a shallow pool on flowstone below Lake Lebarge. The helictites here are basically like those in the WSW branch, but mostly much smaller (less than 10 cm or 4 in long), and of more variable diameter, some tapering to needlelike points.

All three localities have one significant property in common: in each case, the pool receives seepage from flowstone having a large, partially-dissolved gypsum block resting on it, and the helictites are best developed on the side of the pool nearest the gypsum. It is speculated that, where stringers of gypsum-enriched water enter pools already saturated with calcite, localized excess calcium ions appear at points of mixing, and the "common ion effect" causes crystallization of calcite in a helictitic form. Arthur Palmer and Margaret Palmer are analyzing helictite and pool water samples to test this hypothesis.

Subaqueous "Stalactoids" and "U-Loops"

At Station FK5 in the southwest branch is a chamber some 12 m (40 ft) wide which was once filled to a depth of about 3.7 m (12 ft) with a subterranean lake. From parts of the yellowish mammillary crust lining the walls of this room extend beardlike groupings of hundred of slightly wiggly, slender calcite fingers, up to 30.5 m (12 in) long and about .16 cm (1/16 in) to .64 cm (1/4 in) or more wide; some are essentially vertical while others incline as much as 20° toward the chamber's center. Many are connected by U-shaped inverted arches, mostly about 5 cm (2 in) across, which look as if shoestrings had been draped between the fingers and calcified.

These decorations are now inactive, but it appears clear that they grew underwater and are not subaerial stalactites. They are all below the old water level and share the color and surface texture of the subaqueous crust. Many taper to dimensions far less than the 5.1 mm minimum diameter of a sodastraw stalactite (Curl, 1972), nor are there any normal stalactites associated with them. The U-loop connections do not have straws hanging from the bottoms, as might be expected if water had dripped from them. The cross-section of a broken finger shows a fine-grained radial structure but no apparent central canal; they are tentative called "stalactoids" because they resemble stalactites externally but have not grown by a stalactitic mechanism.

A second stalactoid locality has been found in a dry shelfstone pool, about 1.22 m (4 ft) by 1.83 m (6 ft) deep, in a slot downslope from old flowstone in the FLI survey near the southern extremity of the southwest branch. A dense display of them, up to 25.4 m (10 in) long, extends primarily from the lower edges of vertical "chenille spar" fins about .6 m (2 ft) below the pool's main shelf-stone level. Like the original stalactoids, they share the color of adjacent subaqueous crust, often are narrower than soda straws, and do not associate or intergrade with ordinary stalactites. In the new locality they are not only linked by U-loops, but some entire groups are interconnected by perforated weblike sheets, paper-thin and lighter-colored than the stalactoids, and apparently only lightly attached to them.

The origin of all these features is extremely puzzling; possibly the pool waters bore a plastic scum or colloidal suspension that stuck preferentially to the bottoms of projections as the water level repeatedly rose and fell.

Subaqueous Stalactites

The eastern branch of Lechuguilla Cave has extensive areas of bizarre terrain in which walls and breakdown in low-lying areas have been eaten and etched into chains of sharp-edged potholes and dendritic rillenkarren. About the lowest 6.1 m (20 ft) of this zone is stained blackish below a distinct waterline showing that mineralized water was once ponded there.

Part of this pond basin, near station GE5, is characterized by irregular, skeletal-looking groups of stalactites and columns up to 1.37 m (4.5 ft) long, issuing mostly from ceiling joints or from ledges mantled by calcite raft deposits. Unlike the "stalactoid" fingers in the southwest branch, these have internal feeder canals, but show several other traits quite abnormal for ordinary stalactites.

Some of the more slender ones are as narrow as .16 cm (1/16 in) in diameter - much less than the minimum dimension of stalactites formed by dripping water. In larger ones, on the other hand, the internal canals may be large and irregular - up to 2.54 cm (1 in) or more wide, and sometimes open to the outside through "windows" in the columns. Some columns have stalagmite-like mounds at their bases, but these occur only where a column has touched floor; there are no separate, independent stalagmites such as grow beneath dripping stalactites.

Furthermore, these decorations appear only below the old water line, in the calcite-raft zone, and share the dark staining of the walls. There are no stalactites above the water line in this area. Some of the speleothems have either engulfed calcite rafts or have rafts adhering, showing that water surrounded them both before and after their growth was complete. All factors considered, it is highly probable that these blackish stalactites grew subaqueously when mineralized water was standing in this part of the cave.

These stalactites show evidence of a more complex growth history than do the subaqueous helictites or stalactoids, with several differing layers, some of which appear high in iron minerals. The mechanism of growth is unknown, but may, as with the helictites, involve crystallization, via the common ion effect, of barriers in the form of stalactites where plumes of dense solution (probably iron-rich in this case) descended through a body of calcite-saturated water. These stalactites resemble, and may be genetically related to, the marine "rusticles" found growing from the hull of the sunken ship *Titanic*.

The context of the Lechuguilla subaqueous stalactites suggests a hydrothermal process: there may have been hot water standing in this area when the water table was descending through the lower cave levels, with vapor rising into an acidifying atmosphere, condensing on walls above the water and etching pothole fields, then trickling back into the water where minerals dissolved above were redeposited as rafts and stalactites. Leached limestone in a passage directly above the deposits is so heavily coated with a residue of iron and/or manganese compounds as to resemble a body of oxidized iron ore; this unusual concentration of heavy metals is probably the cause of the dark staining of the subaqueous stalactites below, and the reason for their growth being localized immediately beneath the metal-rich bedrock. Chemical and paleotemperature analyses are needed to determine whether their composition is consistent with the above propositions.

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Water Chemistry in the Vicinity of Subaqueous Helictites in Pellucidar, Lechuguilla Cave, New Mexico

A. N. Palmer

Elsewhere in this annual report, Donald G. Davis describes the discovery and characteristics of the first documented example of underwater helictites. These occur in several places in Lechuguilla Cave, New Mexico, where water saturated with calcium carbonate comes in contact with blocks of gypsum just before entering the pools. Davis' interpretation is that the helictites form because of the common-ion effect, in which the calcium from the gypsum drives calcium carbonate to supersaturation. Helictites form where the gypsum-rich water enters the pools through pores in the walls or as digitate stringers of surface flow. This report verifies the chemical aspects of his hypothesis.

On August 12, 1988, A. N. Palmer, M. V. Palmer and Paul Rubin obtained several water samples in the area of the first helictite discovery. These are in Pellucidar, a high-level room above Deep Secrets, in which a small stream enters. The water flows over travertine, then beneath a gypsum block; then a small percentage enters the helictite pool, but most of it bypasses it and flows down a steep flowstone cascade into a calcite-lined pool.

Sample #1 = drip from stalactites 3 m upstream from helictite pool
Sample #2 = helictite pool
Sample #3 = crystal-lined pool 2 m downstream from helictite pool
Sample #4 = first rimstone pool on left in Deep Secrets (for comparison).

The following measurements were made in the cave when the samples were collected. Probable error is approximately 0.5%.

T (°C)	20.2	19.0	19.0	19.9
pH	7.87	8.09	7.87	8.10

The major dissolved components are as follows, in mM/liter (millimoles/liter).

	#1	#2	#3	#4
total Ca	25.6 (.639)	26.8 (.669)	64.1 (1.60)	24.4 (.610)
total Mg	28.0 (1.15)	29.1 (1.20)	29.2 (1.20)	31.1 (1.28)
$SO_4^{=}$ *	13.6 (.142)	23.8 (.248)	160.0 (1.67)	15.1 (.157)
Cl^- *	5.7 (.16)	6.4 (.18)	4.2 (.12)	6.8 (.19)
NO_3^- *	3.1 (.050)	4.8 (.077)	4.9 (.079)	5.3 (.085)

These analyses were made by M. V. Palmer, except (*) = by Jim Whitney, Illinois State Water Survey. Probable error is approximately 1%.

The following were calculated, taking into consideration activity coefficients and ion pairs:

equilibrium P_{CO_2}	.0026 atm.	.0016	.0034	.0016
Mg/Ca (molar)	1.80	1.79	0.75	2.10

Saturation indices: SI = log of (ion activity product/equilibrium constant);
- = undersaturated, 0 = saturated, + = supersaturated:

calcite	+.10	+.32	+.50	+.31
aragonite	-.05	+.17	+.36	+.16
dolomite	+.21	+.43	+.42	+.46
gypsum	-2.72	-2.47	-1.39	-2.71

INTERPRETATION

Source of Dissolved Components

The high Mg content indicates that most of the dissolved load was contributed by dolomite or high-magnesium limestone, the only significant Mg sources in the area. Even pure dolomite can yield a maximum Mg/Ca ratio only about 1.0, so some of the Ca must have been precipitated as calcite or aragonite upstream from the measurement site, probably because of near-surface evaporation. Dolomite is unlikely to precipitate because of its sluggish precipitation kinetics; hence the high Mg/Ca ratio.

Calcium is probably contributed only by calcite, dolomite and gypsum. Therefore, in molar units, Ca = calcite + dolomite + gypsum. Also, dolomite = Mg, and gypsum = sulfate, neither of which is likely to precipitate in this water. Therefore, the measured Mg and sulfate approximate the original amounts of dissolved dolomite and gypsum respectively. The amount of Ca that must have precipitated as calcite = Ca - Mg - sulfate + all calcite originally dissolved by the water. Ignoring the amount of original calcite, which is unknown, this is equivalent to .024 cc/liter of calcite precipitated upstream from #1, .029 cc/liter upstream from #2, .047 cc/liter upstream from #3, and .006 cc/liter upstream from #4. Since all samples are supersaturated with calcite, calcite cannot be dissolved. Therefore, from #1 to #2 the water has precipitated .005 cc/liter of calcite (partly as helictites) and from #1 to #3 the water has precipitated .023 cc/liter (mainly as flowstone and calcite crystals lining the lower pool).

Evaporative Enrichment of Ions

The increase in Mg from #1 to #2 and from #1 to #3 suggests evaporation, because the only obvious source from Mg is dolomite, which cannot dissolve because it is supersaturated. Assuming that none has precipitated, the increase in Mg suggests evaporative enrichment by 4.26% from #1 to #2 and by 4.35% from #1 to #3. Evaporation could also account for the increase in Cl and nitrate (except for the anomalous decrease in Cl from #1 to #3), but these may also be derived from organic sources.

Effect of changes in P_{CO_2} and Temperature

Changes in P_{CO_2} and temperature also affect the saturation level of the various minerals. For this reason alone, from #1 to #2, the water loses its potential to hold 0.161 millimoles/liter (mM) of dissolved calcite. From #1 to #3 the water GAINS the potential to hold 0.134 mM of calcite. This gain is caused by the high P_{CO_2} of pool #3, which is a dead-end pocket and CO_2 trap.

Effect of Gypsum Dissolution

The increase in sulfate from #1 to #2 and from #1 to #3 indicates that gypsum has been dissolved. Of this increase, 4.26% and 4.35% respectively are probably caused by evaporation. Actual gypsum dissolution is therefore the gain in sulfate minus the amount of evaporative enrichment. Therefore, 0.100 mM of gypsum is added between #1 and #2, and 1.522 mM between #1 and #3. This is equivalent to 0.0074 and 0.11 cc/liter of gypsum respectively.

Evaporation plus gypsum dissolution cause a POTENTIAL gain of .127 mM of Ca from #1 to #2 and 1.52 mM from #1 to #3. The ACTUAL gains are .0305 mM and .962 mM. The difference is accounted for by precipitation of calcite. These figures indicate that .097 mM (.0036 cc/liter) of calcite has precipitated from #1 to #2 and .588 mM (.022 cc/liter) from #1 to #3. Most precipitation occurs in the pools themselves. The water at #1 is close to saturation with respect to calcite. By the common-ion effect, any uptake of gypsum has the potential to force an equal amount of calcite to precipitate. Therefore, from the dissolution of gypsum alone, the water gains the potential to precipitate 0.100 mM of calcite from #1 to #2 and 1.522 mM from #1 to #3.

SUMMARY

The POTENTIAL amounts of calcite precipitation for all three factors can now be combined: (a) evaporation, (b) changes in P_{CO_2} and temperature, and (c) dissolution of gypsum:

From #1 to #2:
- (a) = +.027 mM (9%)
- (b) = +.161 mM (56% of total potential)
- (c) = +.100 mM (35%)
- Total = +.288 mM (.01 cc/liter) potential calcite precipitation.

From #1 to #3
- (a) = +.028 mM (2% of total precipitation potential)
- (b) = -.134 mM (counteracts tendency for precipitation)
- (c) = +1.522 mM (98% of total precitation potential)
- Total = +1.416 mM (.052 cc/liter) potential calcite precipitation.

Comparison with the actual calcite precipitation shows that 34% of the potential precipitation has actually been realized in pool #2 and 42% in pool #3. The difference between actual and potential precipitation accounts for the increase in calcite supersaturation shown by the rise in SI values.

Dissolution of gypsum therefore accounts for at least 35% of the calcite precipitation in and just upstream from the helictite pool (#2), and about 98% of the calcite precipitated in and just upstream from pool #3. The chemical character of the cave water obviously changes with time, so the relationships shown here must undergo seasonal variation. During high flow more of the gypsum-laden water would enter the helictite pool, boosting the common-ion effect. Nevertheless, even from this single sample, the hypothesis is clearly justified that dissolution of gypsum has a significant effect on the precipitation of calcite in and around the helictite pool in Pellucidar.

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Fluorite in Glori Cave, Guadalupe Mountains National Park

Carol A. Hill

Glori Cave is located on the north side of Upper Shumard Canyon, along the west escarpment of the Guadalupe Mountains, Guadalupe Mountains National Park, Texas. The cave is on the south side of the same header as Iron Cave and is located about 1 km from it. Glori Cave occurs in the Victoria Peak Member of the Bone Springs Limestone, and is oriented along NE and NW trending joints. Glori and Iron Cave (in a gossan mass of iron oxide) are both developed along the same bedding plane which is located about 12 m down from the Cutoff Shale-Victoria Peak contact. Passage width and height of the cave is from 1-3 m. Speleothems are sparse; helictites are the most noteworthy, but even these are dry and desiccated.

The most notable geological feature of Glori Cave is its fluorite mineralization. Glori Cave is the only cave in all of the Guadalupe Mountains known to contain fluorite. There are three modes of occurrence of this fluorite:

(1) As veins 1 to 8 cm thick which follow joints and fractures in the limestone. Strike and dip of these veins varies: the veins do not necessarily follow NE-NW joint orientations, but fill any small crack or fissure in the limestone. Calcite sometimes alternates with fluorite in the veins.

(2) As crystal linings 0.5 cm thick covering undulating compaction bedding planes and as crystal vug fillings. Calcite is often intergrown with the fluorite (i.e. it is cogenetic with the fluorite), and in a few cases fluorite appears to be included in the calcite.

(3) As small (a few mm) crystals disseminated in the limestone which stand out in relief from the limestone due to cave dissolution.

In all three cases the fluorite predates the cave (i.e. it is truncated by the cave passages).

Fluorite crystals vary from a few mm up to 2.5 cm on a side. The crystals come in all shades of brown and purple, but in general there is an early stage of transparent, resinous-brown fluorite overgrown by a later stage of opaque, light-purple fluorite. The resinous-brown fluorite can occur separately from the light-purple fluorite, or the two can occur together, with purple layers directly overlying the resinous-brown layers.

The fluorite mineralization in Glori Cave is likely related to numerous other fluorite occurrences along the Rio Grande Rift zone. If so, then the Glori Cave fluorite marks the eastern-most known limit of this fluoritization. Time of mineralization is probably Oligocene (30-40 my), the time of Tertiary volcanism and hydrothermal ore emplacement all along the zone.

Calcite cogenetic with the fluorite has a d13C = -7.2 and a d18O = -5.4. This spar plots within the Spar III regime defined by Hill (1987).

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Calcified (?) Balloon Speleothems in Virgin (Blowing) Cave, Guadalupe Mountains, New Mexico

Harvey R. DuChene

During a photography trip made on April 5-6, 1985 to Virgin Cave, New Mexico, several unusual speleothems were observed on the wall and ceiling near the Grinder in the Four O'Clock Staircase area. These speleothems have a remarkable resemblance to hydromagnesite balloons, except that they appear to be made of calcite. Cave coral is abundant in this part of the cave, and the balloons are inconspicuously nestled among the bases of individual coralloids.

The Virgin Cave balloons are estimated to be 3 to 5 cm long and 2 to 3 cm wide. They have a convoluted shape and a matte-textured surface which is beige in color. They appear to be rigid although none were touched to verify this.

These speleothems resemble hydromagnesite balloons in shape only. They lack the pearly luster and appear to be thicker than true hydromagnesite balloons.

The balloons appear to have been fully expanded at one time and then partly collapsed, perhaps due to the loss of internal gas pressure. I suspect that they were once composed of hydromagnesite that received a coating of calcium carbonate some time after they formed.

Several balloons were observed at the lower entrance to the tight crawl at the Grinder, a narrow fissure that leads from the bottom of the Four O'Clock Staircase Pit to the Thanksgiving Room. There is at least one balloon on the ceiling and two on the right-hand wall facing the down-slope entrance to this crawl. All of the balloons are located near the bases of coralloid speleothems.

The fissure passage between the Grinder and the Thanksgiving Room is heavily decorated with cave coral and possibly more balloons are located in this area.

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Cross Cave, Apache Mountains, Culberson County, Texas

Carol A. Hill, Cyndi Mosch and Mike Reid

Cross Cave, Apache Mountains, Culberson County, Texas, is a rock shelter having an entrance lip 30 m wide by 12 m high. The entrance slope descends for about 35 m and then pinches out as a single small passage 1 m wide, 0.5 m high and 3 m long. The cave apparently was named for a cross chiselled on a stalagmite in the entrance zone.

Geology

Cross Cave is developed in the Permian Capitan Limestone. It has a passage configuration strongly reminiscent of Guadalupe Mountain caves, especially Big Door. The cave has a smooth ceiling that descends at an angle of about 20-30° (Figure 6). The configuration of the passage suggests dissolution by ascending, bathyphreatic water and the passage size suggests significant water movement through the Apache Mountain section of the Capitan reef at some time in the past.

Figure 6: Entrance to Cross Cave, showing slope of ceiling. (*Photo by Mike Reid*).

Speleothems are minimal and in a dry, desiccated condition due to entrance weathering effects. Popcorn, small stalagmites, draperies (some sawtoothed) and blistered carbonate crusts were noted. Rhombohedral calcite spar crystals occur in vugs as linings 1-2 cm thick and as crystals up to 3 cm long. These crystals predate the cave as is typical of spar in the caves of the Guadalupe Mountains. The spar has a carbon-oxygen isotopic composition of $d^{13}C = +0.7$, $d^{18}O = -10.2$ and plots within the Spar II regime as described by Hill, 1987.

Cross Cave is developed along a N40°W joint, approximately parallel to the trend of the exposed Capitan reef in the Apache Mountains. Downslope from the cave is an arroyo which cuts perpendicular to the reef trend. Travertine remnants (some semi-rounded, some not) found all along the arroyo indicate a high potential for finding more caves in the area. (As far as the authors know the Apache Mountains have never been systematically check for caves).

Archaeology

At the very end of the 1 x 0.5 m x 3 m passages a semi-lustrous, black object was found that was presumed to be some king of bead or ornament (Figure 7). The object measures 3 cm x 5 cm and is approximately 1 cm thick at the widest point tapering down to 2 mm on three of its edges. At the "top" is a hole 2 mm in diameter. The material composing the artifact is unknown but is unlike wood, ceramic or stone. Graduate archaeology students at the University of New Mexico have suggested that the artifact is made of dyed or painted bone. It is possible that it is an Indian bead or the upper portion of a cruciform.

Figure 7: Black "bead" artifact in situ, at the end of the terminal passage, Cross Cave. Note pen for scale. (*Photo by Mike Reid*).

In the same area where the artifact was found, it was noted that the breakdown appeared unnatural, as if the rocks had been placed there by humans (a possible burial site?).

History

Approximately midway down the entrance slope a Latin cross is chiseled on the flowstone surface of a prominent (0.3 m diameter) stalagmite (Figure 8). The height of the cross is about 45 cm and the width about 30 cm; the depth of chiselling is about 0.5 cm. The chiselled surface has been darkened by a grayish residue. The flowstone adjacent to the stalagmite is undermined by a shallow (1 m deep) man-made excavation.

Figure 8: Latin cross carved on stalagmite flowstone, Cross Cave. (*Photo by Mike Reid*).

The only other inscription noted in the cave was the name "Ruby F Goodwin, Oct. 3, 1909" (Figure 9). This pencil-inscribed signature was found low on the east wall of the small terminal passage.

Figure 9: Pencilled incscription on east wall of Cross Cave, terminal chamber. (*Photo by Mike Reid*).

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Acknowledgement

Permission of access and collection was allowed by land owner Judge Lee Green, Pecos, Texas.

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"Helictite Bushes" - Subaqueous Speleothems?

Donald G. Davis

"Helictite bushes" - intricately branching speleothems up to 1.5 m (5 ft) long - are a much admired, but little studied, feature of Wind Cave, South Dakota. Writers on Wind Cave have treated them as exceptionally large and complex variants on ordinary helictites, but fundamentally similar in character and origin. This is exemplified in the explanation by Shafer (1988): "The helictite bushes...may form when water seeps from the cave through pores so small that the flow is controlled by capillary action and not gravity. This allows water to move uphill and deposit calcite against the force of gravity".

Such interpretations are based on the premise that helictites grow in air. Wind Cave helictite bushes, however, show conspicuous evidence of former submergence, such as calcite rafts lodged in their branches. Palmer (1981) accounted for this as follows: "The helictites formed above water, and the rafts settled over them during a later rise in the water table".

Are these explanations correct? In Lechuguilla Cave, New Mexico, helictites were recently discovered which have grown beneath the water of shelfstone pools. This raises the question of whether the dissimilar but equally peculiar helictite bushes of Wind Cave might also have grown under water.

Nearly all Wind Cave helictites bushes are found in or near the downdip section of an axial passage complex which bisects the known cave, between the Garden Gate and Calcite Lakes. On May 28 and 29, 1988, with Wind Cave National Park permission and Ed LaRock's guidance, several dozen "bushes" in this area were examined and the following observations made:

(1) *All* Wind Cave helictite bushes observed show evidence of former submergence: calcite rafts lodged in branches; encrustations continuous with crystalline subaqueous wall crust; and in some cases, films of compact, apparently water-laid sediment on upper surfaces of helictite arms.

(2) *No* bushes observed are now "alive", i.e., none can be shown to be actively growing in air.

(3) Dripstone, flowstone and shields are normally associated with subaerial helictite growth; yet these vadose speleothems are totally absent from this section of Wind Cave.

(4) Downward vadose seepage normally issues primarily from the ceilings and walls of caves. However, the great majority of helictite bushes grow upward from floor crusts which apparently were calcified before the passages drained. The bushes often arise beside pre-crust breakdown blocks or where other permeable discontinuities appear in the crust. During or after drainage, sediment substrates subsided, extensively undermining and breaking the crust; helictite bushes grew before, but apparently not after, this breakage.

(5) Subaerial helictites typically have internal feeder canals of almost microscopically small diameter, consistent with their vadose capillary-seepage growth mechanism. In striking contrast, broken Wind Cave bush branches usually show large and irregular internal canals, often .32 cm (1/8 in) or more in minimum diameter, and 1.27 cm (1/2 in) or more along the wider axis in flattened branches. In air, it is very unlikely that a helictite with a large internal tube could grow upward far before gravity acting on overflow caused conversion to a soda-straw mode. Straws, in fact, are often seen growing from subaerial helictites but *never* from any Wind Cave helictite bushes examined.

(6) At least one helictite bush shows morphology incompatible with subaerial growth mechanics. This bush - in an alcove on the west side of the passage a few yards south of the emperor Maximus bush- grew upward from the floor crust several inches, where its branches encountered an overhanging ledge. The branches thereupon merged into a thin crystalline crust, whiter than the adjacent walls, for several inches up the overhang. At a sharp breakover to an upward-facing slope, helictite branches at once emerged from the upper edge of the crust and resumed independent upward growth for several more inches. Subaerial helictites, if their feeder canals were disrupted by intersecting a wall, would have no way to "remember" original orientation and resume coherent growth above - but a deposit created by an ascending fluid plume within a surrounding, denser water body could easily do this.

Palmer (1988), after learning of the subaqueous Lechuguilla Cave helictites, revised his subaerial hypothesis for Wind Cave to address some of the above points: "It is possible for helictites to grow under water, but only in unusual conditions. These [Wind Cave bushes] most likely formed in air, growing upward from deposits of weathered limestone powder that accumulated from upper levels, apparently when the powder was moistened by pools of water immediately below. Later rises in water level coated them with layers of calcite, making them thicker and sturdier".

Palmer's scenario would account for their prevalent growth from floors and the lack of association with vadose decorations, the inactivity of bushes away from the water table, and (assuming that normal fluctuations would inevitably flood growths nearby) the universal evidence of inundation. It does not, however, explain feeder canals larger than capillary size, whereas subaqueous growth would not restrain canal dimensions. Nor does Palmer's new mechanism accommodate the bush that reorganized its upward growth after interruption by a ledge. Finally, a wicking process, such as Palmer suggests, should work anyplace that standing cave water abuts a shore of absorbent material in an evaporative atmosphere. This is a relatively common situation. If it gave rise to helictite bushes, they should be widespread in Wind and other caves. In reality, they are virtually restricted to a narrow band of passages along a closely-associated fracture set oriented at right angles to the water table margin.

Accordingly, it seems highly probable that the helictite bushes in this part of Wind Cave grew underwater before the water table fell beneath their levels. Yet they differ in many ways from the subaqueous helictites of Lechuguilla Cave: the latter are capillary-fed, unbranching, downward-growing and shelfstone-associated. It is not known if there are any analogues to the Wind Cave form.

Oceanography provides one suggestive parallel: tubes extended from the sea bed by "smokers" where submarine hot springs vent in ocean floors. A related case has been reported in the speleological literature: Peck (1979) described small tubular speleothems, up to several inches long, some of which had large central canals and which Peck believed had been created in injection of ascending fluid into geode-like phreatic caves. Peck defined the growths as subaqueous "helictites" and "stalactites" (notwithstanding that most of the "stalactites" had grown upward). Like the submarine "smoker" chimneys, these speleothems were composed of sulfide minerals, and it would probably be more appropriate to classify them as a spelean variant of the marine "smoker" phenomenon.

The Wind Cave bushes appear to be composed of calcite, not sulfides. They may also be related to the cave "geysermite" cones described in Hill and Forti (1986) as forming from "upwelling, thermal water," though it is not clear whether the geysermites were submerged when formed. Like geysermites and smokers - but unlike ordinary helictites or the non-thermal subaqueous helictites of Lechuguilla Cave - Wind Cave helictite bushes are probably creations of former thermal water rising along fractures underlying a major passage axis, and interacting with cooler, chemically-distinct ambient groundwater.

Concerning the chemistry of helictite-bush growth, there are so many possible complications and so little evidence that it is pointless to speculate at this time, except to suggest that crystallization from common ion effect mixing may have been involved, as in Lechuguilla Cave.

The Wind Cave helictites bushes have intricate, usually ascending dendritic branching; branch dimensions vary from needle-thin (as in terminal segments of Emperor Maximus) to a 2.54 cm (1 in) or more wide. They are relatively irregularly and coarsely crystalline, with cross-sections varying from circular to angular or flattened. The internal canals vary correspondingly in shape, with irregular partitions and obstructions common. These blockages probably cause the numerous bifurcations that result ultimately in the elaborately arborescent pattern.

Somewhat problematic to the ascending-water hypothesis presented here in this paper is the fact that a few helictite bushes do grow downward - notably the famous Emperor Maximus, the largest known bush complex, in which scores of intertwined branches extend 1.52 m (5 ft) or more down from a ceiling joint. However, its unusual orientation probably results from eccentricities in the local "plumbing." Within a few yards before Maximus, many smaller bushes grow up from the floor in the normal way. Maximus itself is situated where the passage pinches into a joint. If a thermal plume had been rising along that joint beyond the end of the open passage, it would have found no floor crust to issue from, and would have been diverted laterally to emerge at the most open level of the joint, in this case along the ceiling. Maximus also has thinner-walled, more slender branches than most other bushes, and if temperature gradient was the main determinant of growth direction, Maximus may have equilibrated with surrounding water faster than most bushes, letting it grow atypically downward.

Certainly more laboratory analyses need to be done to elucidate the origins of helictites bushes and unusual speleothems located elsewhere need to be assessed regarding possible subaqueous origin.

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Hydrology of the Sistema Huautla Karst Groundwater Basin, Oaxaca, Mexico

James H. Smith

The study area, Sistema Huautla Karst Groundwater Basin, is located 260 km south of Mexico City in the northeastern corner of the state of Oaxaca, Mexico, in the Sierra Mazateca, one of the folded sedimentary ranges of the Sierra Madre Oriental del Sur. Sistema Huautla Karst Groundwater Basin is one of many large karst groundwater basins internally draining the Sierra Mazateca carbonate aquifer by systematic dendritic vertical drainage. To date more than 90 km of conduits have been surveyed in the numerous caves of the basin. The Sistema Huautla alone has 52 km of integrated passages and shafts with 1,353 m of vertical extent.

The dramatic karst landscape of the Sierra Mazateca is fluvial in origin having formed by swallet waters of perennial streams issue at springs from a clastic caprock aquifer (Crawford, 1980) of allochthonous Middle Jurassic rocks. Overlying clastics were removed by erosional processes exposing lower Cretaceous limestones inlyers which were rapidly dissolved along a highly complex anistrophic framework of faults and bedding planes by both allogenic and authigenic recharge. As a result, a solutional topography consisting of two huge dolinas 2 km long were formed in addition to thousands of smaller ones. As the clastic caprock aquifer retreated to its present westerly position, cave entrances once fed by perennial springs were isolated on structurally high ridge tops with greatly reduced drainage catchment. Tertiary uplift of the Sierra Madre Oriental with simultaneous erosion of the clastic caprock aquifer produced an extensive vertical drainage system formed by a combination of two classical cave development theories, vadose and shallow phreatic (Ford and Ewers, 1978).

It is the purpose of this Master's Thesis research to understand the speleogenesis and complex nature of the carbonate aquifer of the Sistema Huautla karst groundwater basin. Extensive literature review and 13 years of exploration within Sistema Huautla helped to construct many hypotheses on which to base research. To test the hypotheses exploration, geologic field mapping and qualitative dye tracing were necessary (Smith, Atkinson and Drew, 1976). The emphasis of the 1988 Sistema Huautla Expedition, fielded by the Huautla Project was hydrologic field work necessary to test hypotheses. The research was supported by the Cave Research Foundation, Center for Cave and Karst Studies, Explorers Club, Richmond Area Speleological Society, Dogwood City Grotto and Chattanooga Grotto in addition to corporate sponsors.

