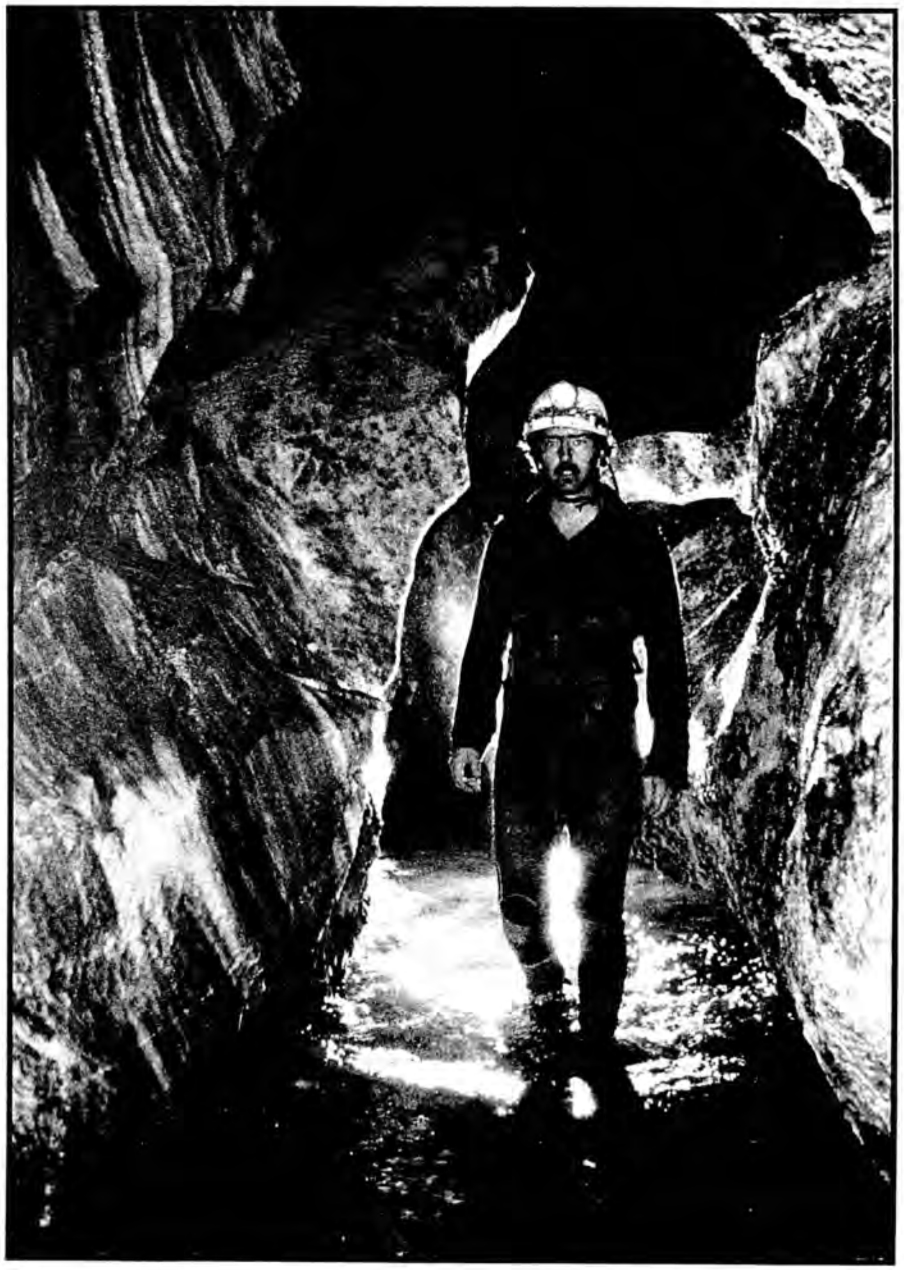
1991
ANNUAL REPORT



Cave Research Foundation

Cave Research Foundation

Annual Report 1991

Cave Research Foundation
1541 Peabody Avenue
Memphis, TN 38104-3831

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 (Figure 1): Glenn Malliet on a survey trip at the bottom of River Pit in Lilburn's Cave, California. (*Photo by Bill Frantz*).

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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 Also, many of the processes that formed the cave passages we travel are no longer active in these areas.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 heir 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 3581O, USA, for excellent advice and guidance for novice and experienced alike.

HIGHLIGHTS OF 1991

This year saw the renewal of our national Memorandum of Understanding with the U. S. National Park Service. Added this year were statements emphasizing the Foundation's commitment to assist the Service in their implementation of the federal Cave Resources Protection Act.

CRF personnel played an active part in Mammoth Cave National Park's 50-year celebration as well as the second annual Science Conference.

The Foundation was please to award a total of $5,000 for the Karst Fellowship and two grants. Details concerning the recipient researchers and their projects are included herein.

The Board of Directors commenced serious land owner negotiations for the purpose of acquiring property adjacent to Mammoth Cave National Park. The immediate goal of such a purchase is to have our own field facility. Long range goals include a national headquarters and a research center.

CRF the and the NSS sponsored another expedition to China. The 7-member team spent over a month locating and surveying caves in Guizhou Province in cooperation with scientists from Guizhou Normal University. Most of the funding for this trip was provided by Smithsonian Magazine. The area showed such promise that a major CRF expedition to the area is being organized for 1993.

Rondal R. Bridgemon
President, Cave Research Foundation

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Figure 2: Father Paul Whiteman checks his cave transmitter prior to sending it into Fitton Cave to mark radio locations. Note the inclinometer on the large surface receiver loop antenna which was used to estimate the transmitter depth below the surface location. (*Photo by Pete Lindsley*).

CARTOGRAPHY

Cartography at Lilburn Cave, California 1991

by Peter Bosted

The survey of Lilburn cave continued in 1991 with the mapping of 2065 ft. of new passage using 204 