The first goal of research was to find the resurgence(s) of the Sistema Huautla karst groundwater basin. Based on geologic field mapping and aerial photographs, two areas existed as potential output for the groundwater basin. These were to the south, in the area of Peña Colorada following the regional strike and westerly dip and to the east, towards the Presa Miguel Aleman along west-east topographic lineaments thought to be tear faults. The first area was the most likely site, but in an attempt to remain objective all springs had to be located along the Río Santo Domingo and Presa San Miguel.

In order to test the hypotheses, a 140 km traverse down the, probably unexplored, Río Santo Domingo, along the Presa Miguel and back up the karst valleys to San Agustín were undertaken on a six-day adventure. Springs were measured for temperature and estimated discharge. Charcoal dye receptors, to receive fluorescein dye, were placed at all likely springs. Fluorescein dye was then injected 600 m deep in Sótano San Agustín. Of the eight charcoal dye receptors in Peña Colorada Canyon and Río Santo Domingo Canyon, dye was recovered at only one spring 1.5 km south of Cueva de Peña Colorada in the Río Santo Domingo Canyon. This led to the conclusion, the Sistema Huautla Karst Groundwater Basin discharges from a single conduit as a perennial spring. Cueva de Peña Colorada, although unproven, is a likely overflow to the Sistema Huautla Karst Groundwater Basin during the summer rainy season (Stone, 1984).

To study the relationship of vertical conduit drainage of physically unconnected drainage systems to Sistema Huautla, multiple dye traces were conducted from a number of caves with streams to confluences deep within Sistema Huautla. In all, fifteen trips were made to depth between 500 and 950 m to set and recover charcoal dye receptors and geologically map within Sistema Huautla.

As a result, two new tectonically and lithologically controlled base level drainages were discovered to connect into the Scorpion Sump of Sótano San Agustín. Each of the two vertical drainage systems are separate 1000 m deep drainages integrated into the Sistema Huautla Karst Groundwater Basin.

Additional dye traces were conducted in swallet waters of the Río and San Agustín dolinas to confluences within Sistema Huautla and to the Sistema Huautla Resurgence in the Río Santo Domingo Canyon. Río Iglesia, the largest swallet was dye traced to the Sistema Huautla Resurgence. The trace concluded that Río Iglesia does not connect into Sistema Huautla, but joins the drainage between Sistema Huautla and the resurgence.

In conclusion, other dye traces further defined the complexity of the Sistema Huautla Karst Groundwater Basin during three months of research. Results of this Master's Thesis study will be published upon completion. Gratitude is expressed to the grantors, cave explorers and to Dr. Crawford, thesis advisor for inspiration and advice during research.

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The Origin and Development of Brucker Breakdown and the Adjacent Area, Mammoth Cave System, Kentucky

Elizabeth K. Estes

Abstract

The appearance and relationships of Brucker Breakdown and adjacent area, a portion of the Mammoth Cave System, imply that complex structural and hydrogeological factors affected and/or controlled passage development. Detailed surveys (Figure 10) include geographic, cartographic, lithologic, morphologic, stratigraphic and paleoflow indicators. The five proposed scenarios were the following:

Case I: All (or most) of the passages were once continuous across the Brucker Breakdown void, which is a subsequent feature.

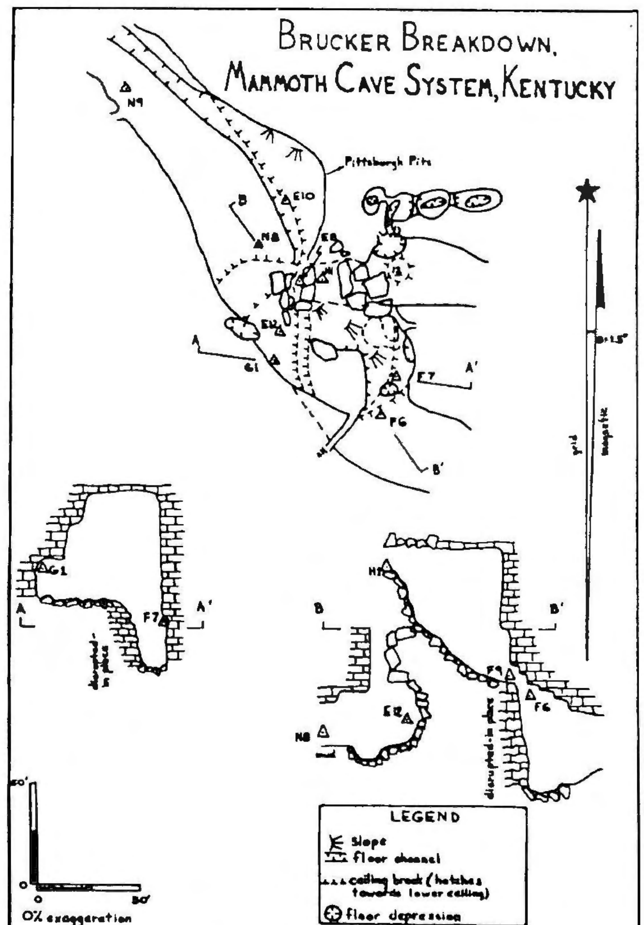

Figure 10: Detail of study area, Brucker Breakdown, Mammoth Cave System, Kentucky.

Case Ia: The Brucker Breakdown (Figure 11) void is a subsequent feature whose development caused morphological changes in the pre-existing passages adjacent to it (traditional hypothesis).

Case II: The passage converge toward or diverge from the Brucker Breakdown void, which acted as either a source or target of flow and is a primary feature.

Case IIa: Several passages converge on the Brucker Breakdown void and few components depart from it, indicating that the Brucker Breakdown void is a primary feature and represented a local potentiometric low.

Case IIb: Several passages diverge from the Brucker Breakdown void, and fewer components converge on it, indicating that the Brucker Breakdown void is a primary feature and represented a local potentiometric high.

Of these, Case IIb was found to most closely represent the situation presented by the data.

To perform this study, a detailed procedure was developed that, until this time, had not been established or outlined in the literature. Once the area of study was chosen and defined, an extremely detailed cartographic and morphologic survey was performed that established both horizontal and vertical data points throughout the area. These data points were tied to existing transit surveys of the surface that linked the subsurface area to U. S. Geological Survey bench marks. The cartographic, geographic and morphologic data were converted with computer aid to map form. The maps were then field-checked for accuracy. Comprehensive geological mapping surveys were executed. Multiple stratigraphic sections were described and measured in each passage segment and these were tied to the vertical data points. Correlations were made between sections and were physically traced whenever conditions permitted. Speleothem dating information from prior research was obtained and correlated throughout the study area. Finally, important features and passage morphologies were documented photographically.

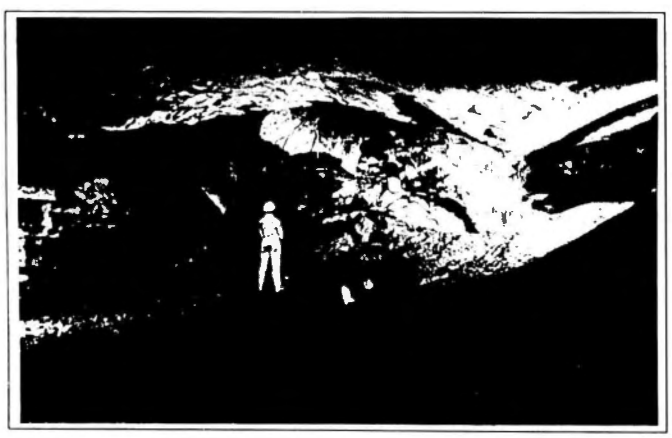

Figure 11: A view of the lower section of Brucker Breakdown as seen from the Cygnus X-1 Chamber (northwest looking southeast), Mammoth Cave System, Kentuck (note meter stick for scale). (*Photo by R. Ewers*).

Acknowledgements

I would like to thank Drs. Ralph O. Ewers and Arthur N. Palmer, good friends who provided invaluable and unfailing guidance, assistance, enthusiasm and encouragement throughout the entire course of this study.

Ms. Lynne Hughes was invaluable as a field assistant, and her boundless curiosity and enthusiasm provided much energy to the work in the cave. Special recognition is given to Richard Zopf and the 33 wonderful volunteers with the Cave Research Foundation who assisted in the long and tiring field work, and without whom, this study would not have been possible. Appreciation is expressed to the staff of Mammoth Cave National Park for their cooperation and interest in this study, especially to James Wiggins.

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Lithologic and Geomorphic Controls on Drainage Basin Morphology and Evolution, Crawford Upland, South-Central Indiana

Jerry R. Miller

The Crawford Upland, located in south-central Indiana, is highly dissected plateau underlain primarily by Upper Mississippian formations of the clastic dominated West Baden, Stephensport, and Buffalo Wallow Groups. Dissection has, however, exposed Middle Mississippian carbonates of the Blue River Group within entrenched valleys of the Crawford Upland. Carbonate exposure generally increases from west to east until reaching the Chester Escarpment. This escarpment represents the boundary between the Crawford Upland and the topographically lower Mitchell Plain; a low-relief karst plain.

Field reconnaissance and examination of topographic and geologic maps of the region qualitatively reveal differences in basin morphology related to both bedrock lithology and karst processes. In order to quantitatively examine the influence of lithology and bedrock dissolution on drainage basin morphology and evolution, 10 parameters describing basin shape, relief, valley morphology, and drainage texture were measured for 105 small basins (7.5 to 0.45 km^2) from USGS 7.5' topographic maps. The basins can be subdivided into two groups: catchments underlain predominantly by clastics of Upper Mississippian and younger formations (40 basins) and catchments underlain by both Middle Mississippian carbonates and Upper Mississippian rocks (65 basins)(Figure 12). The latter group includes 25 basins that exhibit sinking streams which are not surficially integrated with the regional base level: the Ohio River.

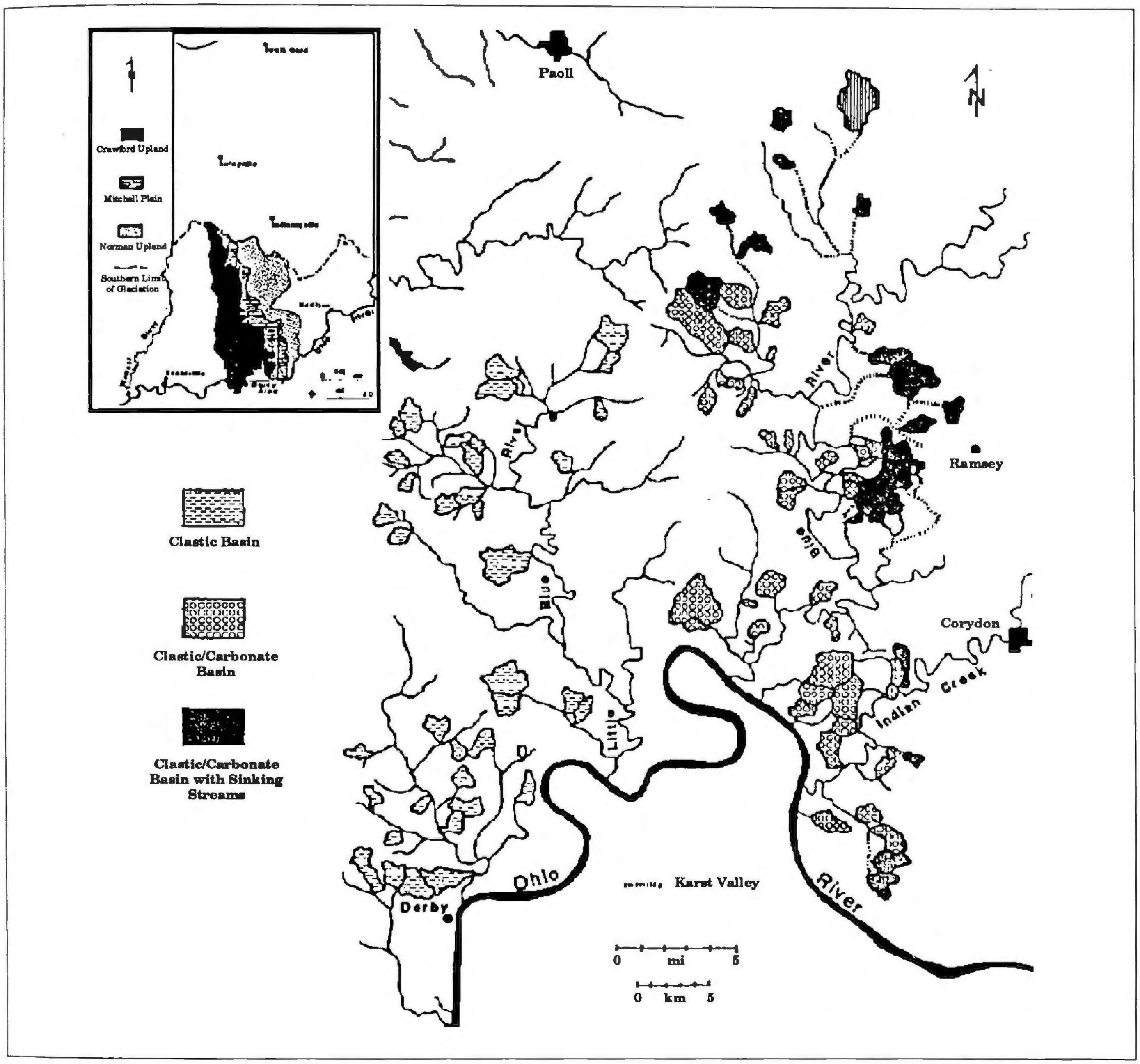

Figure 12: Location map showing A) study area in south-central Indiana, and B) catchments used for morphometric analysis.

Relations between the 10 morphologic parameters were determined using principle components analysis (PCA). The first four components account for 81% of the total variance in basin morphology and describe different attributes of basin morphology. For example, Pc-1 describes drainage texture, Pc-2 pertains to valley width, and Pc-3 relates to basin shape, relief and stream gradient (Table 1).

Variations in drainage texture (Pc-1) within basins primarily underlain by clastics can be explained by the percentage of shale exposed within the catchment; in particular, the areal percentage of the basin underlain by the Buffalo Wallow Group. Variations in drainage texture within clastic/carbonate basins cannot be explained by the abundance of exposed shale or exposed carbonates. However, the similarity between contour maps of Pc-1 scores and sinkhole density suggest that drainage texture is primarily controlled by karst processes.

Variations in Pc-2 and Pc-3 describing basin relief, stream gradients and valley width are primarily related to channel entrenchment during Pleistocene base level lowering of the Ohio River. Presumably, streams unable to entrench their valley floors were diverted into the subsurface creating dry valleys which hang tens of meters above modern base level, while integrated streams rejuvenated their basins creating high relief catchments with high gradient streams that traverse narrow v-shaped valleys.

Examination of PCA scores associated with the 105 basins suggest that catchment morphology is variable within the two broad lithologic groups initially defined. Hence, cluster analysis, preformed on PCA scores of the first four components of the 105 basins, was used to organize the catchments into groups on the basis of morphology. Cluster analysis subdivided the 105 basins into five morphologic groups. The multivariate technique shows that a continuum of basin morphologies exist, but in general, catchments underlain primarily by clastics are morphologically different from integrated clastic/carbonate basins. Additionally, surficially integrated basins differ morphologically from basins characterized by sinking streams.

The substitution of space for time allows the five delineated groups to represent morphologic stages of basin adjustment to changes in bedrock lithology during basin evolution. Changes in bedrock lithology primarily refers to the removal of clastic rocks from the catchment and the exposure of underlying carbonates. General evolutionary trends include 1) a decrease in first order stream frequency and a loss of axial channels as catchment valleys become underdrained resulting in a more coarse drainage texture, 2) a change in basin shape from circular to elongate, 3) an increase in valley width, and 4) a decrease in stream gradients and basin relief. The latter two trends (3 and 4) are accentuated upon the development of dry valleys. Presumably, during this developmental period, the elevation of the valley floor remains relatively constant, while drainage divides are degraded and retreat by continued fluvial and hillslope activity resulting in low basin relief and wide valley floors. Contour maps, reconstructed from the elevation of sinkhole divides of the Mitchell Plain, reveal a former drainage pattern; outliers of the Crawford Upland and highs upon the karst plain apparently correspond to drainage divides. Hence, fluvial processes may have been an important component in the development of the Mitchell Plain which has been designated as the final stage of basin evolution.

In addition to observed changes in basin morphometry, current field studies reveal differences in valley evolution as well as channel morphology, sedimentology, and hydrology between the five morphologic groups. However, the quantification of these differences is still in progress.

Table 1. Rotated factor pattern of the first four components of the PCA analysis of 10 parameters measured from 105 basins of the Crawford Upland.

Variable	Pc-1	Pc-2	Pc-3	Pc-4
DD	0.96	-0.05	0.04	0.04
Fsl	0.94	-0.02	0.02	-0.13
L1	-0.51	0.08	0.15	0.72
R12	0.28	-0.06	-0.04	0.85
K	0.02	-0.16	-0.78	-0.01
Vwid	-0.13	0.90	-0.04	-0.08
Vf	-0.01	0.87	-0.09	0.07
Rh	0.12	-0.48	0.81	0.07
Sg	0.13	-0.52	0.63	0.00
Rn	0.85	-0.17	0.11	0.19

DD - drainage density; Fsl - first order stream frequency; L1 - average length of first order streams; R12 - ratio between average length of first and second order streams; K - basin shape factor; Vwid - ratio of valley width to drainage divide relief; Vf - width of valley floor; Rh - relief ratio; Sg - average stream gradient; Rn - ruggedness number.

The Potential Depth of Underwater Caves in the Orlando Area, Florida

William L. Wilson

Introduction

The City of Orlando and its surrounding metropolitan area, in Orange and Seminole Counties, Florida, is very picturesque when viewed from the air because of the Profusion of nearly circular karst lakes that dot the landscape (Figure 13). Orange and Seminole Counties have 895 lakes, more than 10 acres in area (Hughes, 1974), most of which occur in sinkholes up to 0.6 mi wide that have been flooded by a shallow water table. The density of karst lakes is higher than any other area of comparable size in the United States. The numerous karst lakes, and the development of 10 to 11 new sinkholes per year on average (Wilson and others, 1987), indicate that karst processes have, and still are, actively shaping the land surface.

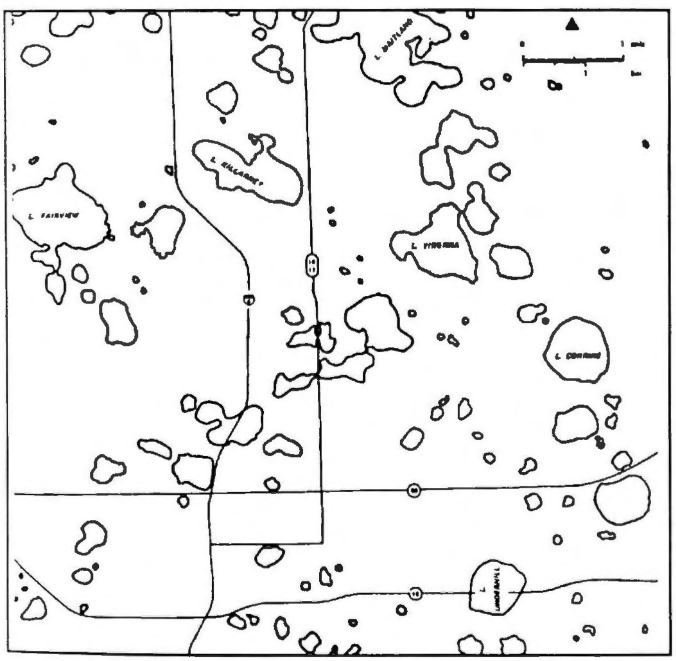

Figure 13: Karst lakes in a portion of the Orlando area, Florida. Chains of lakes are probably developed along bedrock fractures. Cavern development may be most extensive along the cahins of lakes.

Unfortunately, cave entrances are nearly nonexistent because the cavernous aquifer is mantled by sand and clay averaging 120 feet thick. The cavernous aquifer, which is described in a following section of this paper, is typically overlain by 70 to 80 feet of clay and clayey sand which comprises the Hawthorn Formation (Miocene) and 40 to 50 feet of undifferentiated Recent and Pleistocene sand.

Most of the karst lakes are shallow; seldom exceeding 15 feet in depth. Surficial sand and peat have nearly filled most of the sinkhole basins. However, the expression of karst topography through such a thick, generally impermeable cover, indicates prodigious cavern development beneath Orlando. The purpose of this article is to examine the frequency and potential depth for underwater caves, in the Orlando area, by reviewing the available geologic information.

The outstanding karst feature, in Orlando, is Emerald Sink (also known as Mystery Sink). Emerald Sink is approximately 300 feet wide and extends approximately 40 feet below the surrounding land which is at an elevation of 90 feet. At the bottom of the sink is a weed-choked lake approximately 100 feet. The lake extends downward through a 30 foot wide vertical shaft to a depth of 90 feet, at which point, the shaft opens into a room approximately 400 feet wide (Lichtler and others, 1968). The top of the debris cone occurs at a depth of 225 feet. The sides of the debris cone slope to a depth of 390 feet, as reported by Shex Exley, or 405 feet as reported by Hal Watts. Currently, Emerald Sink is ranked as the deepest underwater cave in the United States and the 8th deepest in the world (Knab, 1987).

Please take note that Emerald Sink is privately owned and definitely closed to diving as a result of diving-related deaths that occurred there in 1972. Respect the owner's wishes and do not ask to dive in Emerald Sink.

Cavern Occurrence

Cavern occurrence can be assessed by evaluating the frequency and size of cavities penetrated by drill holes. Lichtler and others (1968, p. 96) reported the occurrence of cavities that were penetrated by 63 drill holes in the Orlando area. The proportion of drill holes that penetrated at least one cavity in each 100-foot elevation interval is shown in Figure 14. Two major cavern zones are separated by a relatively barren zone. The upper cavern zone is 600 feet thick and occurs between elevations of approximately 0 and -600 feet. A 400 foot barren zone extends from elevations of -600 feet to -1000 feet NGVD. The lower cavern zone has not been fully penetrated by a adequate number of wells, but it is at least 400 feet thick and occurs between elevations of approximately -1000 feet to -1400 feet NGVD. The upper cavern zone will be discussed in some detail because it contains the caves that are potentially accessible to divers.

The upper cavern zone is developed in the Ocala Limestone and the Avon Park Limestone of Eocene age. The Ocala Limestone averages approximately 100 feet thick and the Avon Park Limestone is usually 500 feet thick. However, the lower 200 feet of the Avon Park formation is composed almost entirely of dolomite. In the Orlando area, the upper 1400 to 1800 feet of limestone and dolomite form the famous Floridan Aquifer.

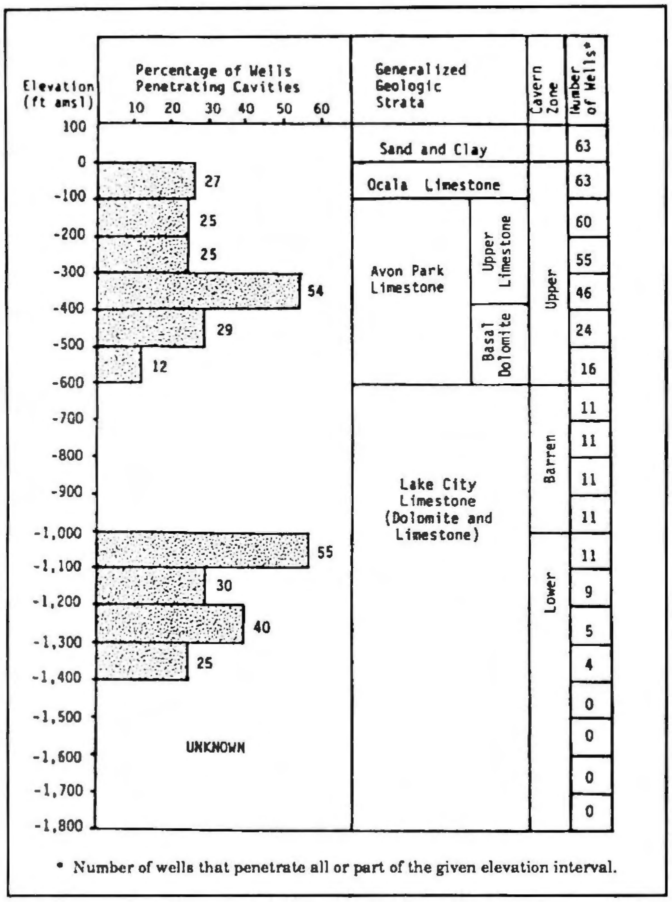

Figure 14: Frequency an depth of cavities beneath the Orlando area, Orange County, Florida, based on 63 selected wells.

A total of 88 cavities were penetrated by 63 wells that were drilled through all or part of the upper cavern zone. Between elevations 0 and -300 feet NGVD approximately 25% of the drill holes penetrated cavities in each 100 foot depth interval. Cavern development reaches a peak (mode) of 54% between elevations of -300 to -400 feet NGVD.

The peak interval of cavern development occurs at the base of the upper limestone unit in the Avon Park formation. At an elevation of -400 feet, the frequency of cavern development begins to decline with depth as the upper cavern zone passes into the dolomite at the base of the Aven Park formation. The lowest reported elevation for a cavity in the upper cavern zone is -650 feet NGVD. The potentiometric surface of the Floridan Aquifer, in the Orlando area, is approximately 50 feet above NGVD, so caves in the upper cavern zone extend to depths of approximately 700 feet.

The height of reported cavities in the upper Floridan Aquifer, used in this tabulation, ranged from 3 to 92 feet and the mean height was 10.7 feet. The frequency distribution of cavity height is shown in Figure 15. The median cavity height is 8.0 feet. Little or no correlation exists between cavity height and elevation as shown in Figure 16. Most of the reported cavities are high enough to be accessible to divers.

The upper cavern zone coincides quite well with the low sea-level stands that occurred during the Pleistocene Epoch (0.01 to 2.0 million years ago), when sea level repeatedly dropped approximately 400 feet. The maximum interval of cavern development occurs at elevations of 300 to 400 feet below modern mean sea level. Caverns at greater depth may represent phreatic flow paths (those that formed entirely below the water table).

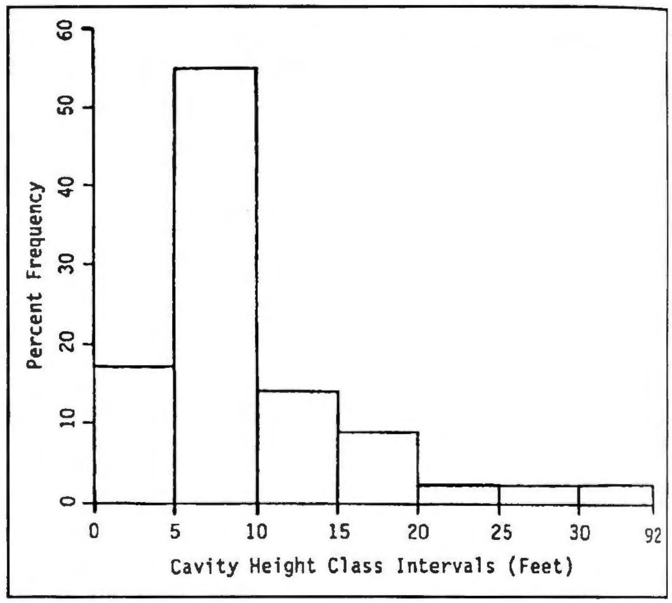

Figure 15: Frequency distribution of cavity height in the upper Floridan Aquifer in the Orlando area, Florida.

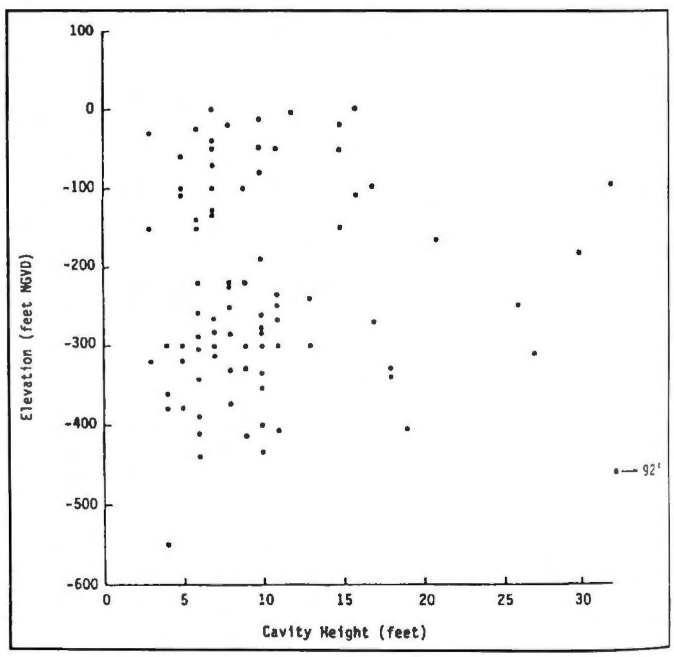

Figure 16: Scatter diagram of cavity elevation versus cavity height in the upper Floridan Aquifer, in the Orlando area, Florida.

Cave Exploration Potential

With the cavern occurrence facts above, the total cave potential in the upper cavern zone can be estimated. Sixty-three drill holes penetrated 942 feet of cave (88 caves x 10.7 feet average height/cave). The total linear drill hole distance, in the 600 foot thick cavern zone, amounts to 37,800 linear feet (63 drill holes x 600 feet/drill hole). So, the percentage of cave in the r cavern zone is approximately 2.5 percent (942 feet/37,800 feet x 100). A volume of rock 600 feet thick and 1 mile square will contain 418 million cubic feet of cave (600 feet x 5280 feet x 5280 feet x 0.025). Assuming the average cave is a tube of 10.7 feet in diameter, then the cavern space is sufficient to form 880 miles of cave per square mile (418,000,000 cubic feet of cave per square mile ÷ 5.35 feet x 5.35 feet x 3.14 ÷ 5280 feet/mile).

The caves will generally occur at depths ranging from 50 to 700 feet below water surface, but they are most commonly developed at depths of 350 to 450 feet. Obviously, most of the caves are beyond the safe limits of scuba with regular compressed air (130 feet). Special air mixtures and more technologically advanced equipment is needed for divers to reach, and safely explore, the tremendous cave ms that must underlie the Orlando area.

The major problem for cave divers in the Orlando area is one of access. Emerald Sink extends into the zone of maximum cave development, but is closed to diving. Other entrances to deep caves are not known. The floors of the numerous karst lakes should be checked more thoroughly for shafts leading into the Floridan Aquifer. Small sinkhole lakes, with surface elevations near 50 feet NGVD, are the most likely targets. A lake with a surface elevation 50 feet is approximately in equilibrium with the potential pressure of the Floridan Aquifer. Lake surfaces at higher elevations are more likely to be in equilibrium with the water table in the surficial sand aquifer. A low water surface elevation indicates that a good hydrologic connection exists between the lake and the cavernous aquifer.

New sinkholes do form in the Orlando area, and potentially a new entrance might be created. For example, the day after Christmas, 1987, the floor of the famous Winter Park Sinkhole (Lake Rose) dropped 30 feet as the sinkhole swallowed 23,000 cubic yards of sediment (Wilson, 1988). Water is now soaking more rapidly through the floor of the sinkhole. A cave entrance might open eventually. Another possibility, is that large diameter water-development wells will penetrate significant cavities. Divers could potentially enter the cavities through a drill hole. This may sound extreme, but it remains a possibility.

If other areas of Florida have the most cavern development at elevations of -300 to -400 feet NGVD, then the frontiers of cave diving lie in deep diving, helium-oxygen breathing mixtures and underwater habitats for decompression. The potential is there, but following it will require a few cases of exceptionally good access, great cave and substantial financial backing.

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Hydrology of Wakulla Spring

William L. Wilson and Barry F. Beck

Introduction

The Florida Sinkhole Research Institute, University of Central Florida, assisted the Wakulla Spring Project and the Florida Department of Parks and Recreation in studying the hydrology of Wakulla Spring. The Wakulla Spring Project was sponsored by the U. S. Deep Caving Team to explore and study the major cave system at Wakulla Spring, south of Tallahassee, Florida. The expedition was led by Dr. Bill Stone, and was sponsored, in part, by the National Geographic Society. Mr. Wes Skiles, President of Karst Environmental Services, served as science coordinator for the project and assisted in performing the dye traces described below. The project took place from October 26 to December 7, 1987. A full report on the expedition, which utilized mixed gases and diver propulsion vehicles, to make penetrations of up to 1216 m (4000 ft) at depths in excess of 91 m (300 ft), is in press (Stone, editor, 1989). The following sections of this report describe the results of the hydrologic investigations of the spring conducted during the expedition, and some of the geomorphic implications for the hydrologic function of the cavern.

Review of the Hydrology of Wakulla Spring

Wakulla Spring is a first-magnitude cave spring located 21 km (13 mi) south of Tallahassee, Florida. The spring forms the head of the Wakulla River which flows 16 km (10 mi) southeast to its confluence with St. Mark's River and thence 7.5 km (4.7 mi) south to the Gulf of Mexico. The low relief, limestone plain around Wakulla Spring (Figure 17), is called the Woodville Karst Plain (Hendry and Sproul, 1966).

Rosenau and others (1977) described Wakulla Spring and the first 305 m (1000 ft) of cave passage known at that time. Discharge at Wakulla Spring issues from the St. Marks Formation; a sandy, fossiliferous calcilutite of Miocene age. The St. Marks Formation extends from the surface to a depth of approximately 30 m (90 ft) in the spring pool, which is itself 38 m (125 ft) deep. Most of the cave appears to be developed

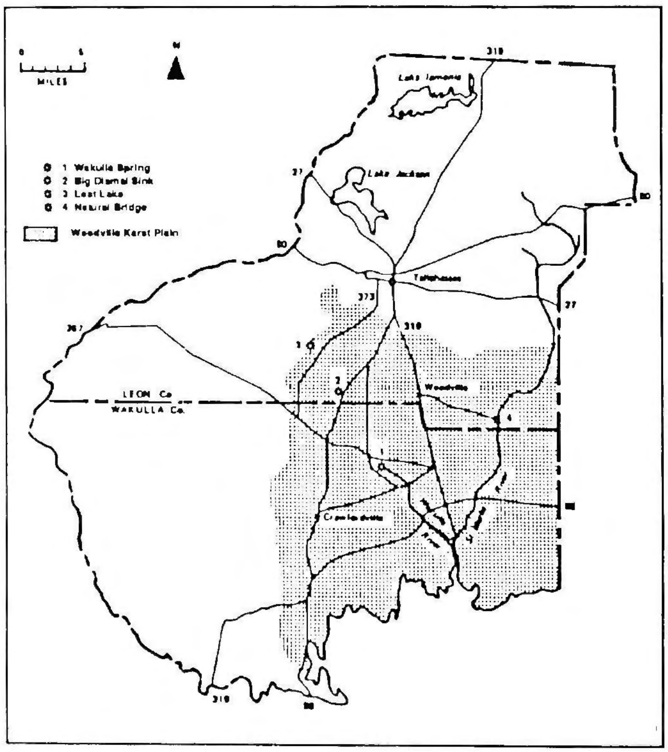

Figure 17: Location of Wakulla Spring and extent of the Woodville Karst Plain in Leon and Wakulla counties, Florida.

in the Suwannee Limestone, which is a fossiliferous calcarenite with laterally continuous beds of dolomite. The Suwannee Limestone is at least 65 m (214 ft) thick and is Oligocene age.

The average discharge of Wakulla Spring is 11.0 m^3/s (390 ft^3/s) making it the seventh largest spring in the state. However, the maximum discharge of 53.7 m^3/s (1910 ft^3/s) is the largest ever reported for a single spring vent, in Florida, thus indicating that Wakulla Cave is potentially one of the largest in the state.

The discharge of Wakulla Spring ranges from 0.71 to 53.7 m^3/s (25.2 to 1910 ft^3/s), which is the greatest known range for any karst spring in Florida. Many cave springs in Florida are characterized by relatively steady flow, which may be the result of low ground-water gradients and diffuse recharge through a nearly ubiquitous blanket of surficial sand. Although the overall range of discharge for Wakulla Spring is not great compared to karst springs in other areas, the variability suggests that, for Florida, Wakulla Spring is well-connected to sources of storm water recharge and/or may have a better interconnected system of cave passages serving to convey flow.

Discharges for Wakulla Spring are not usually measured directly; they are estimated from the discharge of Wakulla River at US Highway 319, approximately 4.8 km (3 mi) south of the spring. At the gaging station, the measured discharge includes the discharge from McBride Slough, Indian Spring, Sally Ward Spring, and base flow from limestone in the floor of the river. The discharge of Wakulla Spring is estimated by subtracting the discharge of the other water sources from the total discharge of Wakulla River. For this reason the discharge of Wakulla Spring is known only approximately. A permanent discharge measuring station should be installed at Wakulla Spring. Divers could install a current meter in the cave, which would allow direct measurement of the water velocity and calculation of the actual spring discharge.

The flow of Wakulla Spring correlates well with rainfall in Tallahassee and Crawfordsville (Rosenau and others, 1977). If approximately 25% of the rainfall recharges the aquifer, then the ground-water basin may cover approximately 1000 km^2 (400 mi^2). Potentiometric maps of the Floridan Aquifer (Rosenau and Meadows, 1986) show that ground water flows to the spring from the northwest. Flow could come from as far away as 64 km (40 mi), originating from near the small town of Sycamore in northwestern Gadsden County (Figure 18). Ground-water gradients near Wakulla Spring range from 0.30 to 0.42 m/km (1.6 to 2.2 ft/mi).

A number of underwater cave systems are known to exist up-gradient from Wakulla Spring, and may convey flow to the spring. The possible tributary systems include Sally Ward Spring, Indian Spring, River Sink, Kini Spring, Sullivan-Emerald Cave, Cheryl Sink, Gopher Sink, Little Dismal Sink and Big Dismal Sink. In January, 1988, divers connected Sullivan and Emerald caves establishing the longest explored underwater cave system in the world with other 12.5 km (41,000 ft) of passage. The extensive cave systems and large volumes of ground-water flow show that the Wakulla Spring drainage basin is one of the most important karst drainage basins in North America.

Quantitative Dye Trace

A quantitative dye trace was performed through a segment of Wakulla Cave in order to determine the discharge of the spring and the ability of the cavernous flow to dilute a water soluble chemical. On November 21, 1987, 15.3 grams

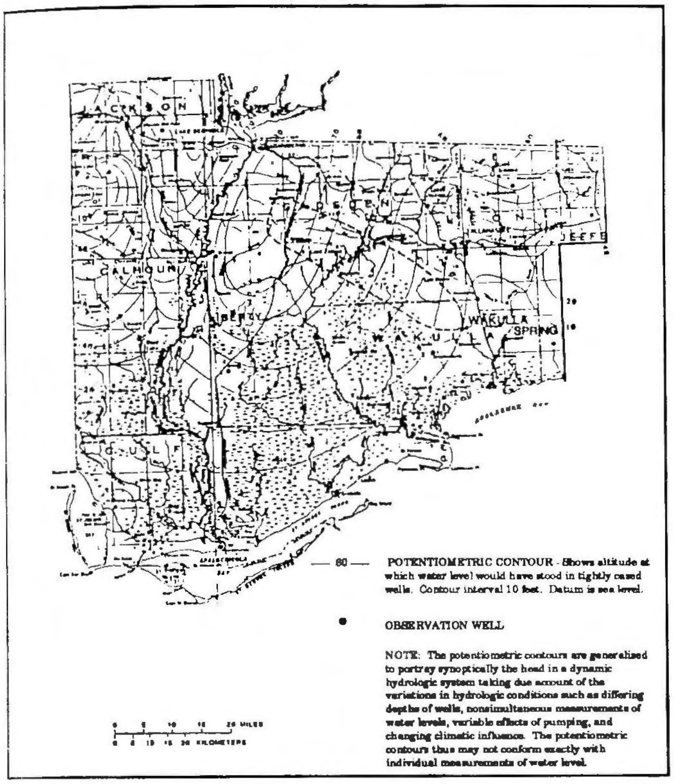

Figure 18: Potentionmetric surface of the Floridan Aquifer System in the eastern part of the Florida panhandle, May 1985, adapted from Rosenau and Meadows (1986). The dashed line extending northwest from Wakulla Spring is the approximate boundary of a possible drainage basin, encompassing 1000 km² (400 mi²), for the spring.

rhodamine B, mixed with 540 ml of water, was released in mid passage at a point 213 m (700 ft) from the entrance.

The dye concentration in the spring discharge was measured with a Turner Designs Model 111 Fluorometer, which was loaned to the Wakulla Spring Project by the Orlando Water Resources division of the U. S. Geological Survey. The instrument was calibrated for rhodamine dye according to procedures described by Wilson and others (1986). Water samples were collected from the end of the boat dock; located approximately 122 m (400 ft) downstream from the mouth of the spring. The sampling interval was 15 minutes for the first 4.5 hours of the test, and 30 minutes thereafter.

The average background fluorescence of the water was equivalent to 0.039 parts per billion (ppb) of rhodamine. For the purpose of calculating the spring discharge, the average background fluorescence was subtracted from the total sample fluorescence to obtain the actual dye concentration.

Dye was initially detected 2 hours after release. The peak dye concentration occurred 3.5 hours after release. Fifty percent of the dye passed after 3.95 hours. The dye concentration returned to background levels after approximately 9.5 hours. The width of the dye curve was 7.5 hours at the boat dock. The peak total sample fluorescence was equivalent to 0.175 ppb. The average total sample fluorescence was equivalent to 0.12 ppb, and the corrected average dye concentration was invisible to the eye and therefore had no affect on tourist operations at the spring.

The shape of the dye curve (Figure 19) was typical for dye traces through cavernous conduits. The ascending limb of the curve rose rapidly to the peak concentration, and the descending limb declined smoothly at a slower rate.

Assuming that 100% of the dye passed the sample station in 7.5 hours, then the corrected dye concentrations and the total amount of dye released can be used to estimated the spring discharge. In order to dilute the dye to the observed concentrations, the average spring discharge during the dye trace was equal to 6.46 m³/s (230 ft³/s). The estimated discharge seems reasonable. The average discharge is 11.0 m³/s (390 ft³/s), and, at the time of the dye trace, the spring was in a stage of declining flow.

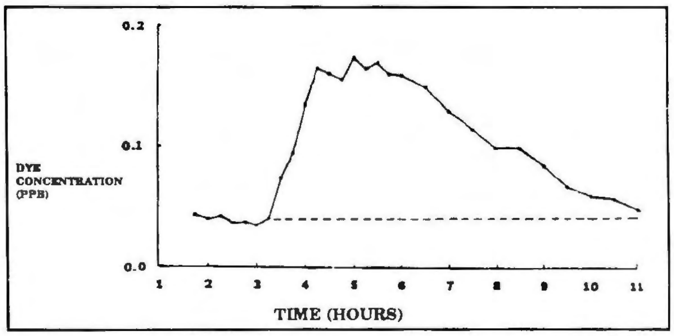

Figure 19: Dye concentration curve for the dye trace performed through Wakulla Cave on November 21, 1987. The tracing agent consisted of 15.3 g of rhodamine B, which was released 213 m (700 ft) inside the cave. The dashed, horizontal line represents the background fluorescence of the spring water.

The main passage of Wakulla Cave is approximately 10 m high and 25 m wide. For a discharge of 6.5 m³/s, the average velocity of flow through the main passage would be 2.6 cm/s or 2.2 km/day (1.4 mi/day).

Additional quantitative dye traces should be performed through Wakulla Cave in order to determine how the peak dye concentration decreases with distance of flow through the cave. Knowledge of such a relationship would allow one to estimate the rate of dilution of water soluble chemicals. Such knowledge would be helpful for managing chemical spills in the karst terrane south of Tallahassee and other areas that have similar hydrogeologic conditions.

Qualitative Dye Trace

On November 22, 1987, divers released 4.5 kg (10 lb) of sodium fluorescein, a bright green dye, into the main siphon tunnel of Indian Spring Cave. Indian Spring is located 2.4 km (1.5 miles) northwest of Wakulla Spring. A faint visual positive was detected at Wakulla Spring approximately two weeks after the dye was released. The positive dye trace is the first proven hydrologic connection between Wakulla Spring and another cave system in the Woodville Karst.

Based on straight-line distance, the minimum velocity of flow between Indian Spring Cave and Wakulla Spring is 171 m/day. This velocity is much slower than the velocity observed throughout the downstream section of Wakulla Cave for the quantitative dye trace. The slower velocity of flow from Indian Spring Cave to Wakulla Spring might indicate that the two systems are not connected by large conduits. Breakdown along some segment (or segments) of the cave system, or small passages may impede water flow and cause the unusually slow velocity. Alternatively, very large cave rooms may exist between the two caves and serve as large in-line storage tanks that slow the flow of the ground water. Chambers more than 100 m long and wide, and many 10's of meters high have been reported by divers in Indian Spring Cave and other nearby caves. The relative proportion of delay caused by inline storage and flow through small passages or obstructions cannot be determined at this time.

Qualitative dye traces should be conducted from other nearby cave systems such as River Sink and Sullivan Sink in order to establish the boundaries of the Wakulla Spring ground-water drainage basin. The quality of water in Wakulla Spring can be protected only by preserving the quality of water throughout the recharge area for the spring. At present, the extent of the drainage basin is poorly known. Also, the velocity of water movement has not been documented between possible input points and Wakulla Spring.

Geomorphology of Wakulla Cave

One of the most significant results of the Wakulla Spring Project was the pattern of cave development revealed by the underwater survey. The project divers mapped the passages as they explored. Over 3475 m (11,400 ft) of passage was surveyed, which extended the known portion of Wakulla Cave by a factor of ten. Divers discovered that the main passage branches into four passages starting at a point 244 m (800 ft) from the spring.

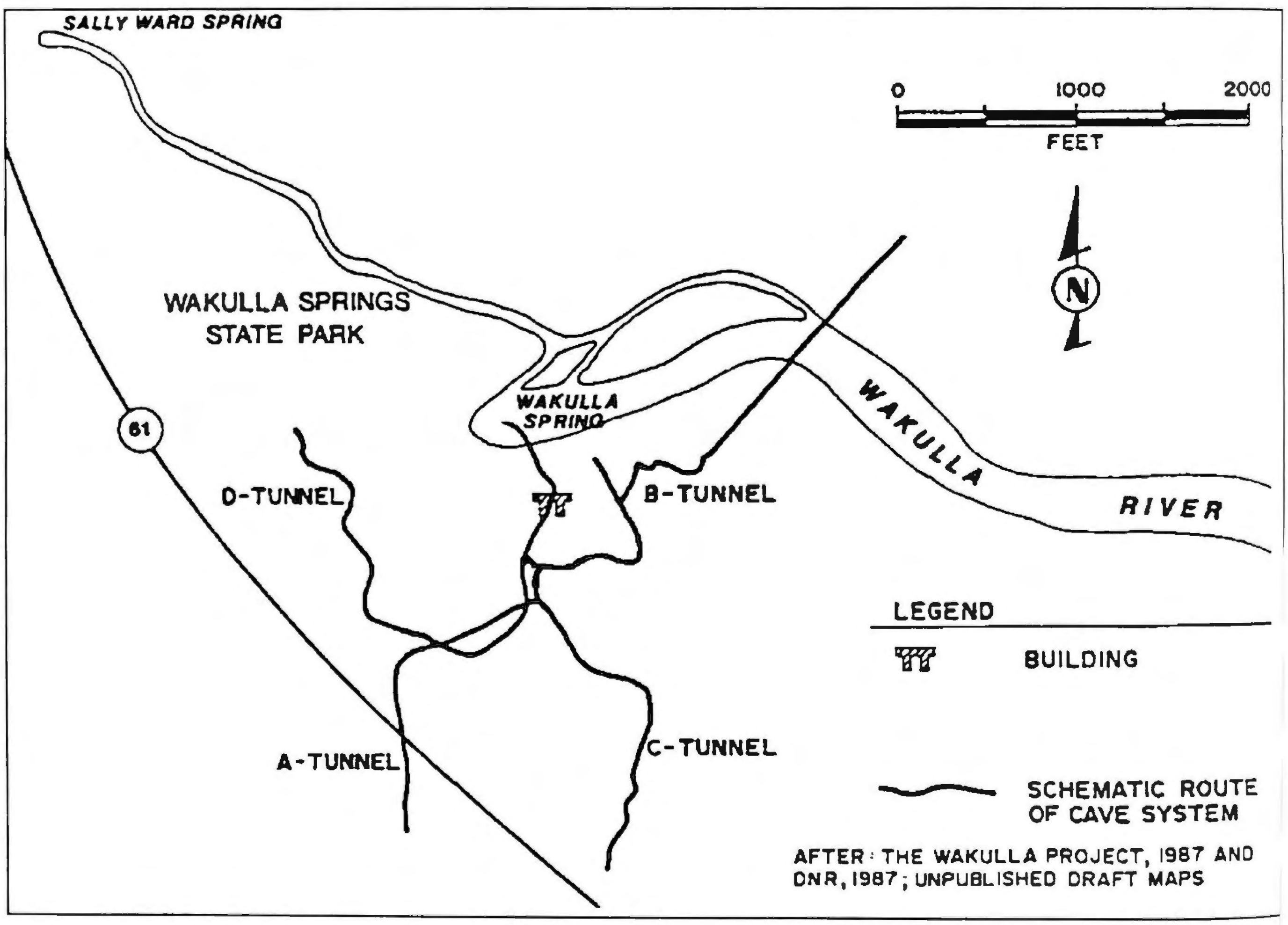

Figure 20: Schematic route of Wakulla Cave.

The newly discovered passages branch toward the south (Figure 20), even though potentiometric maps show that ground water is flowing to the spring from the northwest. The main, or "D", tunnel initially trends south, but, after 300 m (1000 ft), it hooks around and extends northward, thus confirming the situation shown by the potentiometric surface. The "D" Tunnel extends toward Sally Ward Cave, and is probably directly connected. Sally Ward Spring is merely a tap-off passage that allows a small portion of the flow in the main conduit system to emerge.

The southward bifurcating passages indicate that Wakulla Cave may have formed as a swallowhole. A surface stream flowing southeast, across the Woodville Karst Plain, may have sunk at the present spring location, recharged the Floridan Aquifer, and flowed south toward the Gulf of Mexico. The southward-branching passages would have been formed by the infiltrating water. The swallowhole would have been active during Pleistocene glacial stages when sea level was several hundred feet lower. Now that sea level has risen, the hydrologic function of the cave has reversed and the swallowhole is serving as a discharge point. "D" Tunnel, which extends north, may have formed during interglacial stages of the Pleistocene, when sea level was high and ground water flowed toward the spring from the northwest. As many as four changes in function may have occurred during the Pleistocene and Holocene, as glaciers repeatedly formed and melted.

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Groundwater Flow Patterns in Joint-Controlled Networks and Cave Development*

Stephen R. Kraemer

Abstract

Discrete pathways of groundwater flow are likely to develop in carbonate aquifers, following either joints or bedding planes. A computer model has been written to test simplified conceptualizations and build understanding of discrete joint-controlled flow systems in connection to regional boundary conditions (recharge to discharge areas). A mechanism of preferential dissolution of limestone has been proposed that has localized dissolution of carbonate rock occurring in joints with focused infiltrating rainwater just underneath the water table. These same joints are also experiencing greater flow because they are connected to regional boundary conditions.

Summary

A simplified conceptual model of the carbonate rock aquifer is developed for testing of a joint-controlled mechanism of cave initiation. The permeability of the rock aquifer is assumed controlled by extensive vertical master joints. The joint walls are considered as parallel plate fractures. Rock matrix and bedding plane permeability is not considered. The hypothesis is built as follows:

1. Rainwater moving through the upper soil zone contains dissolved carbon dioxide giving that water an enhanced capacity to dissolve limestone. And conversely, water in contact with limestone beneath the water table is likely to be saturated with respect to calcite and not be expected to dissolve more limestone.

2. Rainwater infiltration into joints tends to be focused in the upper zones when there is existing flow in the joint due to continuity of flow. The greater the existing flow, the more infiltrating rainwater is focused in the upper zone of the joint. Rainwater entering a joint where there is little existing flow tends to flow deeper into the joint (i.e. at a dead-end joint, or in an area of ponding of water) .

3. Rainwater focused in the upper zones of a joint will dissolve calcium carbonate in the region just under the water table. Rainwater that penetrates joints deeper will dissolve calcium carbonate over the depth of penetration in the joint.

4. Joints with localized water table dissolution are more efficient at moving water than joints with the same amount of calcium carbonate removed over the depth of the joint. For example, making the aperture of a joint twice its original aperture (over the entire depth) makes it 225% less transmissive than a joint with the same amount of material removed over the top 10% of the joint.

5. Preferred pathways of connected joints to boundary conditions will experience higher flow rates, thus localized water table dissolution (widening of the joints), resulting in the increased capacity (with time) of these joints to transmit flow. Joints with the capacity to handle greater flows will also have a more stable water table than joints of lower flow capacity.

These factors taken together form a positive feedback loop. Once the system crosses over potential critical thresholds (hydraulic, transport, and chemical kinetic) the dominant path should be even further differentiated.

A discrete flow computer program was written to perform experiments based on the above conceptualization. Fracture patterns are generated by controlling the distribution of fracture centers, length, aperture, density, and orientation. Constant head boundary conditions (representing streams, for example) can be superimposed as linear elements; when a fracture crosses a boundary, a node is created and assigned the constant head value. Constant head boundary points representing sinkholes and springs can be located.

Fracture networks are connected to constant head boundary conditions and the resulting flow patterns are graphically displayed. The flow is assumed to be linear, that is the discharge is proportional to the head loss (either Darcian, parallel plate, or pipe flow depending on the proportionality constant used). The solution procedure is based on Kirckoff's laws for electric circuit analysis. Flow is calculated at each branch and adjusted by iteration to maintain a flow balance at each node. Areal recharge is distributed using line sinks to represent the fractures. Dissolution is accounted for by mass balance assuming equilibrium is attained between rainwater and carbonate
rock.

Computer experiments were designed to observe the evolution of preferred (joint directed) pathways between sources and a sinks based on the mechanism described above. One of the experiments will be described. A uniform, evenly spaced jointing pattern was selected to discourage preferential pathway development based on connectivity alone. Flow is created in a fracture mesh between two discrete constant head boundary points. Annual dissolution of limestone is accomplished by infiltrating rainwater, which is equally focused into each joint segment. The flow solution is updated after given time intervals, and the joints in the network are allowed to dissolve (widen) for a period of 800 years.

The result is that the region around the resurgence experienced greatest widening of the joint apertures. This result is in agreement with field evidence for many developed cave systems. However, the dissolution was not accomplished by the greater flow volumes of water at the resurgence; the dissolution of the joints was accomplished by focused rain water in the upper parts of the joints.

* Kraemer, Stephen R., 1988. Groundwater flow patterns in joint-controlled networks and cave development, in *Proceedings of Second Conference on Environmental Problems in Karst Terranes and Their Solutions*, Assoc. of Ground Water Scientists and Engineers, National Water Well Association, Nashville, TN, Nov. 16-18, p. 17-27.

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ECOLOGY PROGRAM

Arthropod Species Diversity in the Big Room and the Environs

Diana E. Northup, James M. Hardy and Kenneth L. Ingham

Introduction

A study of species diversity in the Big Room and Left Hand Tunnel of Carlsbad Cavern was undertaken in 1988 by the authors to further study differences in species diversity that were noted previously by one of the authors (Northup 1988) in her study of species diversity in Carlsbad Cavern, which was carried out in Bat Cave, Sand Passage and Left Hand Tunnel. Hill's N_2 values of species diversity (alpha-diversity) (Hill 1973) were calculated from data collected for all three locations between December 1984 and October 1987. The results showed differences in species diversity between Left Hand Tunnel, and Bat Cave and Sand Passage. Overall, Left Hand Tunnel N_2 values were closer to one, while Sand Passage and Bat Cave had higher values, indicating relatively more even proportions of each species than in Left Hand Tunnel. To investigate whether these results held up at a large scale (i.e. the Big Room through part of Left Hand Tunnel), a series of transects were selected in these two areas. A summary of the methods, results, and discussion is given below. More detail can be obtained from the senior author.

METHODS

Transect and Trap Site Selection

In the Big Room and Left Hand Tunnel, transects were selected to sample representative habitats at increasing distances from the Lunch Room and from park visitor trails. Selection of transects was not done at random due to the delicate nature of some areas and unsuitability of some areas for trap setting due to their solid rock nature. Along the various transects, trap sites sampled vertical heterogeneity, soil moisture content, soil type, distance from trail, distance from Lunch Room, and public vs non-public areas.

Results

Hills N_2 values of species diversity (alpha-diversity) were calculated from data collected for the Big Room and Left Hand Tunnel between February 1988 and September 1988. Overall, Left Hand Tunnel N_2 values remained closer to one, as was observed in Northup's previous study. The species diversity in Left Hand Tunnel was generally lower, but not by much, than in the Big Room, indicating that there is a slightly greater dominance by one species in Left Hand Tunnel.

Species richness was greater in the Big Room (number of species found equals eight) than in Left Hand Tunnel (number of species found equals six). Two of the six species found in Left Hand Tunnel, *C. conicaudus* and the black tenebrionid beetle, were observed from only one specimen. One of the eight species found in the Big Room, the centipede, was also observed from only one specimen. Cavernicolous rhaphidophorids, particularly *C. Carlsbadensis*, overwhelmingly predominate. A significant number of diplurans and collembolans were also observed.

Abundance patterns by date revealed lower total numbers of organisms in the Big Room than in Left Hand Tunnel. Except for the one sampling date in April, the numbers of organisms dropped off in the Big Room following the initial censusing in February.

To investigate the possibility that organisms were aggregating around the Lunch Room, number of organisms found versus distance from the Lunch Room was plotted. The Big Room data especially does seem to exhibit any clear pattern. The separate plot of *Ceuthophilus* spp. found in the Big Room does exhibit a slight pattern of clustering of these organisms around the Lunch Room. The plots of the Left Hand Tunnel data (which consist mainly of cavernicolous rhaphidophorids), show a greater number of organisms than is found in the Big Room. Additionally, there appear to be greater numbers of *Ceuthophilus* spp. near the Lunch Room, even when the greater number of traps set in this area is taken into consideration.

A plot of the number of organisms by the distance from trail in the Big Room, shows only a very slight tendency for organisms to cluster nearer to the trail.

A greater number of Left Hand Tunnel organisms (predominantly *Ceuthophilus* spp.) were found directly behind the gate (between 200 and 350 feet from the nearest trail) (i.e. the Lunch Room) and further back (i.e. 1000 feet) in an area that is believed to be an oviposition site.

To investigate the differences in organism abundance patterns among the differing types of soil substrates, a plot was constructed of the average number or organisms caught in traps of each substrate type. This plot shows greater average number of organisms in moonmilk, rubble and silt. The clay average is misleading because of the low number (N=2) of traps set in clay.

The relationship between average number of organisms per trap and increasing vertical heterogeneity (low, moderate, high) is a fairly linear one, with a higher average number of organisms being observed with increasing vertical heterogeneity.

Because the number of traps set in areas of damp, wet or dry areas surrounded by pools (wdry) was small, this plot can only provide a preliminary indication of relative abundances. The highest average number of organisms per trap was found in the dry area traps.

Discussion

Species Diversity and Richness

The investigation of species diversity at the greater scale of the Big Room and Left Hand Tunnel, showed a similar pattern of generally low species diversity in Left Hand Tunnel as was found in Northup's previous study from 1984 to 1987. Species diversity values for the Big Room were slightly higher. Thus, there is some confirmation that this area, for whatever reason, is different in terms of species diversity than Sand Passage and Bat Cave, which had higher species diversity values. This difference is due to the numerical dominance by *C. Carlsbadensis* in the Big Room and Left Hand Tunnel.

Species richness, which is often tied to the productivity of the area, is greater in the Big Room than in Left Hand Tunnel, and is intermediate between Sand Passage (which is the same as Left Hand Tunnel), and Bat Cave. It is also known that the amount of sampling effort/area is associated with species richness, with increasing species richness with sampling effort/area. Thus, it is possible that with additional traps and/or censuses, we might find additional species. It does appear though, that the Big Room is richer in terms of the absolute number of species found there.

Species Abundance

Two trends seem somewhat evident from the data: (1) there is some clustering, especially among cavernicolous rhaphidophorids, near the Lunch Room, (2) there are greater numbers of organisms in Left Hand Tunnel than in the Big Room. The numbers of organisms observed, especially in the Big Room, may be underestimated due to the effect of the trail resurfacing that was done in March 1988 and covered approximately 1500 feet of trail in the Big Room. Exactly what effect that had on abundance patterns is not known, but it seems likely from the drop in numbers that it had an effect.

Acknowledgements

The authors gratefully acknowledge the field help provided by National Park Service and Cave Research Foundation personnel: Kris Poulson, John Roth, Marilee Houtler, Sandy Brantley, Bill Ziegler, Doug Best, Paul Pfenniger, Coolie Ballou, Fowler, and Dick DesJardins. A special thanks to John Roth for overall assistance with the data gathering and training of personnel, and to Bill Ziegler for assistance with the report.

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Aquatic Communities in Mammoth Cave

Julian J. Lewis

In 1988, study of shallow aquatic communities in Mammoth Cave continued, building on the work of a decade of investigations (Lewis, 1981a; 1982, and T. M. Lewis 1980; 1983). A variety of information is obtainable by this type of study. Previously, the only information available on aquatic species in Mammoth Cave consisted of widely scattered reports on individual species, frequently associated with distribution reports in taxonomic accounts. The goals of this study include determination of what communities exist at various sites, their species' use of microhabitats, relative abundance of the constituent species and life history information. With greater insight into these and other aspects of Mammoth Cave communities it may become possible to determine why the communities assemble in the manner in which they occur.

A second census site, in Mammoth River, was added to the site already being studied in Cathedral Domes (Lewis, 1988)(Figure 21). Mammoth River was selected due to the presence of a community typical of lower level streams in the Mammoth Cave System, along with its relative ease of access. The stream is located near Kentucky Avenue, from which the stream is easily reached via a short hands-and-knees crawlway. The Mammoth River passage in the vicinity of the census area is a walking-height canyon (Figure 22). The stream flows over limestone bedrock covered with gravel, along with occasional pieces of breakdown and small areas of silt. The name Mammoth River is actually a descriptive misnomer, in that this stream in no way resembles the base-level cave rivers found elsewhere in Mammoth Cave Ridge. Very little detritus is found in the stream and the habitat generally appears food-poor. The clay sediments common in other stream habitats in Mammoth Cave are largely absent in the vicinity of the Mammoth River study area. In Mammoth Cave, mud-bottom stream habitats frequently have populations of isopods, amphipods and flatworms grazing them; substrate cultures grow fungi which the invertebrates are presumably utilizing as a food source (dissection of isopod gut samples also reveal the presence of these fungi).

The method of census in Mammoth River is identical to that conducted in Cathedral Domes and described previously (Lewis, 1988). A thirty-foot section of the stream has been divided into 2.5 foot subsections, in which all invertebrates are identified and a size estimate made and recorded.

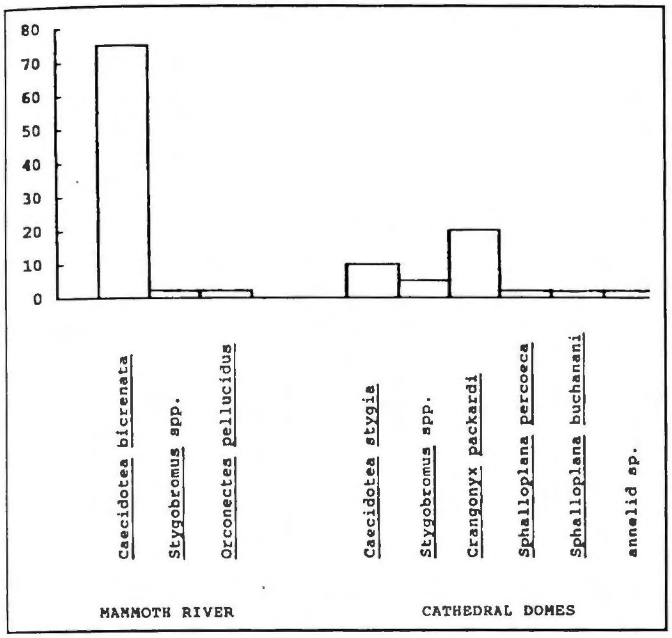

Figure 21: Relative abundance of aquatic invertebrates in Mammoth River and the stream in Cathedral Domes, Mammoth Cave, Mammoth Cave National Park, Kentucky.

A variety of different types of aquatic communities occur in Mammoth Cave. Twelve species (not including commensals), all troglobitic, are present for assembly into different communities: (1) amphipods – *Crangonyx packardi, Stygobromus exilis, Stygobromus vitreus*; (2) isopods – *Caecidotea stygia, Caecidotea bicrenata*; (3) flatworms – *Sphalloplana percoeca, Sphalloplana buchanani*; (4) snails – *Antroselates spiralis*; (5) crayfish – *Orconectes pellucidus*; (6) shrimp – *Palaemonias ganteri*; (7) fish – *Typhlicthys subterraneus, Amblyopsis spelaea.*

Many variables are present in the habitats at different sites in the cave which affect the community structure present in the habitat. Among these are: (1) the elevation of the stream within the ridge, which determines the size, depth and permanence of a given stream; (2) the material present on the stream bottom, which may be sand, silt, clay, gravels of various sizes, breakdown, bare limestone or a combination of all of these; (3) the amount of food available, which varies dependent on the amount of detritus, dissolved organics, substrates for microbial growth and artificial enrichment, e.g., the rotting wood from the rotting staircase present in the stream at Cathedral Domes.

In contrast to the food-rich, highly diverse community found in Cathedral Domes, only three species have been found in Mammoth River (Table 2). These species are all troglobites: (1) *Caecidotea bicrenata*, a common inhabitant of lower level streams in Mammoth Cave; (2) *Stygobromus* sp., specific identification not yet available, a cryptic amphipod occurring in small numbers; and (3) *Orconectes pellucidus*, the cave crayfish of the Mammoth Cave region. The majority of the animals seen in Mammoth River are isopods, accounting for over 95% of the fauna. A single immature crayfish, possibly the same individual, has been seen on both occasions that the stream was censused, with this individual being noted in essentially the same spot on two occasions. Crayfish in general are rare in this stream. During a reconnaissance trip downstream in Mammoth River only a single individual was noted along several hundred feet of passage. One of the more interesting observations in Mammoth River has been the absence of flatworms. Despite searching, not a single individual has yet been found in this stream.

Table 2: A comparison of the stream communities present in Mammoth River and Cathedral Domes.

Cathedral Domes	Mammoth River
amphipods:	
Crangonyx packardi	–
Stygobromus exilis	*Stygobromus* sp.
Stygobromus vitreus	–
isopods:	
Caecidotea stygia	*Caecidotea bicrenata*
flatworms:	
Sphalloplana buchanani	–
Sphalloplana percoeca	–
crayfish:	
–	*Orconectes pellucidus*

Acknowledgements

I would like to thank Nancy Delaney, Kay DeLaney and Marilyn Bowman for providing field assistance in Mammoth Cave National Park.

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Figure 21: View of the Mammoth River census site. The study area shown here is reached by climbing down from an intersecting crawlway directly above the area shown. The stream is censused in 2.5 foot sections using the tape measuring shown as a guide. (*Photo by Nancy Delaney and Julian J. Lewis*).

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Genetic and Morphological Variation in Populations of *Gammarus minus* (Amphipoda)

Ross Jones

Most cave animals have a series of similar morphologies termed cave-dependent characters (Christiansen, 1961). Among these characters are reduction in eye size and the increase in the size of the non-visual sensory structures such as the lateral line system of blind cave fish and antennae in cave arthropods. This increase is commonly assumed to be an adaptation to the cave environment. However, the causes of eye reduction have been a controversy since the time of Darwin.

Most studies of eye reduction in cave animals have been hampered by the lack of a closely related surface species with which to estimate the relative reduction in eye size. The crustacean amphipod *Gammarus minus* is an excellent model system for the study of eye reduction because in one part of West Virginia it is found in both surface springs and cave streams. Populations are found in several underground drainage basins throughout the study area. Surface individuals have a large compound eye containing about 20-40 facets and relatively small antennae. Individuals from cave populations have a much smaller eye containing from 0 - 15 facets and larger antennae.

Table 3 presents data on the variation in eye facet number both within and among spring and cave populations of different drainage basins. S1 - S4 are four spring populations each in a different drainage basin. C1 - C4 are four cave populations corresponding to the same basins as the spring populations. "x" is the average of head length, which was used as a measure of body size, or of the number of facets in each eye. "b" is the slope of the regression of the log of eye size on the log of head length and represents the degree of dependence (allometry) of eye size on body size.

TABLE 3: Morphometric Data

	S1	S2	S3	S4
SPRINGS				
Head length				
x ± SE	0.74 ± 0.02	0.57 ± 0.02	0.88 ± 0.02	0.81 ± 0.02
Eye facet number				
x ± SE	37.90 ± 0.09	16.20 ± 1.00	29.80 ± 0.80	37.80 ± 1.10
b ± SE	0.45 ± 0.09	1.50 ± 0.16	0.85 ± 0.12	0.59 ± 0.10
CAVES	C1	C2	C3	C4
Head length				
x ± SE	0.89 ± 0.04	0.84 ± 0.03	0.84 ± 0.02	0.81 ± 0.02
Eye facet number				
x ± SE	12.50 ± 0.70	5.80 ± 0.50	3.80 ± 0.50	2.40 ± 0.20
b ± SE	-0.58 ± 0.30	-0.98 ± 0.43	-0.07 ± 0.50	1.32 ± 0.46

For the four spring populations the average number of eye facets range from between about 16 and 38. The allometric coefficients (b) are significantly different from each other and show the presence of both positive and negative correlations between eye size and body size.

The average eye size in the cave populations is much less than that of the spring populations ranging from 2.4 facets per eye to 12.5. The allometric coefficients for the four cave populations were highly variable but a test for the equality of slopes (Sokal and Rohlf, 1981) indicates no significant differences. However, an analysis of the variance of the mean facet numbers showed that average eye size was significantly different for the four cave populations.

To summarize, the data on eye size indicate that all cave populations are similar in having significantly smaller eyes than the spring populations. However, within habitat (cave or spring) differences in eye size are present and are indicated by the significant differences in the allometric coefficients among the spring populations and the mean eye facet number among cave populations.

One hypothesis that could explain these differences is that each drainage basin is independent of each other and represents separate adaptations by different populations to the cave environment. If this is true then the reduction in eye size of cave populations of *Gammarus minus* would have happened several times independently of each other. It would not be the result of a single population undergoing eye reduction, either as a result of adaptive or non-adaptive reasons, and migrating throughout the several drainage basins. Therefore, two assumptions of this hypothesis are that each cave drainage represents an independent invasion by a surface ancestor and that selection within each cave drainage has led to the convergent but not identical eye morphologies.

I have previously reported results on a test of the second assumption of this hypothesis (Jones, 1987 and Jones and Culver, 1989). In this study I found that for at least one cave population individuals with smaller than average eye size had higher fitness, representing selection for small eyes. Quantitative genetic studies of these same populations (Fong, 1989) have shown that eye size is a heritable trait, so that selection in one generation can result in the reduction of eye size across generations.

To test the first assumption I have done a preliminary electrophoretic analysis of proteins to determine the pattern of genetic similarity among populations. Populations which have been isolated for a long period of time would be expected to be genetically distinct while those populations which are still in contact or have only recently been isolated would be expected to be genetically similar.

Nine populations (six springs and three caves) from five drainage basins were studied. Starch gel and polyacrylamide electrophoresis was used to detect differences in the structure of 16 enzymes. Figure 23 shows a dendrogram based upon Nei's genetic distance measurement (Nei, 1972). The distances of the segments joining any two populations on the dendrogram represent the degree of genetic similarity, the smaller the distance, the more genetically similar the populations. Dendrograms were calculated using many methods and all gave the same qualitative relationship between populations. The populations indicated (i.e. S1 and C1) do not correspond to those in Table 3.

This dendrogram shows that populations are clustered together on the basis of their presence in the same drainage basins. The populations can be divided into five groups corresponding to different drainage basins. All three cave populations are grouped with spring populations within the same drainage basin and therefore show no sign of an overall genetic convergence. The genetic similarity measurements,

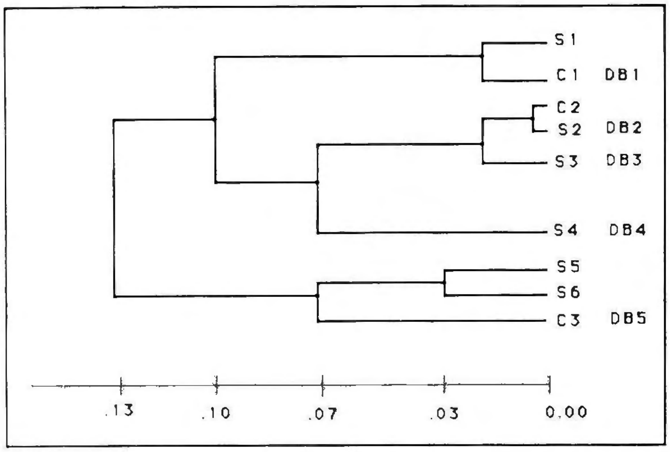

Figure 23: Dendrogram.

indicated on the number line in the figure, represent a relatively high amount of genetic differentiation among these populations which can not be explained as the differentiation of populations in similar habitats (caves or streams).

In summary, the electrophoretic data show that populations within drainage basins are more genetically similar than populations between drainage basins. Therefore, the assumption that the populations in each drainage basin are independent of those in other drainage basins would seem to be true. This is also supported by the fact that while the eye morphology of cave populations do converge (all cave populations have smaller eyes than surface populations) they are still significantly different, indicating that the populations are independent of each other.

The electrophoretic and selection data suggest that populations of *Gammarus minus* have independently invaded several different cave systems and that in each case natural selection has resulted in the convergence of the eye morphology among all cave populations.

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Hall's Cave – Tracking 13,000 Years of Environmental Change

Rickard S. Toomey III

The past 15,000 years are perhaps the most interesting in geological history from a paleoenvironmental point of view. The end of the last glaciation led to large-scale rearrangement of the biota resulting in modern communities and the extinction of many types of large mammals, including mammoths and sabre-tooth cats. The detail and resolution with which we are able to study these changes is unparalleled in geologic history. The goal of the on-going study of Hall's Cave (Kerr County, Texas) is to reconstruct the sequence of environmental changes which Central Texas has experienced during this interval.

Preliminary study of Hall's Cave in the early 1970s and more in 1986 revealed that the cave contained at least two meters of biogenic (guano) and surface derived clastic sediments. These sediments were found to contain abundant vertebrate remains, especially those of bats, rodents and insectivores. In 1987 I began a detailed study of the sediments and bones from Hall's Cave.

Radiocarbon dating of travertine just below the clastic sediment fill, indicates that the cave has been open for at least the last 13,000 years (Tx-6137 13,050 ± 140 yrs BP on travertine just below clastic sediments). This is consistent with the presence of extinct animals in the lowest meter of the clastic sediment. Although radiocarbon dating to determine the rate and continuity of sediment accumulation is largely uncompleted, the cave appears to contain one of the most complete Late Pleistocene through Late Holocene deposits known from North America.

In excavations during the summers of 1987 and 1988 approximately 16 cubic meters of sediment were removed from the cave. Most of it was removed in 5 cm thick levels in order to provide detailed information on faunal changes. The sediments were then wet-sieved through a 2 mm mesh screen in order to recover bone, snails, seeds and insect remains. These remains were then picked from the resulting concentrate and were identified. This processing of the excavated sediment is continuing. Samples of sediment for pollen and mineralogical analysis were also collected from the walls of the pits.

As of the end of 1988 over 3800 vertebrate specimens had been identified and catalogued. These specimens represent over 90 taxa, of which approximately 60 are mammalian. In addition to containing remains of many of the vertebrates found near the cave today, the Hall's Cave fauna contains both extinct taxa and extralimital taxa (animals no longer found in the area today). Extinct taxa which have been recovered at Hall's Cave include flat-headed peccary (*Platygonus compressus*), giant bison (probably *Bison antiquus*), horse (*Equus* sp.), and giant tortoise (*Geochelone* *wilsoni*). Some of the many extralimital taxa from Hall's Cave are shown in Figure 24.

The extralimital species provide much of the information on changing environments. This is because the presence of species that occur in the area today does not indicate changes in environment and the absence of these species may be due to factors other than environmental changes. Figure 23 shows the stratigraphic distribution of several of the most important environmental indicators found in the Hall's Cave fauna.

The appearances and disappearances of taxa at various levels indicate both general environmental conditions and the changes which have occurred in these conditions. Some preliminary conclusions concerning the Hall's Cave fauna and paleoenvironments are presented below.

The presence of horse (*Equus* sp.), bison (*Bison* sp.), prairie dog (*Cynomys* sp.), and meadow vole (*Microtus pennsylvanicus*) in the latest Pleistocene deposits, i.e. below approximately 175 cm, indicates the presence of rather extensive areas of grassland in the vicinity of the cave. Bog lemming (*Synaptomys cooperi*) remains indicate permanent standing water or denser growth meadow nearby (Burt and Grossenheider, 1976). Abundant *Eptesicus fuscus* remains may suggest that trees were at least locally present (Barbour and Davis, 1969). *Sorex cinereus, Phrynosoma douglassi* and *Microtus pennsylvanicus* are clear indicators of cooler temperatures, at least in the summer, and also probably of greater effective moisture.

During the Holocene several faunal changes occur which may indicate environmental changes. These events cannot be more precisely placed within the Holocene until more radiocarbon dates become available. The extirpation of both moles (*Scalopus aquaticus*) and short-tailed shrews (*Blarina* sp.) probably resulted from climatic change. The most likely cause seems to be decreasing soil moisture, which could be due to changes in precipitation, temperature, or both.

Semken (1961) suggested that the disappearance of the geomyids from the Edwards Plateau was a result of anthropogenic induced soil stripping caused by over-grazing during the last 300 years. The late disappearance of geomyids at Hall's Cave supports this conclusion. The least shrew (*Cryptotis parva*) may also be a victim of this soil stripping. As analysis of the Hall's Cave sediments continues, reconstruction of the environments of central Texas during the past 13,000 years will improve. As more of the faunal remains are analyzed, more taxa will be identified and the ranges of those that have been identified will become better established. More radiocarbon dates, pollen analyses and mineralogical studies will provide flesh for the now skeletal reconstruction.

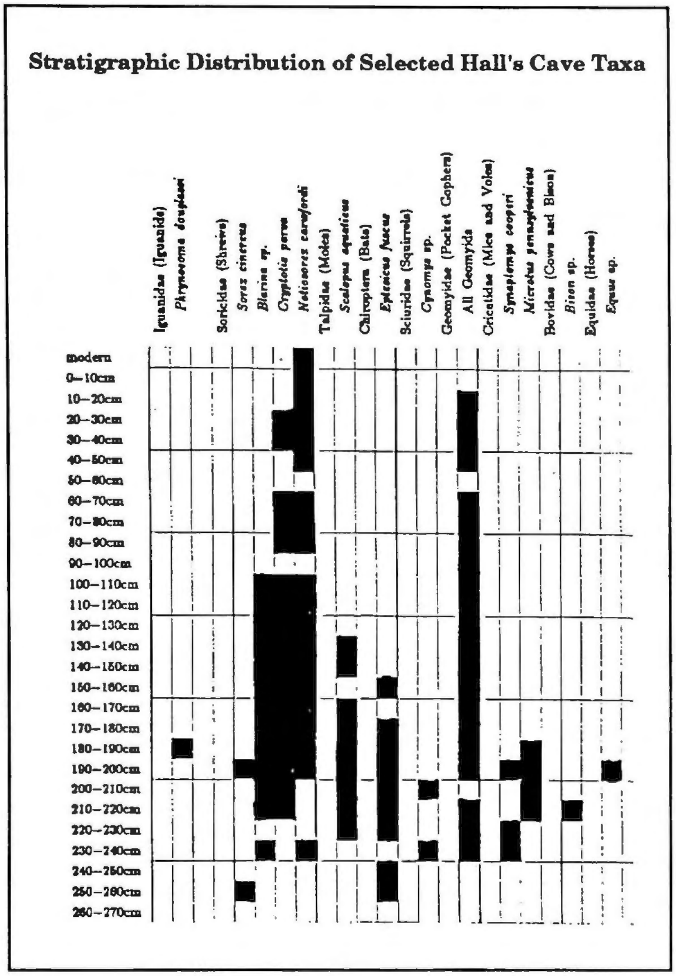

Figure 24: The stratigraphic distribution of selected taxa within the sediments of Composite Pit I of Hall's Cave. The taxa presented here are some of those which provide important stratigraphic and paleoenvironmental information. All taxa except *Notiosorex crawfordi*, *Bison* sp., and *Equus* sp. are extralimital. The data in this figure is accurate as of December 1988.

Acknowledgements

The work at Hall's Cave has been graciously supported by the Cave Research Foundation, The Geology Foundation of the University of Texas at Austin, Geological Society of America, and Sigma Xi. I would also like to thank Dr. Ernest Lundelius, Dr. Steven A. Hall, Donna DeCarlo, and the staff and students of the Vertebrate Paleontology Lab, Texas Memorial Museum for all their help.

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Response of a Model Ground Water Microbial Community to Acute Chemical Stress*

Karl Rusterholtz

Abstract

This study sought to determine if saturated sand occurring in a cave could be used as a model ground water system. The response of the indigenous microbial community to acute chemical stress was also measured. The sample site, established in a remote section of Mammoth Cave National Park, Mammoth Cave, Kentucky, consisted of saturated sand receiving water percolating 70 m down from the surface. Core samples were taken aseptically using modified sterile 60cc syringes. Total cell and total respiring cell densities were determined using an acridine orange/*p*-iodonitrotetrazolium violet (INT) staining procedure. Selected cores were exposed to 5 ug chlordane/g sample for 30 minutes. Cores were subsequently stained with INT in the cave to approximate natural conditions. Total cell counts, 6.2×10^5 - 1.5×10^6 cells per gram, were similar to those found in many shallow aquifers. Over 50% of total cells were found to be actively respiring. This exceeds the proportion of active cells reported for most ground water. The absence of transport and handling difficulties typical of ground water analysis may account for the difference. The microbial community showed a 25.8% reduction in respiration when exposed to chlordane for 30 minutes. Saturated cave sand may be used as a model ground water system. Total microbial community respiration decreases following exposure to 5 ug chlordane/g sample.

* Poster presented at the American Society for Microbiology 1989 Annual Meeting in May in New Orleans, Louisiana.

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Cave Biota Research Reports

Eugene Studier

The following 11 papers represent the efforts of students enrolled in Cave Biota Research, a 1988 Winter terms course taught by Eugene H. Studier and Kathleen H. Lavoie, Biology Department, University of Michigan-Flint, Flint, MI, 48502-2186. Ernest J. Szuch, a lecturer in this department, also participated specifically in one study.

Data for most of the studies were collected on a field trip over spring break from 19-28 February 1988. A hygrothermograph placed on the ground about 15 feet outside the Violet City entrance to Mammoth Cave provided some data on temperature and relative humidity from 1800 hrs on 19 Feb. through 0800 hrs on 28 Feb. 1988. Inadequate standardization caused relative humidity measures to be quite inaccurate; however, it was apparent that relative humidity did reach 100% during every night. Nighttime lows averaged 3.0° C(range -6.7° to 3.3° C) with minimal temperatures occurring the nights of 21, 25, and 26 Feb. and the warmest night being 23 Feb. Daytime highs averaged 13.3° C (range 7.8° - 22.2° C) with peak temperatures on both 22 and 27 Feb. The lowest daytime high temperature was on 24 Feb.

As a space conserving measure, authors have reduced the Materials and Methods sections of their papers to provide minimal information. Details are available from the individual authors. As a second space conserving measure, the Literature Cited sections for all reports are combined and appear at the end of the sequence of papers. Finally, acknowledgments for all papers are included here. All authors worked cooperatively and are mutually acknowledged. In addition to faculty and class students, James Lavoie, Michelle Labbe, Gary Pace, and Connie Downing aided in fieldwork aspects of the studies during the aforementioned trip. Critical comments and suggestions on the manuscripts were helpfully provided by Ernest J. Szuch, Tom Poulson and Dave Griffith. We thank the National Park Service and its personnel for providing access to the caves and the Cave Research Foundation for the use of its facilities in Mammoth Cave National Park.

Egg Laying Rates of the Cave Cricket *Hadenoecus subterraneus*

Michelle Cyr

Studier, *et al.* (1988), in ongoing studies of cave crickets, *Hadenoecus subterraneus*, described characteristics of copulating pairs, and monthly gonadal maturation. Other aspects of reproductive biology were shown to vary with season and location (Hubbell and Norton, 1978). No published studies, however, have dealt with the egg laying rates in this species.

Materials and Methods

Cylindrical cages were constructed. Plastic cage bottoms contained cave substrate and were covered by screen tops. Both types of cages had tops that could be removed and screen cloth placed on the inside wall to allow crickets to roost on the upper surface. Six cages of one type and eight of another were used in the study. Further information on building the cages can be obtained by writing the author. Egg laying substrate, soil obtained from cave floor, was sifted prior to use to eliminate any eggs or debris and was poured into the bottom of the cage to a depth of three centimeters. One (February studies) or two (April studies) adult female crickets (HFL>20 mm) were placed into each cage. At intervals of two days, crickets were removed, ovipositor holes were counted (February studies only) and substrate from each cage was sifted to count eggs. Average number of eggs and holes were determined for each successive two day period.

Results and Discussion

In the February data, the number of eggs laid in the first two days was much greater than in later intervals (Table 4).

Table 4: Ovipositor test holes made and eggs laid per day by caged gravid females, *Hadenoecus subterraneus*. Upper data are from 25-29 April 1987 (n=12) and lower data are from 19-27 February 1988 (n=14). See Figure 1 for further information.

DATE	DAY 0-2	DAY 2-4	DAY 4-6	DAY 6-8
Eggs Laid/Day	.38	.12		
Eggs Laid/Day	5.93	.22	.25	.25
Holes Made/Day	18.43	5.88	6.18	4.50
Holes/Eggs	3.12/1	26.7/1	24.7/1	18.0/1

The large number of eggs laid in the first interval may be normal or due to stress placed on the females. Caging may have induced the crickets to lay many of their available eggs. Some females, however, only laid a few eggs from the first interval to the last. These females may have already laid a large batch of eggs before being placed in the cages. Studier and Lavoie found (personal communication) that female crickets in January laid a few eggs against the glass of empty jars in which they were held for weight loss studies. This suggests that females reach a point where they cannot refrain from laying eggs even in the absence of suitable substrate. The distribution (Figure 25) of hole making over time in February parallels that of egg laying. There are always more holes than eggs; therefore, there are always "dummy" holes made.

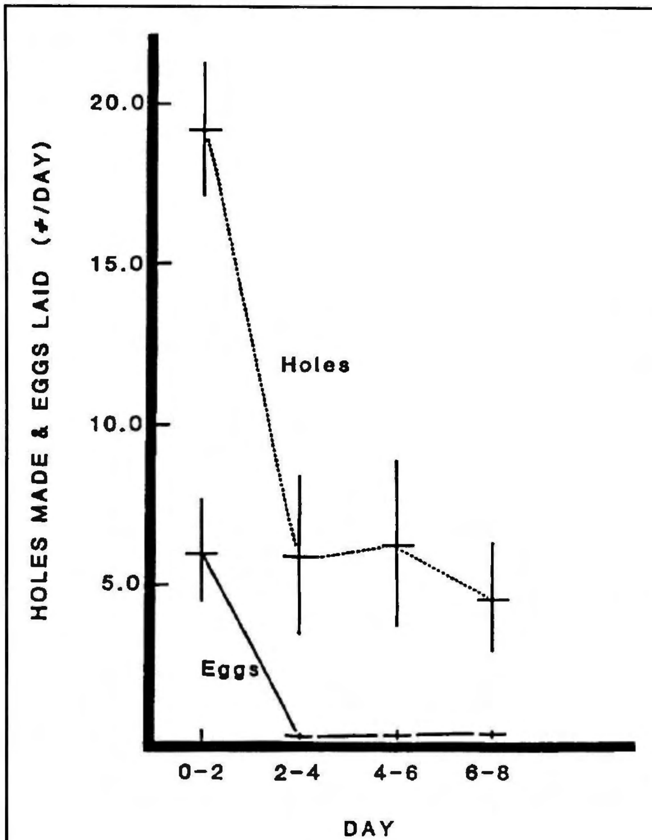

Figure 25: Holes made and eggs laid by caged gravid females *Hadenoecus subterraneus* from 19-27 February 1988 in Sophy's Avenue of Mammoth Cave in MCNP (n=14). Symbols are mean (horizontal line) and +/- one standard error of the mean (vertical line).

Holes observed in Sophy's Avenue in natural and caged conditions never indicated mounds around ovipositor holes and rarely scratch marks. Poulson observed (personal communication) in a natural cave environment (Great Onyx Cave) that the cricket almost always made mounds unless constrained by edges of rock. Table 4 shows the high ratio of holes made to eggs laid. The ratio is low in the first interval compared to the remaining intervals. Laying large numbers of eggs during a short period of time is a reasonable strategy biologically with regard to the egg predator *Neaphaenops telkampfii*. One egg completely fills a *Neaphaenops* for approximately a week or longer (Norton, Kane, and Poulson, 1975) and at least some eggs escape predation at times of year when there are high egg densities (Kane and Poulson, 1976).

Female crickets may exhibit two types of strategies to avoid predation on the eggs. One type of strategy is referred to as predator satiation. This strategy is a defense where reproduction is timed so that the prey (in this case, eggs) are so abundant in one short period of time that predators become satiated, and surviving young quickly grow beyond a size easily handled by the predator (Smith, 1986). In the case of crickets, eggs not eaten hatch and nymphs are not vulnerable to predators (Norton, Kane, and Poulson, 1975). In February, female crickets laid large numbers of eggs in a short period of time. The second suggested strategy is to make large numbers of ovipositor holes to make finding an egg more difficult for predators. Both of these strategies may increase egg survival rate. False holes may represent test probes to find appropriate egg laying substrates (Poulson, personal communication). This possibility seems unlikely in this study since the substrate was uniform and constant for the duration of the study. In this case, the numbers of holes made would be expected to decrease with time if such holes represent substrate test probes. Crickets appear to exhibit a stereotypic behavior in making holes that improves the probability of egg survival by using strategies to avoid egg predation. Table 4 compares data collected in April 1987 and February 1988. More eggs were laid in February than in April. Rates of egg laying correspond to the number of eggs found in gravid females in those time spans (Studier, *et al.*, 1988) and corresponds to the frequency of copulating pairs and appearance of newly hatched eggs in that cave (Hubbell and Norton, 1978).

These data support a seasonal peak in reproductive effort in January and February. In a very rough estimate of annual egg production, it is assumed that during February, 20-30 eggs were laid in a 2-3 day period of rapid egg laying. In April, the slowest rate was one egg laid every eight days and the fastest rate was approximately three eggs laid every eight days, leaving 45 - 136 eggs laid during the remainder of the year. This information gives an approximation of 65-166 eggs laid per year by the cave cricket. In comparison with other Orthopterans, this number is low. *Acheta domesticus* lays 728 eggs in approximately a year, *Blattella germanica* 218-267 eggs, *Melanoplus sanguinipes* 300-400, and *Periplaneta americana* 200-1000 eggs (Altman and Dittmer, 1972). Observations are as expected when comparing cavernicolous animals with surface forms.

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Caloric Density Preference of Cave Crickets, *Hadenoecus subterraneus*

Michael J. DeLong

As with all feeding habit studies concerning insects, it is essential to understand the efficiency of food utilization. Woodring, *et al.* (1979) reported that efficiency of food utilization for adult house crickets increased with increased quality of food, and that efficiency parameters would vary in some species with specific events in the life cycle. Levy (1976), attempted to demonstrate a relationship between food odor and the cave crickets' ability to differentiate among food sources. Levy suggested that small crickets were less selective when foraging than medium or large crickets and that small crickets stopped and ate at the first available food source, whereas larger crickets were attracted to foodstuffs with the strongest odor. Odor seemed to be correlated with caloric density in Levy's studies so she could not assess whether crickets had a preference for caloric density per se.

Materials and Methods

Caloric density preference studies for cave crickets were conducted during the final week of February, 1988, in Marion Avenue, Sophy's Avenue, Frozen Niagara, and White Cave in Mammoth Cave National Park (MCNP), Kentucky. Studies were also performed in Walnut Hill Cave outside MCNP. Initial studies used mixtures of peanut oil: cornstarch and lard:cornstarch, in 10:90, 50:50, and 90:10 (w/w) ratios. In further studies, three mixtures of smooth peanut butter and cornstarch, at 100:0, 50:50, and 0:100 (w/w) were used. These latter mixtures have known caloric densities (5.9, 5.0, and 4.1 Kcal/gm, respectively; Watt and Merrill, 1963). Each mixture was placed in a covered 100 x 15 mm plastic Petri dish under a separate live trap on the cave floor. The three traps with three different mixtures were aligned at intervals of about one meter with the order assigned randomly. Resident roosting crickets had equal access to each mixture and could opt between lower or higher caloric density foodstuffs.

Live traps were constructed of wooden embroidery hoops having diameters of 31 cm and widths 1.3 cm. Upper hoops consisted of an inner and an outer ring that jointly serve to bind a piece of plastic screen cloth in place as the top enclosing surface of the trap. Each double upper hoop was then placed directly above a single lower hoop. Upper and lower hoops were spaced 1 cm apart at four equal intervals around the diameter of the hoops using plastic squares measuring 1 cm per side. Hoops were connected using a continuous strip of duct tape spanning both inner surfaces. Each hoop was propped up by a single rectangle, 3 x 1.2 x 17.5 cm, cut out of plywood. Each rectangle had a 1.5 x 0.6 cm notch cut in its top end. The edge of the hoop sits in the notch. Props served as triggering supports for the hoop traps, and each prop was connected to 15.25 m of heavy gauge string through a 0.4 cm diameter hole drilled near the bottom end.

Individual traps were propped over each food mixture, Petri dishes were uncovered, and traps were allowed to stand undisturbed for approximately one hour. All traps were then activated simultaneously by pulling the taut threads attached to the support props.

The number of male and female crickets captured by each trap was recorded, and hind femur length (HFL) of each cricket was measured to the nearest 0.1 cm using dividers and recorded. Crickets were released at their capture sites after measurements were taken. Data collected were statistically analyzed using the X (chi-square) test of independence to determine if there was selection for food related to caloric density, and if it related to gender and/or size (i.e., age).

Results

The chi-square test of independence was applied to the total number of crickets that were attracted to each foodstuff in all caves. These results pertain to peanut butter:cornstarch mixtures whereas the peanut oil:cornstarch and lard:cornstarch mixtures yielded insignificant data. Table 5 represents experimental data for all crickets captured (separated by size) in all caves. Crickets were not evenly distributed among the foodstuffs (X =15.1, df=2, p<0.001). Sexable, large crickets (HFL>10 mm) were not evenly distributed among the three food sources (X =29.54286, df=5, p<0.001), but non-sexable, small crickets (HFL<10 mm) were. Total crickets for all caves were categorized further into three size groupings; large (HFL>20 mm), medium (HFL 10-19 mm), and small (HFL<10 mm), also shown in Table 5. Large and medium crickets were not evenly distributed among the foodstuffs but small crickets were (X =37.94286, df=8, p<0.001).

Table 5: Total number of crickets captured in all caves. L=large crickets (HFL>20 mm) M=medium crickets (HFL 10-19 mm) S=small crickets (HFL<10 mm). Baits used were combinations of peanut butter (PB) and corn starch. Data were collected from 23-27 February 1988.

	100% PB			50%PB			0%PB		
Location.Date.Run	**L**	**M**	**S**	**L**	**M**	**S**	**L**	**M**	**S**
Marion Ave 23.1	2	0	2	3	1	0	0	0	3
Marion Ave 23.2	0	2	6	4	1	1	0	0	2
Marion Ave 23.3	2	0	0	3	2	3	1	1	2
Sophy's Ave 23.1	1	1	2	1	4	2	1	0	3
Forzen Niagara 23.1	0	1	0	0	2	2	0	0	3
Walnut Hill 24.1	4	7	2	1	6	8	0	0	2
Marion Ave 24.4	4	0	4	0	2	2	0	0	2
Sophy's Ave 24.2	2	3	2	0	2	3	0	0	5
Marion Ave 26.5	3	1	3	1	1	1	0	0	0
White Cave 27.1	0	2	1	0	1	1	0	0	0
Subtotal	**18**	**17**	**22**	**13**	**22**	**23**	**2**	**1**	**22**
Total		**57**			**58**			**25**	

Table 6 shows all crickets captured in all caves separated by sex. Neither male nor female crickets were evenly distributed among the food sources, (X =38.36986, df=5, p<0.001). Both male and female crickets tended to be attracted to foodstuffs containing peanut butter.

Table 6. Number of crickets with HFL>10 mm by sex attracted to each bait for all caves. M=male, F=female. Baits used were combinations of peanut butter (PB) and cornstarch. Data were collected from 23-27 February 1988.

	100% PB		50%PB		0%PB	
Location.Date.Run	**M**	**F**	**M**	**F**	**M**	**F**
Marion Ave 23.1	1	1	3	1	0	0
Marion Ave 23.2	2	0	4	1	0	0
Marion Ave 23.3	1	1	3	2	1	1
Sophy's Ave 23.1	1	1	3	2	0	1
Frozen Niagara 23.1	1	0	1	1	0	0
Walnut Hill 24.1	7	4	6	1	0	0
Marion Ave 24.4	3	1	1	1	0	0
Sophy's Ave 24.2	4	1	0	2	0	0
Marion Ave 26.5	2	2	1	1	0	0
White Cave 27.1	2	0	0	1	0	0
Subtotal	**24**	**11**	**22**	**13**	**1**	**2**
Total	**35**		**35**		**3**	

Discussion

Table 5 shows that total crickets captured in all caves were not evenly distributed among the food sources (peanut butter:cornstarch mixtures), suggesting that crickets have the ability to differentiate among foods of different caloric density. However, crickets were not attracted to peanut oil:cornstarch mixtures, which proposes that something other than the volatile fats of the peanut butter attracted the crickets, therefore, peanut butter's odor is caused by a different compound. Table 5 also shows medium and large crickets were not distributed evenly among all foodstuffs (p<0.001) but were distributed nearly equally between the two highest caloric density foodstuffs. Small crickets were evenly dispersed among total food types. This size-related distribution suggests that small crickets do not optimally forage, i.e., they stop and feed at the first possible energy source no matter what its energy value. These results also suggest that large crickets forage for higher caloric density foodstuffs but only do so by odor, since odor is generally correlated with caloric density (Levy, 1976), and cannot differentiate between foods of different but high caloric content. Table 6 shows that sexable crickets (HFL>10 mm) were not equally distributed among the foodstuffs. The majority of sexable crickets were attracted to food sources containing peanut butter while very few were attracted to pure cornstarch. However, equal numbers of sexable crickets were attracted to 100 percent PB and to 50 percent PB, and the number of males and females were attracted to those two food sources. This suggests that sexable crickets, i.e., adults and sub-adults, differentiate between food sources of differing caloric densities but only by odor. This also suggests that neither males nor females have different abilities in locating and differentiating among high caloric density foodstuffs.

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Cave Entry and Exit Patterns of the Cave Cricket, *Hadenoecus subterraneus*

Robert D. Downing

Animals that go in and out of caves face much more variable climates than species that are permanent cave dwellers. Most cave ecosystems have a much less variable climate than do surface ecosystems and so troglobites (organisms that spend their whole life cycle within the cave) are subject to very small fluctuations in temperature, relative humidity, and light. However the trogloxenes, which leave the cave to feed and/or reproduce, are subject to two very different environments. They must face both the relatively constant hypogean climate and the more highly variable epigean climate.

Trogloxenic cave crickets (*Hadenoecus subterraneus*) tolerate a narrow range of relative humidity because they are unable to maintain water balance in relatively dry air (Studier, *et al.*, 1987). Thus their cave exit patterns might be expected to be correlated with non-stress conditions. The emergence of *H. subterraneus* at Great Onyx Cave, KY in July was well after sunset and seemed to coincide with a relative humidity range of 97 - 99% at temperatures of 19 - 21 C (Leja and Poulson, 1984). The emergence of another trogloxenic cave cricket, *Ceuthophilus conicaudus*, from Spider Cave, NM, occurred close to sunset and peak activity corresponded to nights with greatest relative humidity and greatest cloud cover (Campbell, 1976).

Materials and Methods

This study took place (from 19 - 28 February 1988 and 17 - 20 October 1987) at the Violet City entrance of Mammoth Cave, Mammoth Cave National Park, Kentucky. Data were obtained on epigean temperature, cloud cover, and cricket movement. Equipment and descriptions were omitted due to space availability, but are available on request thru the author.

Results and Discussion

Peak emergence of *H. subterraneus* corresponded to those nights having greatest cloud cover and epigean temperatures closest to that of the constant cave temperature. This is shown by Figure 26 in which 19 - 20 October, 1987 was the only warm cloudy night during these three days. During this time the total number of crickets counted (n=246) was 164% and 180% (respectively) of the total number of crickets counted during the two preceding nights. Although 22 - 23 February 1988 is only a partial nights data, the epigean temperature was 57° F at 11:00 p.m. and 44° F at 4:00 a.m. and a light rain occurred from 11:00 p.m. through 8:00 a.m. On the previous two cold and clear nights (Figure 27), crickets left in much smaller total numbers but in quick succession possibly attempting to leave, feed, and return in a shorter time span thus reducing the chance of desiccation and/or freezing.

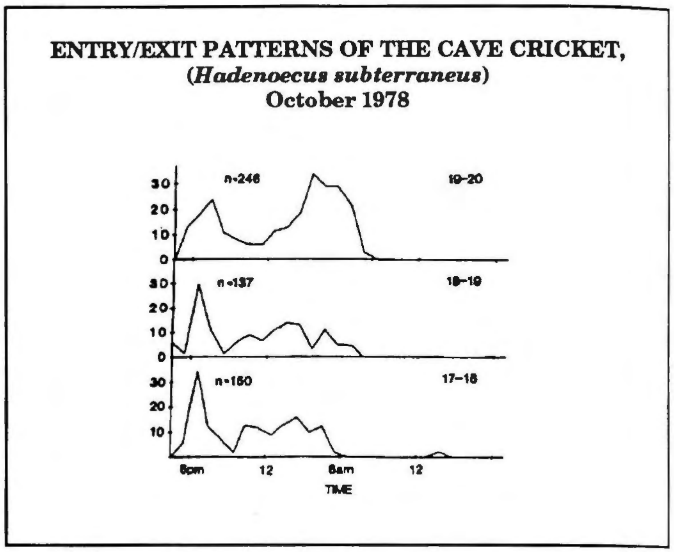

Fig. 26: Number of crickets/hour recorded leaving or entering the Violet City or Mammoth Cave during October in relation to the time of day.

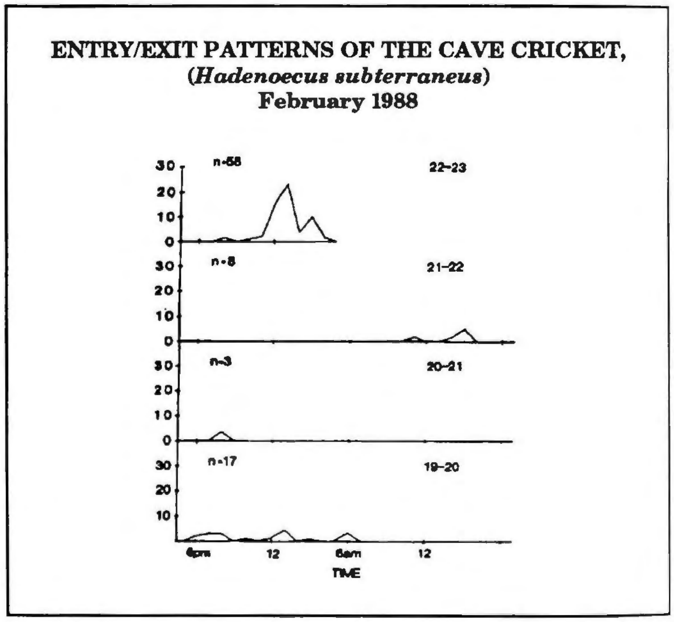

Fig. 27: Number of crickets/hour recorded leaving or entering the Violet City entrance of Mammoth Cave during February in relation to the time of day.

The October pattern suggests that most crickets left soon after dusk but returned slowly. This pattern could be explained if crickets which have difficulty finding food close to the cave entrance are forced to take the greater risk of predation and desiccation and so stay out longer.

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Long Term Intracave Movements of the Cave Cricket, *Hadenoecus subterraneus*

Robert D. Downing and Kurt Hellman

Detrital food chain ecosystems (specifically cave ecosystems) differ from typical food chains in that the major pathway of energy flow is indirectly from photosynthetic sources. Fixed carbon input is mostly dependent on food brought into or wastes deposited in caves by trogloxenes. Cave cricket guano is a major source of energy into the cave utilized in this study.

Studies of long term movement patterns of cave crickets could help describe whether crickets move randomly or in a particular pattern, individually or in a group, or whether there's a difference in movement patterns according to sex. Females tend to bring more fixed energy into the cave per foraging period than do males (Studier, *et al.*, 1986) indicating males may move out to feed more frequently. Where crickets spend most of their time dictates where defecation occurs most frequently, leaving the bulk of the organic matter on which the troglobites will feed. Ultimately, we wish to show how the long term movement patterns of the crickets (therefore, distribution of guano) affect the distribution of troglobites (i.e. cave millipedes, *Scotenpes* and *Antriadesmis*) which are specialized on cricket guano.

Materials and Methods

This study took place from 20-27, February, 1988 in White Cave, Mammoth Cave National Park, Kentucky. Initially, a transect was established as the greatest linear depth into the cave from which the entrance could still be seen, specifically in the first 50 meters of the cave. The cave was divided into successive 5 meter intervals along the transect. Extensive formations in White Cave form a curtain nearly dividing the cave lengthwise into two separate areas. Only the side containing the entrance was studied.

All adult *H. subterraneus* in the third interval, 10-15 m from the entrance, were marked with white liquid paper correction fluid. Marking was accomplished by placing a small amount of liquid paper on the end of an applicator stick and touching it to the dorsal abdomen of a cricket. This same technique was used to mark crickets in the eight interval, 35-40 m from the entrance, with goldenrod liquid paper. Numbers of males and females marked (in both intervals), were recorded separately.

Numbers of male and female crickets with white or goldenrod marks were counted each day (morning) for the next seven days. Data for each day were graphed according to the percent of total white- and goldenrod-marked crickets observed in each interval. Epigean temperature was recorded on a Bendix Corporation, Hygro-thermograph (calibrated to within 2° F). Additional data were collected on cloud cover.

Results and Discussion

Long term intracave movement of crickets is evident within White Cave (Figure 28). As seen in February 21, there was a general dispersal toward the rear of the cave and a single white-marked cricket travelled 25 m within a 24 hour period. This dispersal could have been caused by many factors including; return from feeding, cold epigean temperatures, or effect of disturbance. Distances travelled by groups however, was not substantial, nor patterned.

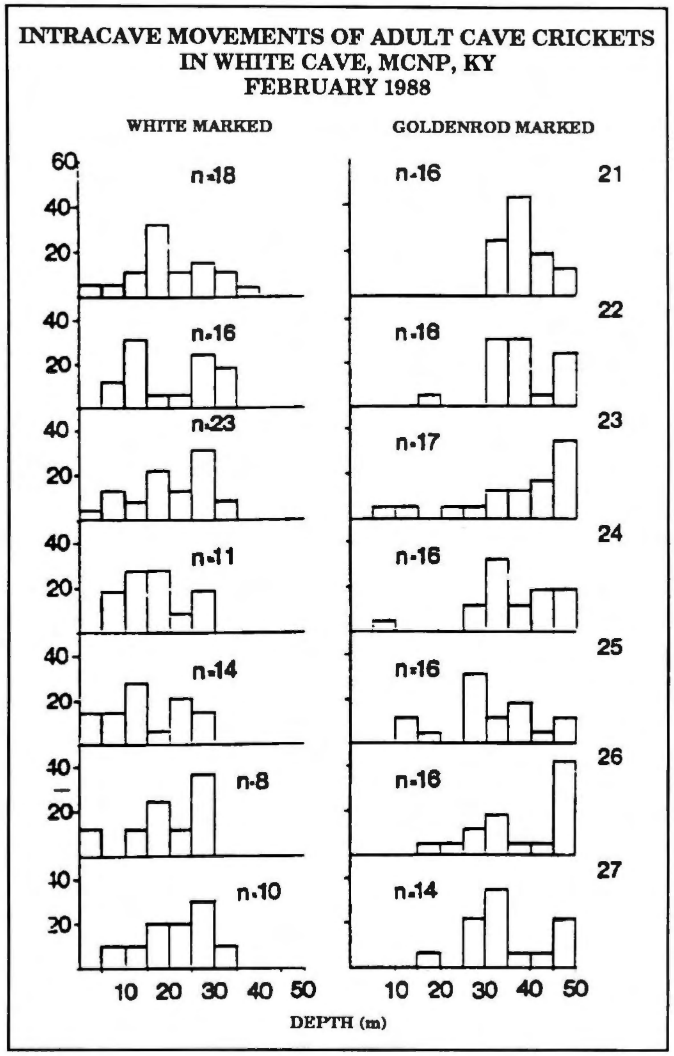

Fig. 28. Percent of white and goldenrod marked *H. subterraneus* recapturable in White Cave, MCNP, KY and the distance into the cave at which they were found.

After the single warm day during the period of observation (72° F) on February 22, there was a recognizable movement from the back of the cave toward the front by the goldenrod-marked crickets. Crickets retreated back to the more stable environment of the deeper cave however after the next, typically cold, day.

Even though there was movement in the cave, there was little, if any, movement outside the cave (possibly due to the cold clear nights preventing feeding). Previous studies suggest that *H. subterraneus* feed every three days (Nicholas, 1962); however, a more recent study suggests optimal feeding intervals of 11.5 days for females and 9.9 days for males(Studier, *et al.*, 1986). Our study (Figure 28) indicates that the more recent study underestimates feeding intervals at least in winter. Further studies will be done to get a more accurate account of possible seasonal variations of intracave movement of *Hadenoecus subterraneus*. In these further studies, crickets on both sides of the curtain formation will be recorded due to the observation of marked crickets and extensive guano slopes behind the protected curtain.

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A Preliminary Study of Apparent Changes in the Population Density of the Cave Cricket (*Hadenoecus subterraneus*) at Frozen Niagara Entrance, Mammoth Cave National Park, Kentucky

Kurt Hellman

Detrital food chains, like those of cave ecosystems, differ from typical food chains in that the primary energy source is non-photosynthetic. Fixed carbon input is mostly in the form of organic matter brought into, or wastes deposited in caves by trogloxenes such as crickets, bats and pack rats. In some caves (e.g. those in central Kentucky), guano produced by cave crickets is the main source of detrital material. The total amount of energy available will influence species diversity and species interactions as well as the biomass of organisms capable of being sustained. Therefore, an accurate estimate of the total number of crickets will give an estimate of the amount of organic material available.

Many modifications of the Lincoln-Peterson index have arisen in order to improve the accuracy of population estimates. Bailey's Triple Catch method (Begon, 1979) was used in this study because it generates only one estimate of population size, determines (indirectly) survival rate, and takes only three days to complete. By completing the experiment in such a short time span the effects of immigration, emigration and mortality in the cricket population are potentially minimized.

As with most mark-recapture methods the boundaries of the study area are not well defined. Boundaries are set by human limitations and are certainly not appropriate for crickets. As such, the segment of the population being studied is that in the vicinity of the cave entrance.

Materials and Methods

This study occurred at the Frozen Niagara entrance, Mammoth Cave National Park, Kentucky. The segment of the cricket population studied consisted of only adult size males and females, as determined by a hind femur length =>20 mm (Studier *et al.*, 1986). Marking was accomplished using small dowel-like applicator sticks (length=14.5 cm; diameter=2 mm) and two colors of liquid paper correction fluid. Crickets were marked on consecutive nights between 17:00 - 18:30 hours (Central Daylight Savings Time). This time period was chosen to avoid public tours but to be before crickets exited the cave to feed.

In this study the crickets were not actually captured; rather, we assumed they could have been captured if a cricket was within arms reach. A single dot of liquid paper was placed on the dorsal abdomen. Crickets that were out of reach (e.g., too high on the ceiling, too deep in a crack, too far under a shelf, etc.) were ignored. This marking procedure was quite easily performed as the crickets are rather sedentary, allowing us to approach them and lightly mark their dorsal abdomen. Furthermore, by not actually capturing animals, the possibility of disrupting the population or physically damaging crickets was greatly reduced.

Markings were date-specific, achieved by the two colors of liquid paper. Two different periods of mark-recapture (17-19 October 1987 and 20-22 February 1988) were performed. Different colors of liquid paper were chosen for each period to decrease the chance of counting crickets marked during the previous study period.

On the first night all adult crickets (within arms reach) were marked and the total number of marked animals recorded. On the second night again all crickets (within arms reach) were marked with a different color and the total number recorded. Those with first day marks were marked in such a way as to distinguish between the two marks. Additional data collected were those animals with marks and those without marks. No marking was done on the third night but data collected consisted of those animals with first day marks ONLY, those animals with second day marks (regardless of any first day marks) and those animals without marks.

Data collected from both study periods were analyzed using the formulas of Bailey's Triple Catch to determine separate estimates of population density, standard errors of the estimates, and survival rates of the populations.

Results and Discussion

Data collected for October 1987 and February 1988 are shown in Table 7. Calculations of population size (N2), survival rates (phi1), birth rates (b2) and standard errors of these estimates are found in Table 8.

Estimates of the population size of crickets for the two study periods are different. There appears to be an approximate fourteen fold decrease in density between October (976.8) and February (70.6). Although no actual estimates of population size were determined, Studier *et al* (1987) indi-

Table 7: Number of crickets captured(n), released(r) and with day-specific marks(m) for the two study periods.

October 1987 - Total Crickets

day:	**1**	**2**	**3**
capture:		33 (n_2)	280 (n_3)
day 1-marked:		59 (m_{21})	22 (m_{31})
day 2-marked:			64 (m_{32})
released:	407 (r_1)	337 (r_2)	

February 1988 - Total Crickets

day:	**1**	**2**	**3**
capture:		25 (n_2)	28 (n_3)
day 1-marked:		6 (m_{21})	5 (m_{31})
day 2-marked:			9 (m_{32})
released:	52 (r_1)	25 (r_2)	

Bailey's Formulas:

$$M_{21} = \frac{m_{31}(r_2 + 1)}{(m_{21} + 1)} + m_{21} \qquad N_2 = \frac{(n_2 + 1)\, M_{21}}{(m_{21} + 1)}$$

$$Phi_1 = \frac{M_{21}}{r_1} \qquad b_2 = 1 - \frac{(m_{31} + 1)\, n_2}{(n_3 + 1)\, m_{21}}$$

cated populations to be largest in winter and smallest in summer. The data are not consistent with those general impressions.

The estimate of survival, phi, is the proportion of the population sampled that survives from one marking day to the next. One minus phi then is the estimate of loss from the population or the proportion of the marked population that is lost from one marking day to the next. The value b is the estimate of gain or the proportion of the population sampled that entered the study area from one marking day to the next (see tables for formulas).

Estimates of loss from the population are the same for October (0.57) and February (0.63), (i.e., the fraction of the marked population that dies or migrates from the study area remained constant). Since we know adult *H. subterraneus* to possess a relatively long life span (8-17 mos.) (Studier *et al.*, 1987), it does not seem reasonable to conclude that approximately 60% of the crickets at the entrance die from one marking period to the next (24 hours). Migration to presumably inaccessible or non-sampled areas of the cave must then be the major factor contributing to the loss of individuals from the entrance population. Crickets probably only go to the entrance in order to feed (Hubbell and Norton, 1978). Perhaps they remain in the safety of the deep cave until a "need" to feed (maybe affected by season), then move to the entrance, or as close to the entrance as possible depending on the physical conditions (humidity, temperature, etc.), and wait for a chance (favorable conditions) to feed. After feeding they return to the cave entrance and migrate back to the smaller and/or deeper recesses of the cave. This they appear do to the same extent regardless of the number of crickets at the entrance or time of year. Therefore, the proportion of crickets lost from the entrance population to inaccessible or unsampled areas is the same in each study period. Since the crickets are feeding outside the cave predation may occur; however, this is assumed equal in both study periods.

Estimates of gain (b) for the two study periods are different. In October, 53% of the population observed on day 2 of the study period were not present on day 1. In February, only 14% of the population observed on day 2 were not present on day 1. Since the study deals only with adult size crickets, gain is accomplished only by migration of animals from inaccessible or unsampled areas. Although sub-adults molting to adults during the study period could increase the number of unmarked crickets, this contribution is minimal since there is not a large pool of sub-adults (Lavoie and Studier, unpublished data). Therefore, the proportion of the population at the entrance that migrate there between sampling times is about four times lower in February compared to October.

Table 8: Estimates of density, survival, loss and gains for the two study periods.

Population characteristic	October 1987	February 1988
N2 (density)	976.8 (±209.4)	70.6 (±35.9)
Phil(survival)	0.43 (±0.07)	0.37 (±0.14)
1-phil(loss)	0.57	0.63
b2 (gains)	0.53	0.14

This indicates that the crickets are moving less in February, perhaps due to the fact the crickets are feeding less in the winter (Studier, personal communication), or moving to deeper, sandy areas of the cave for egg laying (Hubbell and Norton, 1978).

The fact that the crickets appear to be moving less frequently in February will result in a much lower estimate of population size. In other words, because the crickets are relatively inactive in February a much larger proportion of the marked crickets will be recaptured resulting in a small estimate of density (70.6).

In conclusion, is this drastic drop in estimates a real change, indicating a crash in the population size, or simply an apparent change due to the inactivity of the animals? It is my feeling that the population is quite stable and the densities do not fluctuate greatly from season to season, rather the crickets are simply behaving differently—they are not moving as often in Winter. These preliminary studies will be continued at Frozen Niagara. Similar studies should also be conducted at different cave entrances and in a deep-cave situation, perhaps bubbly pit in Great Onyx Cave or Sophy's Avenue.

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Preliminary Quantification of Several Parameters of Evasive Behavior in the Cave Cricket, *Hadenoecus subterraneus*

Elizabeth J. Mason

Cave crickets (*Hadenoecus subterraneus*) typically move from place to place by walking. Long and/or repeated hops generally seem to be utilized as an escape mechanism. That these crickets hop to escape is general knowledge to anyone who has attempted to catch one. Kastberger's studies (1982, 1984) concerning the effects of ground inclination on the evasive behavior of *Troglophilus cavicola*, a cave cricket occurring in the Alps and Dinarides in winter, appear to be the only previous investigations of jumping parameters in cave crickets. His work does not apply to my study, however.

This study is an attempt to quantify several parameters. I recorded primary compass direction taken, number of hops, individual hop length, total hop length (THL), mean free path (MFP), and time to exhaustion. I also investigated how these parameters related to sex, hind femur length (HFL), and crop fullness in cave crickets forced to jump to exhaustion. Exhaustion is defined in this study as the point at which crickets refused to or were physically unable to jump further.

Materials and Methods

Studies were conducted during daylight hours on 1 May and 10 July, 1987 and during the week of 21-28 February, 1988 in Marion or Sophy's Avenue of Mammoth Cave in Mammoth Cave National Park, Kentucky. Most male and female crickets were collected by hand from cave walls. Very small crickets (HFL<8 mm) were collected by brushing them gently from the wall into a plastic vial. Crickets were taken immediately to a wide, smooth area of cave floor, which served as the jumping arena, and covered by a hand. Approximately 7 people stood in a circle around the cricket and pursued it upon release. Crickets were forced to jump to exhaustion, which often required variable amounts of prodding. Locations of each landing/take-off spot were marked with a white plastic ring (cut from plastic pipe).

When crickets were exhausted, HFL was measured with dividers, to the nearest 0.1 mm and crickets were weighed to 0.1 mg. Crop fullness was determined by difference, using whole live weight and calculated crop-empty live weight (Studier, *et al.*, 1986). Sex of the cricket was recorded. Primary compass direction taken by the cricket was recorded, as was time (seconds) from release to exhaustion. Rings were counted to determine total number of hops. Individual hop lengths were measured to the nearest half centimeter and total distance hopped was determined from these values. Mean free path was determined by measuring the shortest distance between the starting point and the final hop.

Primary compass direction data were analyzed with Chi square. All other data were analyzed using linear regression and/or multiple regression (where HFL and crop fullness served as independent variables).

Results and Discussion

Multiple ANOVA and regression analysis for February data have shown four significant relationships to exist among the aforementioned variables. These data are presented and discussed below.

Number of hops is related to HFL2, HFL, and crop weight (CWT) where $p < 0.0002$ (F=7.478; DF=3 and 60; R-sqr=0.272), and is represented by the equation (numbers in parentheses are standard errors of the means):

$$\text{No. Hops} = \underset{(\pm 0.018)}{-0.068\ \text{HFL2}} + \underset{(\pm 0.5)}{1.8\ \text{HFL}} + \underset{(\pm 4.1)}{8.0\ \text{CWT}} + \underset{(\pm 3.6)}{5.9}$$

The number of hops taken by a cricket varies directly with HFL and CWT. Crickets with longer hind femurs and heavier crops jump more times than crickets with shorter legs.

Mean hop length (MHL) is related to HFL and CWT where $p < 0.0001$ ($F=69.10$; $DF=2$ and 61; R-sqr=0.694). 0.694 is the best R-sqr value that we found, indicating that this is the strongest relationship of those investigated.

$$MHL\ (cm) = \underset{(\pm 0.12)}{1.46\ HFL} - \underset{(\pm 5.7)}{26.2\ CWT} + \underset{(\pm 2.25)}{4.25}$$

This equation states that MHL varies directly with HFL and inversely with CWT. Crickets with longer hind femurs can jump further than crickets with shorter hind femur lengths. Average hop length varies inversely with CWT; therefore, crickets with emptier crops are able to jump further than full crickets of the same HFL. This seems logical since a fuller crop hinders the cricket by adding more mass to be moved with each hop.

Total distance hopped is related to HFL2 and HFL where $p < 0.0014$ ($F=7.31$; $DF=2$ and 61; R-sqr=0.193) and is represented by the equation:

$$\text{Total distance (cm)} = \underset{(+0.64)}{-1.31\ HFL2} + \underset{(+19.7)}{49.1\ HFL} \underset{(+126.5)}{-36.44}$$

Again, we see that HFL is directly related to distance hopped and it follows that if crickets with longer hind femurs can jump further with each individual hop, then the total distance hopped will be greater.

Table 9 shows a synopsis of data collected during the three study periods.

Table 9: Hopping Variables in Adult *Hadenoecus subterraneus* of both Sexes in Winter (n=32), Spring (n=26) and Summer (n=18, *n=20). Range in parentheses.

	19 Feb. '88 (Winter)	**1 May '87 (Spring)**	**10 July '87 (Summer)**
Number of Hops	11.5 ± 0.6 (7-20)	8.0 ± 0.6 (3-15)	13.4 ± 0.7 (9-19)
Time to "Exhaustion" (sec)	15.3 ± 0.2 (8-24)	11.2 ± 0.7 (7-18)	23.3 ± 2.0 (14-50)
Total Distance Hopped (cm)	419 ± 24 (212-898)	334 ± 26 156-688)	484 ± 33* (274-927)
Average Hop Length (cm)	36.7 ± 1.2 (23.8-46.9)	43.0 ± 2.1 (22.3-71.7)	36.8 ± 1.5 (22.8-48.8)

Preliminary analysis of the data suggests an annual cycling of jumping ability. In May, crickets can jump fewer times, for a shorter period of time, and for a shorter total distance before reaching exhaustion. Individual hop length is greater, but because they jump for a shorter time and fewer hops, total distance is shorter. These data imply that crickets are physiologically at their weakest point of the year in May after a winter with very little food and high reproductive output (Studier and Lavoie, personal communication and Cyr, this issue). As the weather becomes more conducive to frequent feeding, crickets get progressively stronger. This would explain the increased number of hops, increased time to exhaustion, and increased total hop distance in July. I predict that autumn data would either show a slight increase in these parameters from summer (before falling off again in winter) or be intermediate to the summer and winter data.

An alternate hypothesis is that crickets have different ratios of hypertrophied and atrophied red and white muscle in different seasons. Over winter, red muscle may atrophy faster than white muscle, therefore in spring the crickets would be using predominantly white muscle in jumping. Fast twitch (white) muscle is used for quick bursts of strength, and tires quickly. In other seasons however, crickets seem to be using more red muscle fiber than white muscle. Red muscle (slow twitch) is the type used in endurance activities and takes longer to exhaust than white muscle.

Compass direction taken by crickets shows no significant pattern. Only data from the February test period were analyzed and Chi Square analysis of these data shows the direction taken to be random ($p > 0.5$).

Finally, it should be noted that some crickets went into "contracture" upon reaching exhaustion. This phenomenon is characterized by an inability to flex one (incomplete) or both (complete) hind legs at the knee. When in contracture the hind legs are useless in locomotion, and bang on the ground if the cricket attempts to walk. Duration and occurrence of contracture varied widely. In spring, an unrecorded number of individuals exhibited this phenomenon. For one spring tested male, 7 minutes, 17 seconds were required for contracture to run its course. For one spring tested female, time required was something greater than 37 minutes. Of 22 summer tested cave crickets (11 of each sex), 5 males and 2 females exhibited partial or complete contracture. In these instances, contracture duration lasted less than 2 minutes. Of 66 winter tested cave crickets, we observed 29 that went into contracture for an unrecorded amount of time.

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Short-Term Intracave Distributional Patterns for a Cave Cricket (*Hadenoecus subterraneus*) Population

Steven J. Neilson

Casual observations of cave cricket (*Hadenoecus subterraneus*) populations indicate uneven distribution of individuals throughout available roost sites. This study represents a first attempt to quantify the intracave distribution of these crickets using established measures of randomness and dispersion.

Materials and Methods

Research was conducted during the last week of February 1988 in Floyd Collins Crystal Cave, MCNP, Kentucky. This cave was chosen due to the very flat ceiling in the cave entrance area. Determination of cricket distribution was achieved by laying out a light projected quadrant system on the ceiling through the first 28 meters of the cave. Within each 1 square meter quadrant, visual inspection was used to determine the relative age (based on hind femur length) and sex (if determinable) for each observed cricket. Sampling was conducted at 6 hour intervals every other day for a total of three sampling days. Initial analysis of distributional tendencies were modelled after those employed by Campbell (1980).

Results

Values for index of dispersion and chi square were generated for adult, non-adult, and the entire population for each data collection period (Table 10). All sampling times showed clumping and significant departure from even distribution. The degree of clumping exhibited by adults was greater than juveniles in seven of the twelve samplings. There is no apparent trend in the degree of clumping for adults, juveniles, and the entire population with respect to time of day.

Distribution of crickets across the width of the cave was analyzed with results shown in Table 11. An over-representation of crickets is seen in quadrants closest to the passage periphery (A, E, and F) versus those quadrants in the middle of the cave ceiling (B, C, and D).

Distribution along the length of the cave was analyzed in four meter intervals through the sampling area (Table 12). An uneven representation is exhibited in the various intervals with no apparent relation between distance into the cave and the numbers of crickets.

Figure 29 shows the population apportionment tendencies over the entire study period in individual quadrants.

Inspection of the total population counts with respect to day and time of collection demonstrates a cyclical pattern, as shown in Table 4. Highest population counts were at 1800 hours while fewest were seen at 0600 hours.

Table 10: Daily distributional tendencies as measured by Morisita's Index of Dispersion (I_d) and Chi Square for adult (HFL≥20.0 mm), juvenile (HFL<20.0 mm), and total cave cricket population. I_d =1 indicates random distribution; I_d=0 indicates uniform distribution; I_d approaching n shows increasingly clumped distribution. n (number of quadrants) = 206 for all time periods.

	HOUR	ADULT		JUVENILE		TOTAL	
		I_d	CHI²*	I_d	CHI²*	I_d	CHI²*
DAY 1	1200	4.06	290.7	5.07	514.3	4.90	603.0
	1800	3.51	285.4	2.35	313.2	2.41	370.9
	2400	2.41	230.4	2.77	300.8	2.23	295.8
	0600	8.24	378.8	3.27	302.5	4.19	431.6
DAY 3	1200	4.74	313.3	2.92	370.0	3.16	455.2
	1800	5.46	347.8	2.42	324.6	3.04	444.1
	2400	4.29	310.3	4.67	471.6	4.34	552.2
	0600	5.32	333.5	3.33	330.8	4.00	460.1
DAY 5	1200	4.36	295.7	4.47	454.7	3.88	495.8
	1800	7.09	387.7	4.85	578.9	4.72	692.4
	2400	4.15	302.8	3.51	410.9	3.96	542.4
	0600	5.07	319.1	4.23	414.7	4.38	529.5

*All time periods significant to $p < 0.001$ for d.f.>120

Table 11: Lateral distribution of crickets over all sample periods for rows which contain 5 and 6 columns, respectively. Numbers are actual cricket counts for each column with contributions toward Chi Square in parentheses. Letters denote 1 m wide columns starting at the left wall.

A	B	C	D	E
207	37	14	20	97
(232.3)	(19.3)	(49.6)	(40.3)	(6.5)

$X^2=348.0^*$ (df=3)

A	B	C	D	E	F
83	15	18	43	61	59
(28.7)	(21.3)	(17.5)	(0.26)	(4.5)	(3.4)

$X^2=75.6^*$ (df=4)

*p < 0.001

Table 12: Longitudinal distribution of crickets in 4 meter intervals over all sample periods. Numbers are actual cricket counts with contribution toward Chi Square in parentheses.

Distance into Cave in meters	1-4	5-8	9-12	13-16	17-20	21-24	25-28
Number of Crickets	71	117	320	218	138	96	197
Contribution to Chi Square	(42.4)	(7.7)	(189.2)	(29.8)	(1.1)	(20.0)	(14.0)

$X^2=304.1$ (df=6) $p < 0.001$

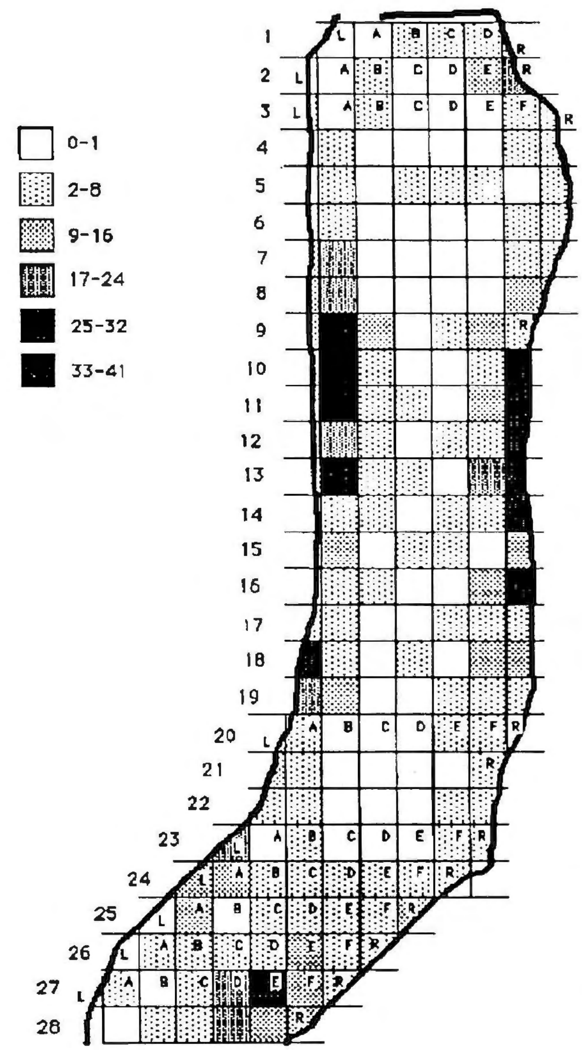

Figure 29: Cave cricket distribution from counts summed over the entire study period for each 1 square meter quadrat.

Discussion

The emergence of more crickets into the study area during the 1800 hour count is consistent with crickets sampling entrance conditions to see if epigean climate is appropriate for foraging (Studier *et al.*, 1986). Since cave crickets would exit the cave around this time, more crickets would be expected nearer the entrance, i.e., in the sampling area.

Crickets probably retreat and emerge from inaccessible areas or deep cave areas. The latter is consistent with the fact that many crickets were seen at distances beyond 28 meters. The occurrence of occasional freezing temperatures at the entrance may explain a shift from normal roosting areas. Since the sample area contained few prospective sites of refuge, I believe population fluctuations could be explained by migrations of crickets into the deep cave during cold weather. Without marking crickets, however, it is difficult to test this hypothesis.

The high degree of clumping exhibited along the periphery of the cave passage my be an indication of more favorable or stable microclimates in those areas. Studier *et al.* (1987) have shown that *H. subterraneus* are extremely stressed in moving air not saturated with water. Areas of the ceiling closest to the wall or other small hiding places will act as a barrier to air movement. Cold air from outside is funnelled into the cave through the sinkhole entrance resulting in a pool of cold, dry air in the first 6 to 8 meters of the cave. A perceptible thermocline exists at that location and is followed immediately by the major roosting areas.

Table 13: Total counts of crickets within the sample area for each time period by day. Contribution to Chi Square in parentheses. Chi square = 35.3504 ($p < 0.001$, d.f.= 11).

HOUR	DAY 1	DAY 3	DAY 5	TOTAL
1200	103 (0.2494)	117 (1.8311)	102 (0.0151)	322
1800	119 (2.4025)	118 (2.1071)	130 (6.9304)	366
2400	75 (7.7294)	105 (0.0296)	115 (1.3372)	295
0600	72 (9.4582)	86 (2.8819)	97 (0.3783)	255
TOTAL	369	426	444	

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Ingestion Rates and Caloric Density Preference of Cave Crickets, *Hadenoecus subterraneus*

Eric K. Wildfang

Cave crickets, *Hadenoecus subterraneus,* of the Kentucky karst regions are omnivorous scavengers (Hubbell and Norton, 1978). Food is carried into cave entrances by wind or water, but such food is sparse and renewed unreliably. Cave crickets leave caves on warm, humid evenings to opportunistically forage on seasonal fruit, decaying vegetation, animal feces, and decaying animal carcasses (Barr and Kuehne, 1971). The high proportion of unidentified material in cricket guts is consistent with this scavenging habit. (Levy, 1978).

Whenever they leave the cave, crickets are in danger of predation by insectivorous animals which inhabit the areas surrounding the cave. For this reason, one would expect crickets to eat as quickly as possible and return to the security of the cave. Whether the cricket will eat the first available food source discovered is not known. In the cave, Levy (1978) showed that cave cricket adults and later instar nymphs have a greater attraction towards higher caloric value foodstuffs (peanut butter and rotting meat) than to lower caloric value foodstuffs (horse manure and leaf litter). Levy showed that food odor was an influencing factor. The experiment reported here examines whether cave crickets eat higher or lower caloric value foodstuffs at different rates and in different quantities, while holding odor constant.

Materials and Methods

The experiment was conducted in Marion and Sophy's Avenues of Mammoth Cave in Mammoth Cave National Park, Kentucky, from 20-25 February, 1988. Resident cave crickets were captured by hand from cave walls and ceilings in the test site area. Crickets were placed into a small screen cloth cage and weighed to the nearest 0.1 mg using an analytical balance (Allied Fisher Scientific Model 2100, Livonia, Mich.),and then placed into pens. Two types of pens were used. One was a prefabricated cricket cage (0.15 m in height by 0.15 m in diameter, Southern Mfg. Co., Duluth, Ga.) with a rectangular piece of screen cloth, attached with a rubber band, covering the opening. The other pen was constructed by bringing the short ends of a 0.38 m x 0.28 m rectangular piece of aluminum screen cloth together and overlapping the edges by 5 cm. The ends were fastened together by threading wire through the overlapped screen mesh. The top five centimeters were folded over once, to act as a lid. The resulting cylinder was rigid enough to stand without additional structural support. The cave floor served as the second pen's floor. Food, mixtures of peanut butter and cornstarch in 1:0 and 1:1 weight ratios (peanut butter:cornstarch), of known caloric values of 5.9 and 5.0 kcal/gm dry weight (Watt, 1963), respectively, was put into a small plastic petri dish (10 mm x 35 mm) and placed into the pen with the cricket for a two hour feeding period. One group of crickets was fed the pure peanut butter and another group was fed the 1:1 peanut butter:cornstarch mixture. Crickets were then removed from the pens and reweighed, to the nearest 0.1 mg, to determine the amount of food eaten. Crickets were then sexed, and their hind femur length (HFL) measured to the nearest 0.1 mm using a thumbscrew compass that was transferred to a ruler. Total caloric intake was calculated as the product of food eaten and food caloric density. Crop empty live weight (CELW) was calculated to determine fullness prior to eating (Studier, et al, 1986). Data obtained were analyzed by ANOVA, regression, and t tests to determine if statistically significant relationships or differences between parameters exist.

Results

Crickets of HFL less than 12 mm are undifferentiated so they were used once to determine male data and again for female data. The relationship between amount of food eaten (g/hr) and hind femur length (HFL) in female *Hadenoecus subterraneus*, HFL 7.2-26.0 mm, feeding on 100% peanut butter is highly significant ($F=17.9576$; d.f.=1&21; $p=0.0004$; r-sqr=0.4610) and expressed by the equation:

$$\text{Food eaten (g/hr)} = \underset{(\pm 0.0019)}{0.00823}\ \text{HFL(mm)} - \underset{(\pm 0.05946)}{0.07132}$$

where the values in parentheses are standard errors of the means. This equation is represented in Figure 30. The test data for male crickets feeding on 100% peanut butter also proved to be significant ($F=8.14574$; d.f.=1&27; $p=0.0082$; r-sqr=0.2318), the obtained results yield the equation:

$$\text{Food eaten (g/hr)} = \underset{(\pm 0.00152)}{0.00434}\ \text{HFL(mm)} - \underset{(\pm 0.04507)}{0.03138}$$

also shown in Figure 30. Table 14 shows the relationships of ingestion rates of adult male and female crickets (HFL 20-26

Table 14: Ingestion rates (g/h) of adult *Hadenoecus subterraneus* (HFL 22-26 mm) feeding on 100% peanut butter or 50:50 peanut butter:cornstarch. Values are mean and standard error in parentheses. (n=5,*=8)

	Females	Males	P
100%	0.1532 (0.0278)	0.0768 (0.0480)	NS
50:50	0.0650* (0.0200)	0.0081 (0.0031)	< 0.05
P	< 0.05	NS	

mm) eating 100% peanut butter or the 50:50 mixture of peanut butter:corn starch. The only gender related difference is among adult crickets eating the 50:50 mixture. In this case adult females ate more than adult males (t=2.2037; d.f.=11; $p<0.05$). There were no significant differences between adult males and females feeding on the 100% peanut butter. There were also no significant differences among adult crickets feeding on the two different foodstuffs.

Discussion

A comparison of adult male and adult female cricket ingestion rates, of 100% peanut butter shows that females eat more and faster than males. These ingestion rates, for both adult male and female crickets, greatly exceed the expected ingestion rate for forest floor arthropods calculated by Reichle (1968). My data, in Figure 30, show that not only do female crickets eat more than males, but also, that females eat at a faster rate. Data shown in Table 14, comparing male and female crickets eating a 50:50 mixture of peanut butter and cornstarch, further supports the data in Figure 30, that females eat significantly more than males ($p<0.05$). Female crickets are, therefore, expected to spend a shorter period of time in each foraging bout outside of the cave, as compared to males, and hence, be subject to less epigean predation per feeding period. This is consistent with studies by Studier *et al.* (1986) reported that female crickets have higher average wet crop contents and a larger dry biomass than males, which suggests that females, because of their larger overall size, are anatomically more capable of consuming and storing more food than males. The ability of females to consume and store more food per foraging period indicates that they may not be required to forage as often as males.

Table 14 shows reduced ingestion rate data for adult male and female crickets eating 100% peanut butter or a 50:50 peanut butter:cornstarch mixture. Due to the high degree of variation among the data, statistically significant results were difficult to obtain. Although only females vs. males eating the 50:50 mixture show significant differences (t=2.20; d.f.=11; $p<0.05$), all other t tests are nearly significant. If one compares ingestion rates for all females vs. all males, it can be argued that females tend to eat more that males (t=2.007; d.f.=34; p=0.053). Further, it may be suggested that among adult crickets feeding on 100% peanut butter vs. the 50:50 mixture, adult crickets tend to eat more of the pure peanut butter (t=1.973; d.f.=34; p=0.057). This suggests that females may be capable of distinguishing among foodstuffs having high caloric density, and choosing the one with the highest value. Levy (1978) reported that adult cave crickets were capable of preferentially choosing foodstuffs of greater caloric density which tended to have a more intense odor and volatility. Because both foodstuffs in this study contained the same peanut butter component, there can be no qualitative differences in volatile materials released. Further, there is little likelihood of significant quantitative differences, in odor. Adult females may therefore be able to distinguish between foodstuffs releasing the same volatile materials, but having different caloric density.

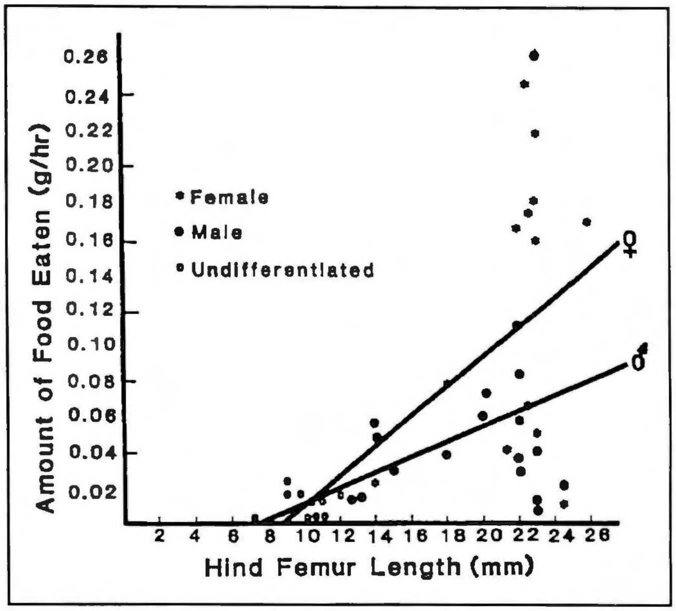

Figure 30: The relation amount of food eaten (g/hr) to hind femur length (HFL) in *Hadenoecus subterraneus*.

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Thermal sensitivity of microbes from the digestive tract of adult cave crickets, *Hadenoecus subterraneus*.

Stephanie G. Phillpotts

Introduction

Symbiotic relationships exist between many insects and microorganisms. The ability of the Orthopterans to live on many different and often very poor diets has been linked to cryptic microbial assistance (Trager, 1970, Dadd, 1984). Orthopterans depend on intrinsic and ingested microbes to aid in digestion, fermentation, and production of secondary metabolites, including potential toxins, present in their food (Martin and Kukor, 1986). Reducing the microbes associated with cockroaches had an adverse effect on their offspring which were pale in color and showed limited growth. Bacteroids are only found associated with the myetocytes (fat body) and in the ovaries of roaches. Examination of the fat bodies of these treated roaches showed no bacteria (Trager, 1970), supporting the symbiotic association between microbes and roaches.

In previous studies done in MCNP on cave crickets, unusual amounts of ethanol and gas were noted during dissection and gas-distended crops even occasionally burst (Studier, and Lavoie, personal communication). These changes could have resulted from exposure to increased temperatures causing unregulated growth of microbes in the crop. Lavoie and Studier believe that crickets may be restricted to a narrow temperature range in order to keep their crop microbes under control. My experiment determined the effect of temperature on the growth of microbes isolated from the crop of cave crickets. As in related cockroaches, cave crickets may be adversely effected with a change in microbial concentration or activity.

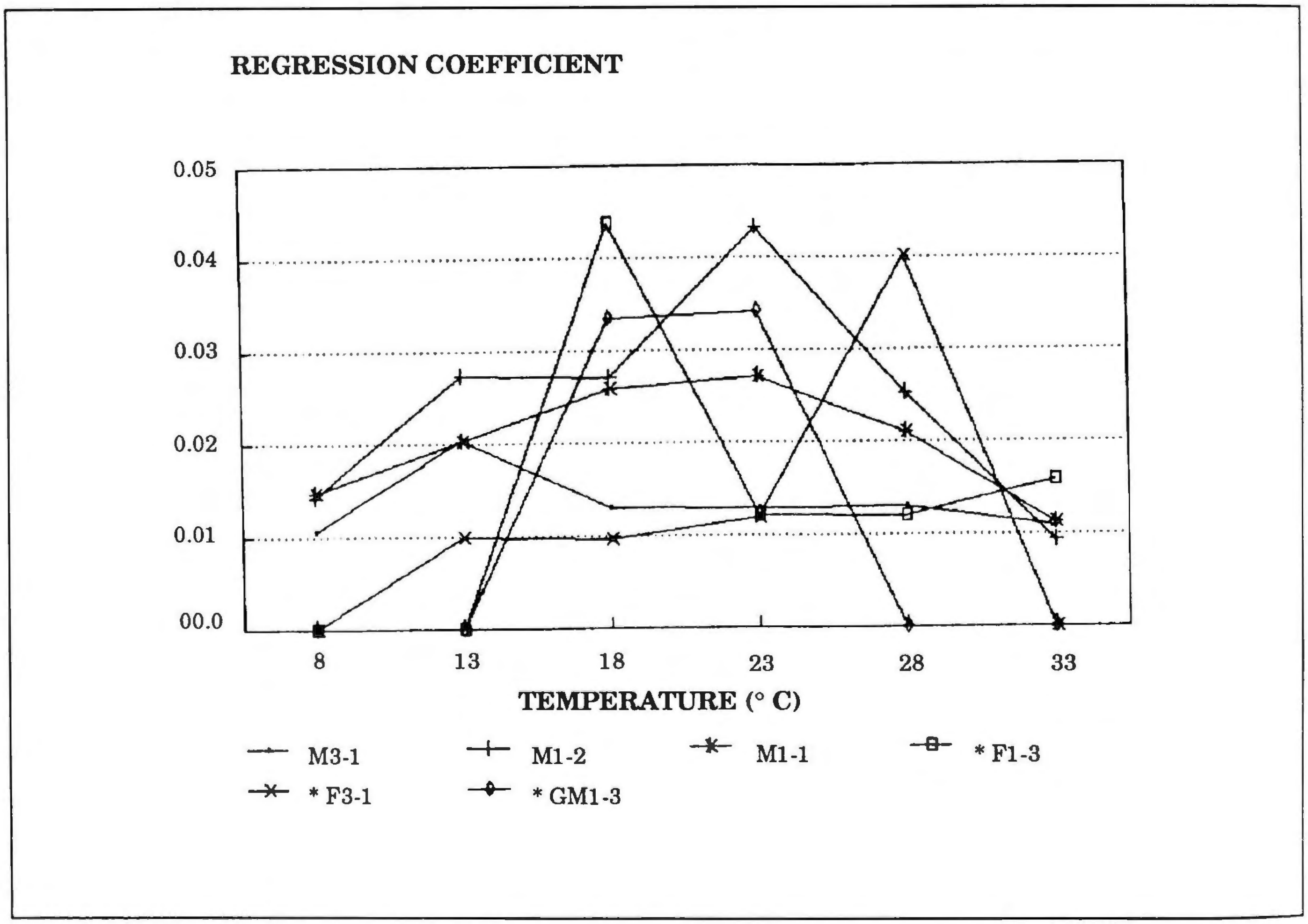

Figure 31: Specific growth Rate (K) expressed as a regression coefficient of *Hadenoecus subterraneus* microbes in relation to temperature at 8, 13, 18, 23, 28, and 33° C. M1 and M3 were isolated from male crops, F1 and F3 from female crops, and GM1 was from a male hindgut. An asterisk indicates that log phase growth was not reached for a particular temperature, so K is underestimated.

Materials and Methods

Six adult crickets (3 male, 3 female) were collected in Sophy's Ave of Mammoth Cave on 19 Feb 1988 and killed by freezing. Crop and hindgut contents were streaked on nutrient agar plates and incubated for four days at 25° C. Representative isolates were selected as stock cultures for my study. Each stock was transferred to 6 flasks of nutrient broth and incubated in water baths set up in Marion Avenue of Mammoth Cave. Incubation temperatures used were 8, 13 (ambient), 18, 23, 28 and 33° C. A Spectronic 20 was used to monitor growth and absorbance was converted to number of cells per ml using a standard curve. A regression analysis was done using ABSTAT on data collected while each culture was in log phase and used to calculate the specific growth rate (K hr^{-1}) for each culture at each temperature.

Results and Discussion

The relationship between K (specific growth rate) and temperature for microbes isolated from the crop (M3-1,M1-2, M1-1, F1-3, and F3-1)) and hindgut (GM1-3) of *Hadenoecus subterraneus* are shown in Figure 31. The data for M3-2, M1-2 and M1-1 are the average of two flasks while the others represent single data points. The isolates in Figure 31 were all Gram negative rods except for F1-3 which was a Gram positive cocci. The curves marked with an asterisk have underestimated K values since lack of time prevented these cultures from reaching log phase for an extended period of time. Other microbes isolated in my study were tested for the production of extracellular enzymes, as discussed in the paper by White.

An increase in specific growth rate is seen with increasing temperature to the optimum growth temperature for that microbe. Above the optimum, K rapidly declines. Optimum temperatures for M3-1 and F3-1 are about 28° C, M1-2 and GM1-3 about 23° C and for M1-1 and F1-3 between 15 and 23° C. Organisms which grow between about 20-40° C are classified as mesophiles while organisms with growth optima below about 20° C are classified as psychrophiles.

Analysis of 133 different proteins in *E. coli* at higher and lower growth temperatures showed change in protein composition with temperature (Herendeen, 1979). Meyer, Kappeli and Fletcher (1985) state that ethanol yield markedly increases with temperature in aerobic ethanol production by a yeast. It is not unlikely that excessive temperatures and rapid microbial growth resulted in excessive gas and ethanol production in cave cricket crops as noted by Studier and Lavoie. I did not test any yeast samples, so further studies need to be done on the source of the ethanol.

This hypothesis is consistent with some unpublished data of Studier and Lavoie and weight loss of *H. subterraneus* as a function of ambient temperature in water-saturated air. At temperatures above 16° C rapid weight loss was seen with crickets dying in a few hours at temperatures above 23° C. Most of my bacterial isolates showed good growth at cave temperatures (about 13.5° C) and an increase in K above that temperature. The crickets could have been killed by growth of microbes in their crops above cave temperatures resulting in an excess of toxic metabolites. I agree with Lavoie and Studier that there is a causal relationship between specific microbial growth rate and the death of crickets with increasing temperature. Microbes exhibit significant but controllable growth at cave temperature and may serve as a source of digestive enzymes in the crops or hindguts.

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Digestive enzymes of the cave cricket, *Hadenoecus subterraneus*

Chad R. White

Introduction

Organisms like cave crickets that consume plant detritus, decaying fruit, rotting wood and herbivore dung (Levy, 1976) ingest a variety of bacteria, protozoa and fungi along with the plant tissue that constitutes the bulk of their food (Martin and Kukor, 1981). If ingested microorganisms survive and proliferate in the digestive tract or liberate enzymes that remain active in the gut milieu, the microbes can augment or extend the digestive and metabolic capabilities of an organism that consumes them (Martin and Kukor, 1981). Bayon and Mathelin (1980) found high levels of volatile fatty acids in the midgut of the beetle *O. nasicornis,* suggesting that fermentation processes, presumably by ingested or resident bacteria, had generated products of potential use to the beetle. Upon dissection of the digestive tract of *H. subterraneus*, a distinct odor of ethanol has been detected and gas sometimes distends the crops to the point of bursting (Studier and Lavoie, personal communication). The crop lies between the esophagus and hindgut and acts as a storage and fermentation chamber where an assemblage of microbes may degrade the forage (Lavoie *et al.*, 1986; Studier *et al.*, 1986). Johnson and O'Keefe (1981) showed that intact bacterial cells of *Rhizobium leguminosarum* ingested by the pea leaf weevil, *Sitona lineatus,* were more prevalent in the anterior and middle portions of the midgut whereas bacteroids with mostly disrupted cell walls were observed in the posterior portions of the gut. My study determines enzyme levels in the crop and hindgut of cave crickets and establishes a possible correlation between these enzymes and those produced by resident microorganisms.

Materials and Methods

This study was performed during the last week of February, 1988. Crickets were collected from several sources as summarized in Table 15. Crickets were killed by freezing, and dissected immediately. Digestive tracts were separated and weighed. Crop and hindgut enzymes were extracted separately according to the method of Martin and Kukor (1981).

Assays were performed of enzyme activity of amylase, xylananse, hemicellulase, and cellulase using the appropriate sugar substrate. Proteolytic enzymes were also assayed using Azocoll as a substrate. All assays were done using methods adapted from Martin and Kukor (1981). Preliminary assays were performed at 13.5, 23, and 33 ° C to establish the optimum temperature for enzyme activity.

I also tested the microbes isolated by Phillpotts from cave cricket crops and hindguts using differential medium for production of caseinase (a protease) on skim milk agar, lipase on spirit blue agar, and amylase on starch agar.

Results

Comparison of crop and hindgut wet weights (Table 15) indicates crops were slightly heavier than hindguts. These crickets showed very little food in their digestive tracts compared to crickets at different times of the year (Lavoie and Studier, personal communication).

Table 15: Crop vs Hindgut wet weights of samples for enzyme analysis. Weight in grams. ND = not determined.

Location	Date	n	Sex	Crop Wt	Hindgut Wt
Sophy's Ave	Feb 24	1	F	0.0270	ND
Frozen Niagara	Feb 24	5	F	0.1072	0.1910
Frozen Niagara	Feb 25	6	M	0.3021	0.1889
Walnut Hill Cave	Feb 25	5	M	0.5710	0.1392
Walnut Hill Cave	Feb 25	2	F	0.3404	0.1075
Frozen Niagara	Feb 26	6	F	0.1196	0.2148
Frozen Niagara	Feb 26	6	M	0.1592	0.1934
White Cave	Feb 26	6	M	0.2784	0.1812
White Cave	Feb 26	6	F	0.0968	0.2411
White Cave	Feb 27	6	M	0.5361	0.1226
White Cave	Feb 27	6	F	0.2836	0.2081

Total Weight: **2.821±1.7878**
Avg. Weight*per cricket: **0.0513±0.0331**

*n for crop = 55
n for hindgut = 54

Crop and hindgut extracts showed a range of activities against all substrates tested, as shown in Figure 32. Crop and hindgut activity data were analyzed by paired t-test and found not significantly different in all cases (glycogen, t=0.972, df=16; amylose, t=0.6256, df=13; chitin, t=1.279, df=15; cellulose, t=0.655, df=15; xylan, t=0.020, df=11; Azocoll, t=0.842, df=9).

Microorganisms isolated from crops and hindguts all exhibited growth on differential media showing enzyme activity as seen in Table 16.

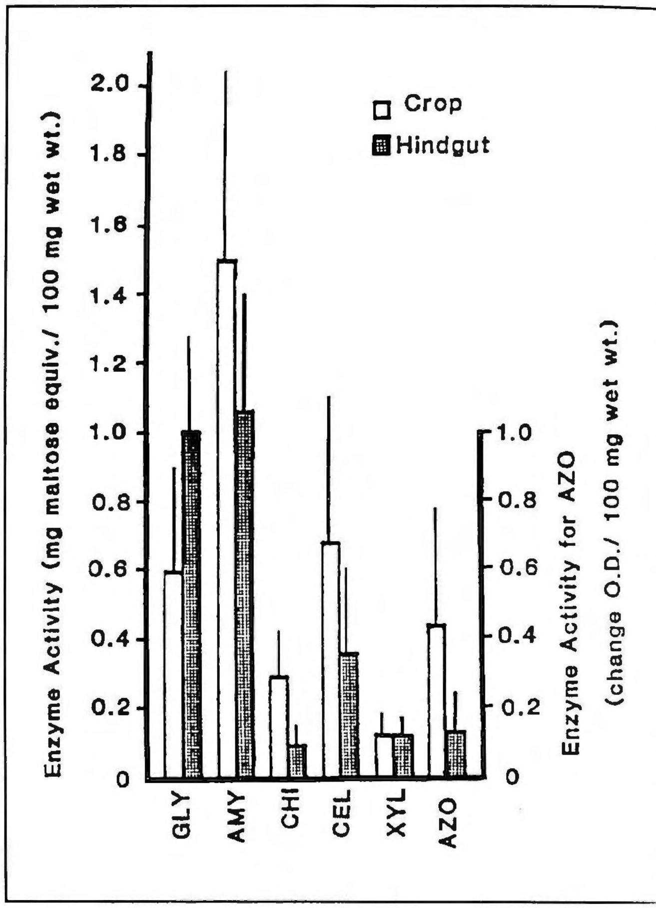

Figure 32: Enzyme activity in mg of maltose equivalents per 100 mg of crop/hindgut wet weight. Average enzyme activity plus standard error. T-test of crop vs hindgut activity is not significant for all enzymes assayed. GLY=glycogen; AMY=amylose; CHI=chitin; CELL=cellulose; XYL=xylan; AZO=azocoll.

Discussion

Extracts from both portions of the digestive tract exhibited activity toward cellulose and xylan indicating, according to Martin *et al.* (1981), the ability to digest the common structural polysaccharides of plant cell walls. Activity toward Azocoll and chitin was also detected in both gut segments indicating proteolytic and chitinase activity. The greatest activity exhibited by both crop and hindgut was toward amylose and glycogen indicating ability to digest alpha 1,4-glucans which are the chief storage polysaccharides of higher plants and animals (Martin *et al.*, 1981). This digestive ability would only be useful to organisms that include such material in their diet. According to Levy (1976) *Hadenoecus* have a diverse diet that includes plant and animal detritus, decaying fruit and other animals. Data collected during my study supports that same conclusion.

It has been suggested that these hygrophiles forage only when epigean conditions resemble cave conditions (13.5 °C, 100 % RH) (Studier *et al.*, 1985). During the week of testing nightly temperatures ranged from -4 °C to 12 C with relative

Table 16: Production of enzymes by pure cultures of predominant microbes isolated from the crop and hindgut of cave crickets. Caseinase detected on skim milk agar, lipase on spirit blue agar, and amylase on starch agar. All isolates grew on all media.

ID#	Gram	Morph.	caseinase	lipase	amylase
F3-1A	+	yeast	-	+	-
F31-B	-	rod	+	+	+
F1-3	+	cocci	-	+	-
GF1-1	-	rod	-	+	-
GF1-4	+	rod	-	+	-
GF1-3	-	rod	-	+	-
M3-1	-	rod	-	+	-
M1-1	-	rod	-	+	-
M1-2	-	rod	+	+	-
GM1-3	-	rod	-	+	-

humidity in the 90% range (R. Downing, personal communication). Epigean temperature was not conducive to crickets exiting the cave, crop contents were lower than normal, and enzyme activity was primarily toward animal storage polysaccharides, which all suggest that these crickets were feeding on animals, probably on each other.

Activity patterns exhibited toward the substrates were low compared to those reported from other terrestrial and aquatic detritovores (Martin *et al.*, 1980, Martin, Lawson *et al.*, 1981) and from fungus-feeding beetles (Martin, Kukor, Martin, O'Toole, *et al.*, 1981). Activity may have been low because of the extended time between foraging bouts in crickets at this time of the year.

Midgut activity was toward the same polysaccharides as crop activity suggesting that enzymes are produced in the crop, although there is the possibility that enzymes are produced in the midgut and refluxed into the crop. Average crop weight per individual was 0.0513 g, which is considerably lower than in other seasons (Studier and Lavoie, personal communication). Normally the crop contains more material and retains it longer than the hindgut, so more digestion normally takes place in the crop than the hindgut.

Preliminary data for microbial growth on specialized media indicates some activity toward protein, lipids, and starch as shown in Table 16. Enzyme production by resident microbes may need to be induced by the presence of the substrate. Optimum growth rates for resident microbes isolated from cave cricket crops are observed in a temperature range between cave temperature (13.5 °C) and 23 °C (Phillpotts, personal communication. Greatest activity towards substrates in my tests was observed at 23 °C.

Lavoie *et al.* (1986) suggest that microbes in the digestive tract may be responsible for digestion of food in the crop of cave crickets. My data tend to support this suggestion, but further studies are needed. One test would be to analyze the same enzymes in isolated microbes. It would certainly be useful to repeat this study at a time when crops are full after recent feeding, or to feed crickets a known diet and then test for enzyme activity. A comparison between crickets in caves in a forest *vs* a pasture would also be useful since these crickets would be likely to feed on different materials. We are not sure if observed microbes are from foods eaten or from a smorgasbord of exogenous microbes ingested along with the food.

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Use of a Localized Food Source by *Peromyscus leucopus*, Determined with an Hexagonal Grid System

Dennis P. Viele

Caves containing large populations of trogloxenes, which regularly leave caves to forage outside, provide a predictable prey source which attracts predators. Such situations have long been known for cavernicolous bats as prey for raptors (Allen, 1939). Cave crickets, *Hadenoecus subterraneus*, and camel crickets, *Ceuthophilus stygius*, occur in large populations in many caves within Mammoth Cave National Park (MCNP). Crickets leave caves on warm, humid nights to feed opportunistically and omnivorously as scavengers (Barr and Kuehne, 1971), and provide potential prey for insectivorous mammals. Observations in all seasons show that *Hadenoecus* are rarely found more than seventy meters from cave entrances (Norton, 1978). Nocturnal, ground dwelling, insectivorous mammals should find foraging crickets easy prey. Hamilton (1941) examined 180 *Peromyscus leucopus* between November and April in New York and found their diet contained 72.8% arthropods. The life cycle of the parasitic nematode, *Pterygodermatites coloradensis*, in Kentucky includes *Ceuthophilus* as an intermediate host and *P. leucopus* as a definitive host (O'Brien and Etges, 1981); thus, camel crickets are eaten by *Peromyscus*. Cave cricket foraging patterns lead us to expect high concentrations of small insectivorous mammals near cave entrances.

Trapping of small mammals was conducted at MCNP, Kentucky, from 21-27 February and 28 April- 2 May 1988. Traps were set in an hexagonal grid, consisting of ninety Sherman live traps, centered around the cave entrance (White Cave) on a generally South facing slope (see Figure 33). Each trap was set ten meters from any adjacent trap. A long axis of the grid was placed at the contour of the cave entrance. Each trap, baited with peanut butter, was placed with its entrance directed away from the cave opening. Traps were set at dusk (checked at 10 pm in February) and then tripped at dawn for seven nights in February and four nights in April and May. Captured individuals were identified to species and capture site was recorded. Sex and reproductive condition were noted. Specimens were toe clipped and released to monitor recaptures.

Statistical analysis was done using a computer generated program of Chi-square goodness of fit test. Data were collected for a period of 630 trap nights in February and 360 trap nights in April and May. The absence of captures in the southern portion of the test grid can be explained by the presence of a large foraging animal tripping the traps spring mechanism. Four scrotal male *Peromyscus leucopus* were captured a total of fifteen times in February. Surprisingly, the only small mammals captured were *P. leucopus* and few of them. Significant chi-square results (x2= 23.156, dF = 4, p < .001) in February indicate that these captures are not randomly or evenly distributed over the tested grid. Examination of capture sites in February show that home ranges of *Peromyscus* overlap (Figure 33). Captures in April and May again show extensive home range overlap with six of the seven captures located in ring one and the seventh capture located in ring five (x2=70.571, dF = 4, p < .001). Overlapping of home ranges are extensive at the cave entrance which indicates that *Peromyscus* use the cave entrance as a localized food source.

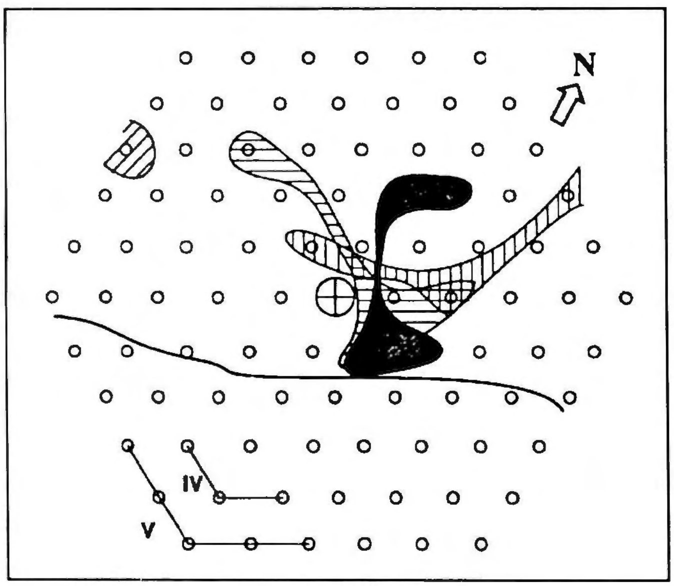

Figure 33: Home ranges of four male *Peromyscus leucopus*, in February, using a cave (White Cave) as a localized food source. Home ranges may terminate at the edge of tested grid. Successive rings are denoted by Roman numerals. An East/West trail runs through tested grid.

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ARCHAEOLOGY PROGRAM

CRF Archaeological Project, Shellmound Archaeological Project and the Green River Archaeological Survey, 1988

Patty Jo Watson

CRF Archaeological Project activities included a presentation by Pat Watson on Mammoth Cave National Park archaeology at the National Park Service "Research in the Parks" conference in Gatlinburg, Tennessee (Great Smoky Mountains National Park), May 14, 1988.

On May 14, Watson joined CRF and NPS personnel in a trip to a cave near Dennison Ferry noted by Guy Prentice's crew (see below) when they were carrying out archaeological surface survey there. The cave was explored and apparently well-known earlier in the century, but because there was some prehistoric cultural debris around the entrance, Prentice wanted an assessment by archaeologists familiar with local cave archaeology. The assessment group included Richard Faust, Guy Prentice and Bruce Manzano of the Southeast Archaeological Center at Tallahassee, Florida; Henry Holman of Mammoth Cave National Park; John Bassett, Sam Frushour, Patrick Munson, Ken Tankersley and Pat Watson of the Cave Research Foundation. Although there is plentiful evidence of historic activity in the cave, including speleothem mining, there is no indication we could recognize prehistoric exploration or exploitation.

On the evening of May 15, the CRF members of the group went to Mummy Ledge and Campbell Ledge to take photos for a publication on prehistoric crystal mining (especially for selenite) in Mammoth Cave.

On December 10, Pat Watson and Christine Hensley joined Guy Prentice's excavation crew in the testing of two small rockshelters in Mammoth Cave National Park. Prentice has issued a detailed interim report on the first year of the Park Service's 3-year cultural resource evaluation in MCNP. Prentice is in charge of the work, which is being carried out by the Southeast Archaeological Center, Tallahassee. Christine Hensley and Pat Watson have been in close touch with Prentice so that Hensley's dissertation research in the Big Bend of Green River (partially supported by CRF) can be coordinated with the NPS work. Hensley's research (the Green River Archaeological Survey) builds upon work done in the Big Bend, Butler County, Kentucky, by Shellmound Archaeological Project personnel (see previous CRF Annual Reports beginning in 1975 for accounts of the Shellmound Archaeological Project and its relation to the CRF Archaeology Project). She is investigating non-shellmound sites of the same cultural horizon (Archaic to Early Woodland, approximately 2500 to 3500 years ago) as he shellmound people. These sites are of the types sometimes known as "burnt-rock middens" and "lithic scatters", and are not well understood in our part of Kentucky. Yet they contain important information on chronology, subsistence, and settlement patterns characterizing the human groups who explored and mined the big caves in the Mammoth Cave area, and their colleagues who accumulated the shell middens farther west along Green River.

Hensley's 1988 fieldwork (supported by grants from the Kentucky Heritage Council, the Cave Research Foundation, and Sigma Xi) began in July with surface assessment of a list of potentially relevant sites compiled from the Kentucky state files. Test-excavation of three sites near Morgantown, Kentucky, was carried out from September to November, 1988, with further test-trenching planned for summer 1989. The field and laboratory results of these investigations will form the basis of a Ph.D. dissertation at Washington University, St. Louis, Missouri.

Acknowledgements

As has been the case since inception of our work in 1963, we are grateful to the officials of Mammoth Cave National Park for their continuing interest and cooperation with CRF Archaeological Project personnel. It is a privilege to carry out research on the unique archaeological materials contained in the world's longest cave, and we greatly value that privilege.

We are also thankful to Richard Faust, Chief and to Guy Prentice of the Southeast Archaeological Center for being so careful to coordinate their work with ours, and for permitting us to join their field parties on several occasions. We look forward to many more years of fruitful collaboration.

In the Big Bend of Green River, we are equally fortunate to have the goodwill and cooperation of hospitable and generous people who not only allow us access to archaeological sites on their property, but also aid and abet us in numerous ways on a daily basis. We owe special thank to Waldemar and Ethie Annis - friends and colleagues for the past 15 years, Kathleen Thomas, Gordon and Francis McKee, Dr. Wan, Kenneth York and Dave and Christine Render.

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Green River Archaeological Study: A Preliminary Report

Christine K. Hensley

The Green River Archaeological Study is an outgrowth of the Shell Mound Archaeological Project (see CRF Annual Reports from 1975 to present for accounts of SMAP and its relation to CRF Archaeology Project). Whereas the former study focused upon the shell mounds, specifically the Carlston Annis mound, 15Bt5, the Green River Archaeological Study is investigating four open-air sites that have similar artifact assemblages, but lack the large accumulation of shell refuse. Given the substantial amount of basic archaeological research already conducted in the Middle Green River Valley (Marquardt and Watson 1983; Webb 195x0), including sites found on the floodplain, within karst features, and in rock-shelters, the study of the non-shell midden sites will make it possible to address questions of settlement patterns for the Late Archaic to Early Woodland period, 2500 to 3500 years ago. An equally important aspect of this study is further documentation of plant cultivation during the Late Archaic. Recent models proposed to explain the beginnings of horticulture have emphasized the relationship between sedentarism and the domestication of plants (Brown 1985; Smith 1987).

Geoarchaeological investigations (Leach 1988) were carried out at twelve sites within Butler and Ohio counties, Kentucky, that were believed to date to the Late Archaic and/or Early Woodland period. Based upon the geoarchaeological testing, I chose four of the twelve sites for further excavation; three of these are in the floodplain (15Bt45, 15Bt92 and 15Bt91); and one is on the bluff overlooking the Green River, 15Bt46.

The geoarchaeological testing at 15Bt46, the upland site, was not conclusive, but indicated a thin deposit below the plowzone. This site is important because it is the only known upland, open-air site in the immediate area of the shell mounds that has not been affected or destroyed by the expansion of Morgantown. The site, once in a cultivated field, is now covered with a heavy secondary growth that prohibits any surface collection. Systematic shovel tests were made in the area of the site where the earlier geoarchaeological study indicated intact cultural deposits (Leach 1988). Despite the additional intensive testing, we were unable to locate cultural deposit beneath the plowzone.

Directly below Bt46 on the floodplain is a temporally undefined site, 15Bt45. Excavations at this site revealed two cultural zones: the upper zone is primarily restricted to the plowzone and artifacts recovered date to the Late Woodland period; the lower cultural zone is sealed by a fluvial sand deposit. Cultural materials recovered from this intact horizon consist mainly of sandstone and lithic debris as well as charred nutshell and wood. No temporally diagnostic artifacts were found in any of the excavation units for the second cultural zone, but samples will be submitted for radiocarbon determination.

The third site tested, Bt92, is located within the Big Bend of the Green River, less than 100 m from the river's edge. The site on a ridge of levee-like deposits overlying sediments of Pleistocene lacustrine origin. Bt92 can best be described as a "burnt-rock midden"; that is, the deposit has a high density of fragmentary sandstone, presumably burnt. The artifacts recovered from the surface and excavation units date to the same period as the shell mounds.

One 2x2 m square was placed at the apex of the midden and excavated to a depth of 100 cm below surface; a second 1x2 m unit was placed 40 m on a east-west line from the first 2x2 m square, at the edge of the site, and was excavated to approximately the same depth. In these two tests units similar stratigraphical sequences were observed. The first cultural zone, surface to xx cm below, appears to date to the Late Archaic period based upon the artifact styles; a second cultural zone was encountered at approximately xx cm below surface. This second cultural zone is not as yet well defined: it occurs in the levee sand (approximately 90 cm below surface and 30 cm below cultural zone 1) and is represented by one spent core fragment, lithic debris and a scattering of burnt nuthull.

The fourth site, not yet tested, is Bt91. This site differs from the others in that it is adjacent to a hell midden, Bt12. It is not yet clear what the relationship is between the shell midden deposit and the non-shell aspect of the site. What is clear, however, is that the shell refuse is concentrated in a n area measuring 100 x 65 m and that immediately adjacent to it is a locale, slightly larger, with similar artifacts and rock debris, but no shell. Unfortunately, the site was unexpectedly inundated with early winter flood waters in the final weeks of our excavation season and we were unable to work there. Further investigation of Bt91 is scheduled for the early summer of 1989.

The Green River Archaeological Study is focused upon sites inhabited during the same general time period as the shell mounds in order to provide another perspective upon this important archaeological district. Preliminary analysis of the materials recovered is currently underway and the numerous flotation samples collected from both features and general excavation proveniences will be processed soon. One of the questions raised by this first season of field work is "why shell there and not here?". In the case of Both Bt91 and Bt92 there are shell mounds in close approximately, yet at these sites there is no shell refuse. Were the areas as environmentally similar as they appear to be, making the placement of shell middens somewhat random along the river banks? Or are there factors we do not yet understand that contributed to the original decisions about where to process mollusks? Or do these sites, Bt91 and Bt92, represent later occupations by people in the Green River valley, after the exploitation of mussels ceased, and a different subsistence emphasis or exploitation pattern was being followed?

Acknowledgements

The Green River Archaeological Study is funded by the Kentucky Heritage Council, Cave Research Foundation, and Sigma Xi. The geoarchaeological study was conducted by

Elizabeth Leach. I was assisted during various stages of the fieldwork by George Crothers and Kevin Kuykendall as well as numerous volunteers from Washington University and the University of Tennessee. none of this work would be possible without the support of our friends in the Big Bend and Morgantown, especially Waldemeer and Ethie Annis, Dave and Christine Render, Kenneth York and Dr. Wan.

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CRF Fellowship and Grant Support

Each year, the Foundation may award up to $7500 as Fellowships or as one or more grants for graduate research in karst-related fields. The truly exceptional proposal may receive a Karst Research Fellowship (limit $3500.00), meritorious proposals may receive one or more Karst Research Grants, in amounts less than $2000.00, awarded to qualified students in the natural or social sciences. Proposals are screened by a committee of scientists. These judges seek promising or innovative topics, supported by evidence that the student has command of the literature and of the methodology. A detailed announcement of the competition is mailed in early Autumn, and the deadline for receipt of the proposal, supporting documents, and letters of reference is January 31.

The Cave Research Foundation received 10 proposals in 1988. Of these, two proposals were deemed essentially equal and were awarded Fellowships; three proposals received grants. The name, school, title of the proposal, and an encapsulation of the research are given for each funded proposal.

1. **For his proposal entitled "Halls Cave Project: Paleoenvironmental reconstruction of Pleistocene and Holocene of Central Texas"**, Rickard S. Toomey III, Department of Geological Sciences, University of Texas, Austin, Texas, 78712, was awarded a CRF Fellowship in the amount of $2,500.00. The research is multidisciplinary and and involves study of a well-stratified deposit of clastic sediment containing vertebrate remains, surface-derived clay minerals, and pollen which will make an important contribution to knowledge of the transition from Pleistocene to Holocene climatic transition of a heretofore unstudied part of the southwestern United States.

2. **For his proposal entitled "Fluvial geomorphic controls on karst evolution in the Crawford Upland and Mitchell Plain, south-central Indiana"**, Mr. Jerry R. Miller, Department of Geology, Southern Illinois University, Carbondale, IL 62901-4324 is awarded a CRF Karst Fellowship in the amount of $1000.00. Mr. Miller's research takes a systematic approach to fluvial processes; he is developing a model which demonstrates and explains the role of fluvial systems in the initiation and development of karst landforms. For 12 watersheds, Jerry will incorporate comparative analyses of basin shape and relief, assemblages of fluvial and karst landforms, and characterizations of hydrologic and sedimentologic regimes as indicators showing how fluvial channels of karstified areas respond to alterations in the supply of water and sediment.

3. **For her proposal entitled "Prehistoric hunters-gatherers and their transition to plant husbandry: an example from the Eastern woodlands"**, Christine Hensley-Martin, Department of Anthropology, Washington University, St. Louis, MO 63130, is awarded a CRF Grant in the amount of $1,000.00. Ms. Hensley-Martin's research is an important step towards a regional synthesis of the prehistory of central Kentucky. Among the hypotheses to be tested is the notion that the Middle Green River Valley, including both the karst area and the shell mound district, is one subsistence-settlement system. Analyses of small, transiently-utilized open-air archaeological sites, which are distinct from the more spectacular and previously studied shell-mound sites, have not been carefully studied. These presumed short-term sites will be evaluated to determine (1) the time periods the sites represent; (2) what activities took place and at which seasons, and (3) what the subsistence base was. These sites can then be fitted into a comprehensive picture showing the regional prehistory partitioned as permitted among the various types of sites in the region, the shell mounds, the caves/rockshelters, and the open-air sites.

4. **For his proposal entitled "Regional modeling of ground water in carbonate terrain: joint controlled flow in the Indiana karst"**, Stephen R. Kraemer, School of Public and Environmental Affairs, Groundwater Modeling Laboratory PV-377, Indiana University, Bloomington, IN 47405 is awarded a CRF Grant in the amount of $1,000.00. Mr. Kraemer's study includes an interactive computer program that will help build and test conceptualized models of flow in fractured aquifer systems.

5. **For his proposal entitled "Hydrologic Investigation of the Sistema Huautla drainage basin, Oaxaca, Mexico"**, James H. Smith, Department of Geography and Geology, Western Kentucky University, Bowling Green, KY 42101, is awarded a CRF Grant in the amount of $1,000.00. Mr. Smith's research involves dye testing of hydrogeological elements in the Sistema Huautla drainage basin, including the hypothesis that Cueva de la Pena Colorado is the resurgence of Sistema Huautla. The study will also test whether the remaining unconnected 25 kilometers of mapped watercourses really are part of the Sistema Huautla and enjoy the same resurgence as the remainder of the system.

Research summaries and progress reports submitted by these and by other investigators are published elsewhere in the CRF Annual Report. Please refer to those summaries and contact the respective authors for additional details concerning the research.

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INTERPRETATION AND EDUCATION PROGRAMS

Figure 34: Jim Goodbar becomes the first person to enter Tongtianluo Shaft, China. (*Photo by Ron Bridgemon*).

EDUCATON PROGRAM

V-Vats and Rectangular Hoppers in Mammoth Cave

Angelo I. George

Visitors to the Historic Section in Mammoth Cave are treated to a cross section of pioneer engineering and industrial chemical ingenuity. Relics of the saltpeter mining industry are visible in Houchens Narrows, Rotunda, Methodist Church and Booth's Amphitheatre. From about 1798 to 1815, Mammoth Cave was used as a saltpeter mine. As ownerships changed, so did the method of saltpeter extraction. In late 1811 there was a major alteration in saltpeter vat construction from V-vats to the introduction of large rectangular hoppers. These new hoppers were augmented with a hydraulic pumping and pipe line system built to convey fresh water to leaching vat processing areas and to transport vat leachate to furnaces located on the surface. Charles Wilkins is considered the engineer-architect responsible for major saltpeter improvements seen today in the cave (DePaepe, 1981, p. 27).

Three different kinds of saltpeter hoppers are present in Mammoth Cave. The earliest variety is of simple V-vat construction. Nationally, V-vats were used from the Colonial period, to well into the late 19th Century. Five caves in the Mammoth Cave National Park still have this kind of construction: Dixon, Longs, Jim, Martin and Mammoth Cave. Separate bottom drain rails of these vats can be seen in Mammoth Cave near the entrance to Audubon Avenue (DePaepe, 1975, p. 68; Mullins, 1986, p. 4). And there are ridge dumps on the west side of the Rotunda (George, these proceedings).

The Ridgely (1811a) map of Mammoth Cave shows the location of 14 V-vats positioned in the vestibule just before the Houtchens Narrows Passage. The second Ridgely (1811b) map shows about 24 V-vats in approximately the same area of the cave. Today, there are no standing V shaped wood leaching hoppers any where in the cave. DePaepe (1986, p. 18) says V-vats "were not used in Mammoth Cave during the War of 1812." On going investigation shows the physical existence of V-vats along the west wall of the Rotunda (George, these proceedings). Smaller V-vats were also operational at Booth's Amphitheatre. The V-vats operated in tandem with the large rectangular hoppers.

During 1811, Charles Wilkins and Fleming Gatewood retooled the cave into a modern saltpeter manufactory. Under their direction, the double pipe line system, 3 elevated pump lift stations, rectangular vats and an expanded evaporation furnace complex was built. By August 25, 1812, Hyman Gratz had bought out Gatewood and prior land owners to Mammoth Cave (Thomas, *et al.* 1970, p. 324-325). Wilkins with his new business partner, continued to improve the saltpeter operation. No historic information has been discovered to suggest what kind of improvement was made by Wilkins and Gratz. Meloy (1969, p. 2) said, Fleming Gatewood " is reported to have enlarged the saltpetre works used by the McCleans; and it was probably he who built the hoppers at the cave entrance – the ones used prior to building of the large hoppers in the Rotunda." Prior to this, it is generally supposed the leaching of saltpeter earth took place on the surface, out beyond the Historic Mammoth Cave entrance. For saltpeter processing at Mammoth Cave, it does not seem practical or logistically feasible for the McLeans to haul saltpeter earth up the entrance breakdown slope and process it on the surface. With a water source in the entrance vestibule and saltpeter impregnated earth along the entrance passage, the original V-vats must have been here, and in the same place as shown on the 1811 Ridgely maps. Only in situations where no water source exist or low cave passage ceiling level, were vats constructed outside the cave and usually near a spring or surface stream.

In 1811, Dr. Frederick Ridgely, M.D. writes of a "curiosity" to his Philadelphia colleague and mentor, Dr. Benjamin Rush, M.D. He encloses a large format, colored sketch map of Mammoth Cave. This is the earliest known map of Mammoth Cave (Meloy, 1968, p. 56; 1975, p. 26). Ridgely shows the location of 14 V-vats called "leeches" found just before Houtchens Narrows in the entrance vestibule. The center entrance trail is flanked on both sides by gangs of seven V-vats. By mid 1811, Ridgely (1811b) or associates produced a second map showing an enlarged Houtchens Narrows V-vat complex. The map contains an expanded note that says "at the Big room (to which it is contemplated to convey the water and erect Leeches)...." The Big Room is now called the Rotunda (Meloy, 1975, p. 26). This map was sent to Archibald McCall on June 11, 1811. It has always been presumed by contemporary saltpeter investigators that the reference to "erect leeches" refers to rectangular vats built in the Rotunda. This led Meloy (1969, p. 2) and Mullins (1986, p. 12) to suspect the Rotunda rectangular hopper complex was built first. I suspect, between June 11, 1811 and September 1811, the V-vats and the pipe line were probably built in the Rotunda. This V-vat hopper complex operated through the final life of saltpeter mining at Mammoth Cave. Written documentation is wanting, yet the bottom drain rails from V-vats are still present in the Rotunda. And the negative molds of V-vats flank the west wall of the Rotunda (George, these proceedings).

Dr. Daniel Drake, M.D., obtained an early copy of a copy of the Mammoth Cave map; and Meloy (1968, p. 56) assigned a post 1811 date. This is probably another Ridgely and associates map and its date of preparation could be late 1811 (George, in manuscript).

Drake's map copy indicates Booth's Amphitheatre and not the Rotunda as the first place for the construction of the large rectangular leaching hoppers. Four vats are shown complete with pumping tower. A pipe line connects to a second pumping lift station in the Rotunda, and a third lift station at the entrance to the cave. No V-vats are indicated on this map. The free hand sketch in the Draper Manuscripts is obviously a special purpose map showing only the layout of this new engineered construction and was not meant to show every artifact in the cave.

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Rotunda V-Vat Complex, Mammoth Cave, Kentucky

Angelo I. George

Upon entering the Rotunda in Mammoth Cave, the visitor is confronted with three large nearly square saltpeter hoppers, elevated lift station and pipelines. In addition the whole complex is sunk into the floor of the cave, giving the appearance of a crater. According to tradition, lixiviated earth was taken from these hoppers and spread out in all directions, forming a saltpeter apron. The apron stands at and above the level of the trail in Main Cave. A larger saltpeter apron also exist at Booth's Amphitheatre.

Each rectangular hopper complex and saltpeter apron has some auxiliary features often referred to as lixiviated soil mounds (Mullins, 1986, p. 3), or dumps of processed petre dirt (DePaepe, 1985, p. 17) that take on the appearance of miniature mountain chains (Hovey, 1897, p. 291). White (1967; in manuscript) found similar features called ridge dumps in Great Saltpetre Cave, Rockcastle County, Kentucky. White (in manuscript) suggested they formed by unhitching an ox cart and tipping it backward, discharging its load onto the ground. This formed linear shaped hummocks.

Historians generally agree that these hummocks are the lixiviated remains of saltpeter earth shoveled or dumped from the large rectangular hoppers (Mullins, 1986, p. 3). It was here along the west wall of the Rotunda the lixiviated soils would renitrify themselves in 3 years time (Meriam, 1844). The Rotunda-Audubon Avenue tourist trail is cut down through this lixiviation mound between the west wall and the rectangular hopper complex (Mullins, 1986, p. 4). DePaepe (1975, p. 68) though the V-vat channel logs in the Rotunda, "...may represent smaller vats which were in the vestibule of the cave." And that V-vats were not used during the War of 1812 in Mammoth Cave (DePaepe, 1986, p. 18). There is some doubt these hummocks represent soils removed from the rectangular hopper complex.

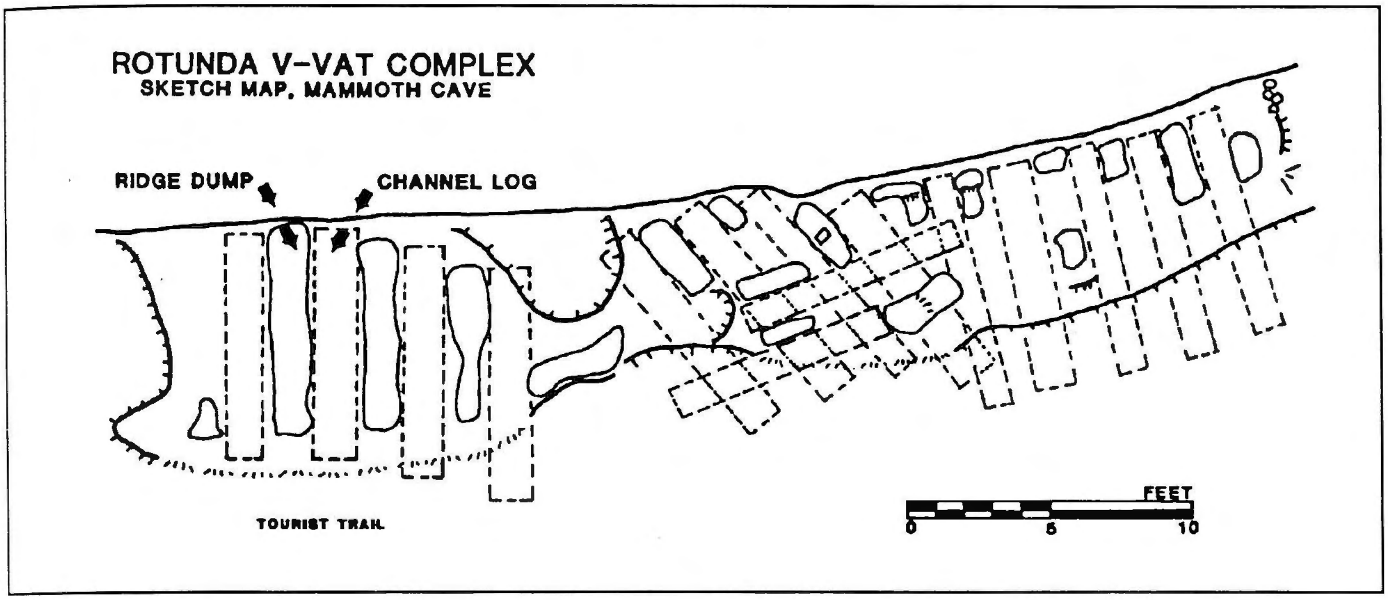

Figure 35: Sketch map of the Rotunda V-vat complex.

Evaluation of the lixiviation mounds shows them to be the intervening soil wall support to a gang of V-vats. The V-vats operated in tandem with the Rotunda rectangular hopper complex. Meriam (1844, p. 318-319) says the Rotunda "...saltpetre hoppers are constructed in the same manner as ash leaches are made...." I have seen no documentation for rectangular hoppers being used in the wood ash conversion process of vat leachate to saltpeter. There is information targeting V-vats in the wood-ash conversion process (Hunter, 1802). Meriam is not making reference to rectangular hoppers, rather this is a direct reference to then existing V-vats in the Rotunda.

There is a kind of regularity associated with the hummocks in the Rotunda. A sketch map was made of the surface topography along the west wall (Figure 35). The topography consist of linear shaped earth ridges, rarely over 3 feet high and usually 2.5-5 feet between ridge crest (on center). Lengths vary from 1-7.5 feet and approximately 1 foot wide at the crest. They have flat-topped triangular cross sections. The cavity floor averages from 1.3-1.8 feet wide. The majority of the ridges are perpendicular to the wall of the cave. Nearest the tourist trail, 4 of them are parallel with the trail and oblique to the general geography of the 14 other ridges. The 4 oblique mounds probably represent a later generation in V-vat construction.

Near the south wall of the Rotunda are the remains of 7 channel logs (bottom drain rails) of V-vats. Channel logs are in various lengths, all are broken pieces and some show charring on one end. These are massive logs that measure from 2-7.7 feet long and 1.35 feet in diameter or greater. The smallest channel log was carried over to the lixiviated mound area. And placed in several of the cavities with remarkably good fit (Figure 36).

The Rotunda V-vat complex may have had average channel log length of 8 feet, internal hopper cavity of 7.5 feet and wall height of about 3 feet. Based on this reconnaissance, a plan of what the V-vat complex may have looked liked is submitted (Figure 35). Positions for at least 15 hoppers with 8 feet long channel logs can be fitted into this picture. Two of these hoppers are superimposed and signify later V-vat construction.

The Rotunda gang of V-vats is positioned on a higher saltpeter apron than the apron formed by the rectangular hoppers. Such a V-vat arrangement infers this apron grew at a faster pace than the rectangular hopper apron. Furthermore, the V-vats had to have operated in tandem with the rectangular hoppers. These V-vats were relatively empty at the end of the last mining season. All wood structures have been removed and tourist traffic has erased obvious signs of wood imprints on the cavity side of the ridge dumps. Bird (1837, p. 431-433) and other ante bellum writers says the cave guides upon entering the Rotunda would provide additional torch light and bonfires to illuminate this large room. The guides tore up existing vats to make these fires. The large crib vat show only a little damage. So, the guides cannibalized these V-vats for fire wood. Deliberate vandalism has removed all wood vestiges and other V-vat ridge dumps during the commercial tourist life at Mammoth Cave.

The ridge dump complex at Booth's Amphitheatre flanks both sides of the tourist trail and has good evidence for smaller V-vats. Here imprints of wood facing shingles and exterior supports are visible. This area of the cave is planed for future investigation.

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Figure 36: Small V-vat channel log in place with lateral ridge dumps. (*Photo by Diana Emerson George*).

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Mammoth Cave Narrative Description Program

Mick Sutton and Sue Hagan

The Narrative Description program consists of two inter-related components; a gazetteer of Mammoth Cave place names, and a comprehensive description of the passages and features of the cave. During 1988, we have concentrated on the former, but substantial progress has been made on both fronts.

Gazetteer

During 1988, the assembly of a gazetteer of Mammoth Cave names hit a roadblock when the database exceeded the limited capacity of the Apple IIc computer being used for its assembly. The purchase by CRF of a Macintosh Plus computer and the use of a more sophisticated database allowed the job to continue. The database (Fourth Dimension) allows the entry of open ended text fields, thus permitting more background information to be stored, and making editing much easier. As the database has been transferred to the new program, it has also been updated and greatly expanded. At the beginning of the year, information had been assembled on 480 place names. At the end of 1988, we have generally more detailed information on 840 names. The range of information varies from the simple fact that a name appears on a map to a relatively detailed description of the feature and a background on the history of its name. All names, whether in current use or not, are recorded. A separate bibliographic database is being assembled in parallel with the gazetteer.

The information used to expand the gazetteer came from three types of sources:

- Published descriptions, ranging from early 19th century newspaper clippings to recent CRF trip reports.
- Trips into the cave to identify and write descriptions of named features.
- Consultation with the guide staff at Mammoth Cave National Park.

Assembly of this information is already proving to be of considerable use and interest, incorporating as it must a great deal of the history of the cave. As a spin-off, we have been able to straighten out some nomenclatural confusions, and to correct some mistakes. For example, the passage joining Ganter Avenue to Serpent Hall has been commonly called (at least among CRF cavers) "Fox Avenue", but this is almost certainly a misreading of the Kaemper map. There is good historic evidence that the true Fox Avenue is the cutaround off Main Cave at Wright's Rotunda - indeed, an examination of the passage revealed a "Sarah Fox" signature dated 1839. Likewise, "Engle Way" in Flint Ridge was found to be a corruption of the earlier "Ingalls Way". Many names have changed definitions over the years - for example, "Black Snake Avenue" originally referred to the westernmost part of what's now known as Ganter Avenue, the present Black Snake Avenue being originally "Arched Way". Even recent names are subject to this sort of confusion- "Gravel Avenue" in Flint Ridge, discovered c1957, has gone through some very contorted permutations.

The process of assembling data will continue through 1989. We estimate a minimum of 200 additional entries, and perhaps a good many more, will be needed to complete the document. We greatly appreciate the interest and assistance of the Mammoth Cave guide staff, particular Mr Lewis Cutliff.

Passage Description

The writing of passage descriptions takes a two-tiered approach. The main emphasis is on a systematic description of a particular area. During 1988, passages on which we have concentrated are those included in the Half-Day tour. Secondly, descriptions are assembled opportunistically for scattered passages and areas, when it is convenient to do so in combination with other projects, usually the mapping program. Areas for which we collected data in this way in 1988 include the Grund Trail (a complex series of pits and canyons in Flint Ridge) and Solitary Cave.

Half-Day Tour: A description of the passages from the Carmichael Entrance to the Frozen Niagara Entrance is in an advanced stage of production. Several special purpose trips were taken into the Kentucky Avenue area to write and refine passage descriptions. The descriptive work is intended to complement the 1:600 tour trail maps recently completed. We are collaborating with the cartographic program in devising ways to publish both maps and description. In addition, descriptive data was collected for the passages between Boone Avenue and Cathedral Domes, part of the Wild Cave tour.

Other Areas: A detailed description of the Grund Trail area is being prepared by Richard Zopf. The Grund Trail is a complex and poorly understand tangle of canyons and pits, and writing an adequate description is an essential step to understanding its speleogenesis. A detailed description of Solitary Cave and its associated side passages was prepared by Rick Olson as a corollary to a resurvey project. Descriptions of part of the eastern Fox Avenue and of the Mammoth River maze section were written during survey and sketch refinement trips.

Photography: A new aspect of the program in 1989 was the use of photography as an adjunct to the descriptive work. Photographers Harry Grover and Wayne Levin have been primarily responsible; we hope to expand the use of photography during 1989.

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Expedition to the Caves of Southern China

Rondal R. Bridgemon

After more than a year of correspondence and planning, the first American caving expedition to the People's Republic of China took place over the month of March, 1988. The expedition was a joint venture of the Cave Research Foundation, the Institute of Karst Geology (Guilin), and the Speleological Society of South China Normal University (Guangzhou). China contains more reserves of limestone than the rest of the world combined, but fewer than one percent of the country's thousands of caves have been thoroughly explored. Recent work by British and Belgian teams uncovered extensive cave systems in Guangxi, Guizhou, and Hubei provinces, but the CRF team was the first to search for caves in Guangdong and Hunan, and the first to work simultaneously with these two Chinese caving organization.

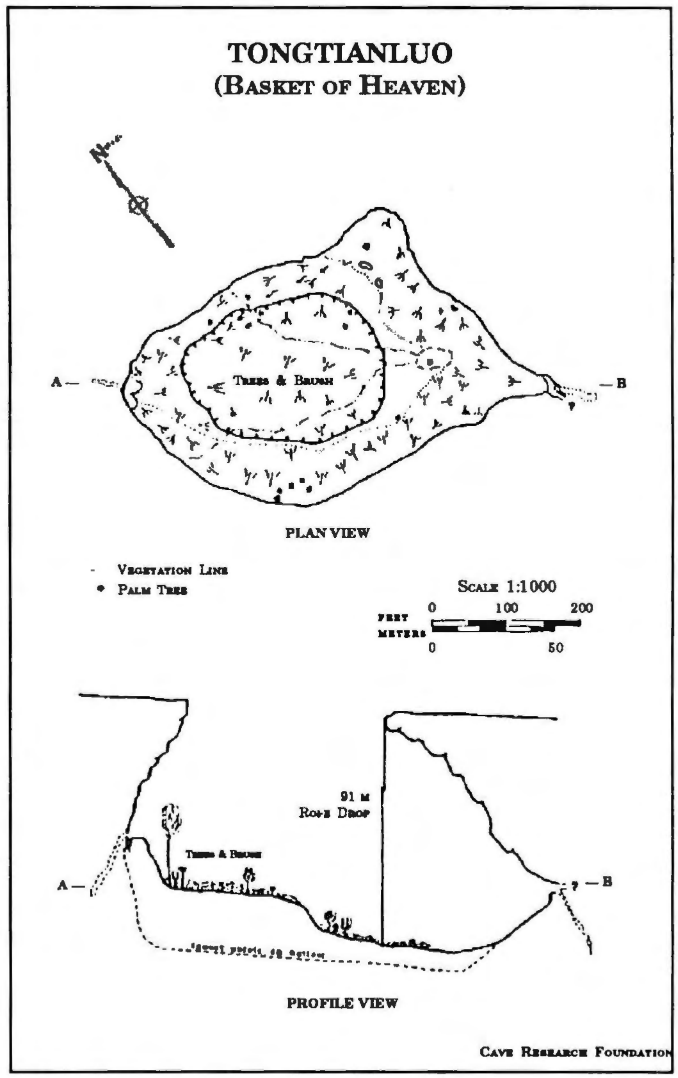

Figure 37: Map of Tongtianluo (Basket of Heaven) Cave, located in southern China.

Figure 38: Looking out of the entrance to Swallow Cave, Gaungdong, China. (*Photo by Ron Bridgemon*).

The objective of the expedition was threefold: 1) establish a long lasting friendship and scientific exchange between our organizations; 2) investigation of caves in the provinces of Guangdong, Hunan, and Guangxi; 3) and an exchange of information regarding cave research, cave development, and cave conservation.

Teams

The CRF expedition team was comprised of the following individuals:

Rondal R. Bridgemon	Leader
Robert H. Buecher	Asst Leader & Cartographer
W. Calvin Welbourn	Biologist
David H. Jagnow	Geologist
Ronal C. Kerbo	Funding/Equipment
Ian Baren	Translator
Phil Whitfield	Safety/Rescue
Jim Eller	Communications
Debbie Buecher	Cartography
James Goodbar	Vertical/Equipment
Michael R. Taylor	Writer
Ronald Simmons	Photographer

The Speleological Society of South China Normal University (SSSCNU) team was led by Prof. Mo Zhang Da and the Institute of Karst Geology (IKG) team was directed by Prof. Wang Xunyi. This cooperative venture would not have taken place or have been the success it was without the planning and assistance of these two fine friends.

Results

Sixteen caves were visited during the expedition and over eight kilometers of passage were surveyed. The area explored with the SSSCNU team was the Plum Blossom karst plateau located in the extreme northern portion of Guangdong Province. The spectacular Tongtianluo Shaft (Grain Basket Looking to Heaven) was the focus of work here. This 80 meter wide opening with an estimated 200 meter drop (see Figure 34) was discovered by the Chinese team a year previously but they lacked the equipment and experience to attempt such a vertical cave. The cave had been known by locals and received some publicity for the past three decades. The cave was particularly appealing to the scientists as a tall virgin forest was visible at the bottom, a stark contrast to the nearly denuded surface. Tongtianluo turned out to be a collapsed sink and only 100 meters deep; the solutional cave below never being reached (Figure 37). Other caves in the area did not reveal the large system we were looking for. Near

Figure 39: The waterfall at the "end" of Wanhuayan, Hunan, China. (*Photo by Ron Bridgemon*).

the end of our allotted time in Guangdong, teams were sent to Swallow Cave (Figure 38) which is located near the city of Ruyuan at a much lower elevation. The large entrance is situated at the bottom of a tremendous sink. Explorations revealed large rooms and underground rivers. Large cave entrances located above Swallow and trending down toward it suggest potential here for a truly large system.

The CRF team spent two days with SSSCNU team members familiarizing them with vertical equipment and practicing single-rope techniques. Basic caving gear, rope, and vertical gear were given to our Chinese hosts so that they could utilize their newly acquired skills.

The CRF and IKG teams concentrated their efforts on a karst area located a few kilometers southwest of Chengzhou in southern Hunan Province. Headquarters for the expedition was at the mouth of Wanhuayan Cave (Figurd 39). Approximately two kilometers of river passage have been developed as a premier tourist cave. The Chinese were interested in exploring and surveying a major side passage (the main river actually) in hopes of reaching its believed source, Songjadong. The two teams surveyed over 4 kilometers upstream in this beautifully decorated river passage until a large 10 meter waterfall was encountered. While Songjadong is indeed a major cave, a kilometer of survey here showed it trending away from Wanhuayan. Several other caves were entered but a connection was not made. The waterfall in Wanhuayan is certainly climable and a good deal a cave remains to be found within this interesting karst system.

In Guilin, information was exchanged on the operation of both the Cave Research Foundation and the Institute of Karst Geology. Since the CRF team had cave specialists from the National Park Service, the Bureau of Land Management, and British Columbia Parks, the Chinese were very interested in our views on the development of tourist caves, cave conservation practices, and protection of karst areas from pollution.

While no systematic collection was made, Dr. Welbourn observed cave fauna in all cave areas visited. The heavy use and deforestation of the surface lands appears to have caused the biota to be sparser than we are used to encountering. The study of the cave fauna in China is just beginning but the potential for study is tremendous.

The Future

Lasting friendships were developed as a result of this expedition. Plans have been formulated for future exchanges with the CRF hoping to return in 1990 to study caves in western China.

Acknowledgments

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Cave Books

"Cave Books" is the operating publications affiliate of the Foundation and operates under the jurisdiction of the Publications Committee. It is further divided into a Sales/Distribution function and a Publishing function.

The sales and distribution of Cave Books' publications materials, wholesale and retail, is being managed by:

Roger E. McClure .... Business Manager
Thomas A. Brucker .... Sales Manager
Rich Wolfert .... Retail Sales (for western areas)
Richard A. Watson .... Used and Small Lot Remainders.

Cave Books created a publishing initiative in 1983 with the goal of publishing one new cave book each year. Funding and management of this publishing effort will be handled independently of other internal publication efforts. The personnel managing publishing include:

Roger E. McClure .... Publisher
Richard A. Watson .... Editor
Karen Lindsley .... Production Manager
Thomas A. Brucker .... Wholesale Distributor

Initial funding for publishing was provided by $10,000 in donations from thirty Foundation personnel. The first book in the series, The Grand Kentucky Junction, was released in the spring of 1984. Revenue from its sales will support the cost of a second book, and so on, thereby providing self-sustaining funding for each following publication.

Publications represents a major and growing effort in the Foundation. We continue to solicit manuscripts and add new items to our inventory. Revenue from this effort provides primary support for many Foundation programs, including the Annual Report. Books published by Cave Books (Intl. Standard Book Number ISBN prefix 0-93978-) are now listed in Books in Print, and Cave Books is listed in the standard directories as a publishing house with interests in nonfiction and fiction having to do with caves, karst and speleology. The general address for Cave Books is 756 Harvard Ave., St. Louis, MO 63130 USA. A complete listing of books and maps available through Cave Books may be obtained by writing to this address.

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THE CAVE RESEARCH FOUNDATION

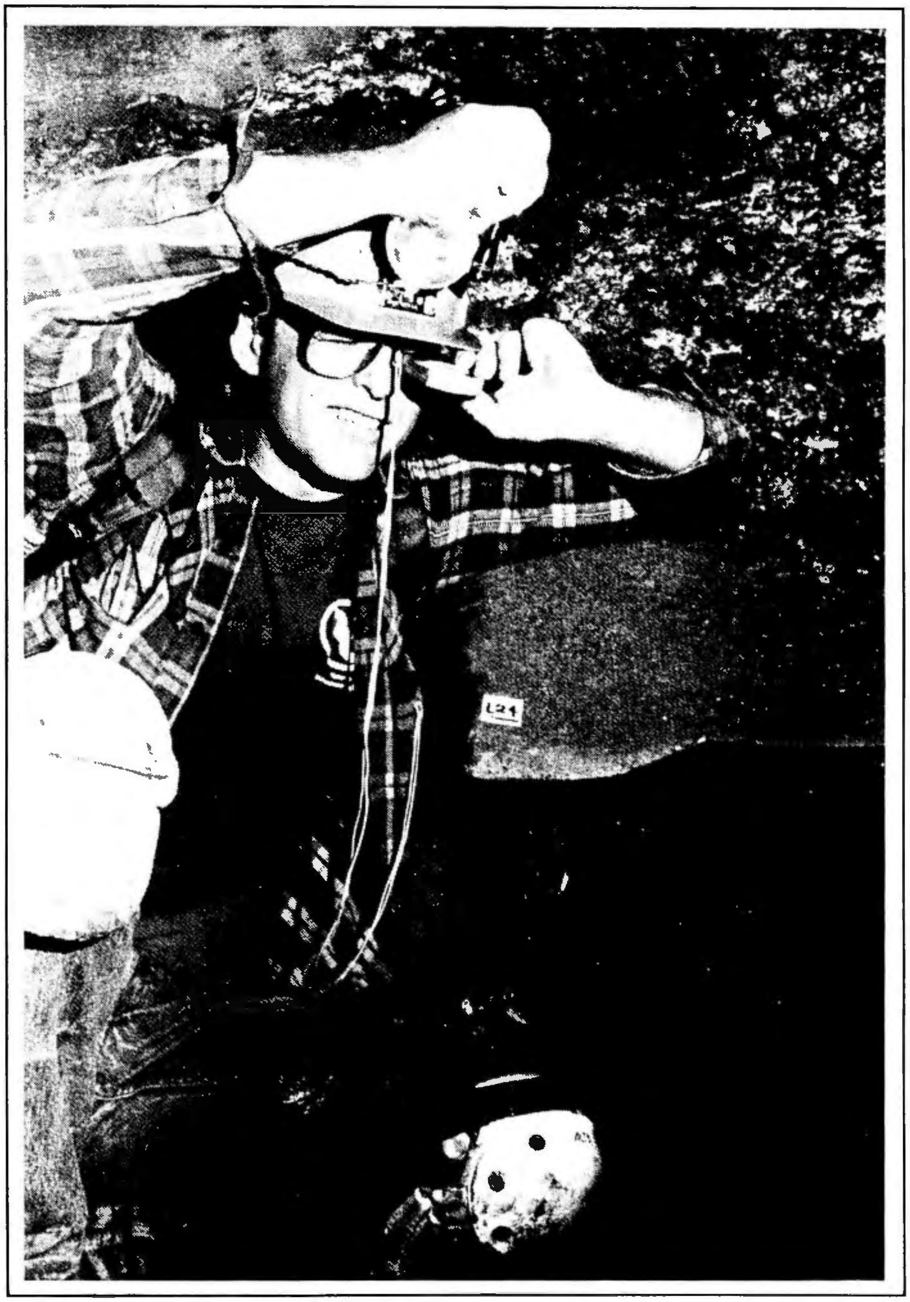

Figure 40: Randall Royal taking a reading with a Suunto compass while surveying in Fitton Cave, Arkansas. (*Photo by Pete Lindsley*).

CRF Management Structure 1988

Directors

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R. Pete Lindsley, Secretary
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Science Committee Chair .... John Tinsley
Conservation Committee Chairman .... Sarah G. Bishop
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- Cave Books Editor .... Richard Watson
- Cave Books Sales Manager .... Tom Brucker
- Cave Books Retail Sales .... Dave Hanson
- Cave Books Production Manager .... Karen Lindsley

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Mick Sutton
Annual Report Editor .... Karen Lindsley

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Personnel Officer .... Phil DiBlasi
Chief Cartographer .... R. Scott House
Medical Officer .... Stanley D. Sides
Safety Officer .... Bob Osborne
Supply Officer .... Jan Hemberger
Vertical Supplies Officer .... Dick Market
Log Keeper .... Gail Wagner
Field Station Maintenance .... Lee Snead

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Personnel Officers .... Dave Cowan, Sandra Cowan
Chief Cartographer .... Peter Bosted
Safety Officer .... Howard A. Hurtt
Science Officer .... John W. Hess
Field Station Maintenance .... Mike Spiess

Lava Beds National Monument (LABE)

Project Director, LABE .... Janet M. Sowers
Personnel Officer .... David Cowan
.... Sandra Cowan
Cartographer .... Mike Sims
.... Bruce W. Roger
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Marianne Russo, Bruce Roger, Ellen Benedict,
Mark Perkins, Steve Cross, Jim Nieland,
Libby Nieland, Charley Larson,
Dan Weinberg, Dave Cowan,
Bill Devereaux

Guadalupe Escarpment Area Management Personnel

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Personnel Officer .... Joli Eaton
Chief Cartographer .... Dave Dell
Finance and Supply Coordinator .... Bill Ziegler
Fieldl Station Maintenance .... Ron Kerbo
Hooter Editor .... Barabara amEnde

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Project Manager .... Pete Lindsley
Operations Manager .... Gary Schaecher
Chief Surveyor .... David Hoffman
Project Cartographers .... Gary R. Schaecher
Robert L. Taylor
John P. Brooks
Jack Regal

Operating Committees

The Foundation has established permanent committees to help conduct its business. All Committees are chaired by a Director of the Foundation.

Science Committee: coordinates the Foundation's diversified efforts in all areas of cave science. This includes the Fellowship Grant program, the Annual Report and interaction with scientists in all fields.

John C. Tinsley, Chairman	E. Calvin Alexander	William P. Bishop
Nicholas Crawford	David J. DesMarais	John W. Hess
Carol A. Hill	Francis Howarth	Thomas Kane
Kathleen H. Lavoie	Arthur N. Palmer	Margaret V. Palmer
Thomas L. Poulson	Patty Jo Watson	Ronald C. Wilson

Finance Committee: drafts Foundation budgets, provides advice to treasurer and seeks sources of funds to support Foundation programs. The Cave Research Foundation is a non-profit, tax-exempt organization recognized by the Internal Revenue Service under IRS Code, Sec 501 (c)(3) and assigned Federal Number 31-6052842. The primary source of funds for operation of the Foundation is derived from gifts, bequests and other private contributions. Revenue from the Foundation Endowment Fund, established in 1974, is used to support a Grants/Fellowship Program to support research in karst-related disciplines. Other sources of income are obtained from the sale of publications and limited contract projects. The Foundation is maintaining good financial stability with the growth and subsequent increased revenue from our Publications affiliate, Cave Books and the endowment Fund.

Roger E. McClure, Chairman/Treasurer	L. Kay Sides

Publications: provides policy guidance and direction on all Foundation matters, proposes publications initiatives, assists individuals/groups in accomplishing their publication goals, review/coordinates all proposed publications, insures all publications meet desired quality and format standards and represent the Foundation in a favorable manner. Publications activity has become a major force in CRF operations over recent years, primarily through the Foundation's publishing affiliate, Cave Books. The effort has been two-fold: first, to provide a service to CRF and the caving community; and second, to produce revenue to fund Foundation activities.

Roger E. McClure, Chairman	Thomas A. Brucker	Karen Lindsley
Richard Watson	Dave Hanson	

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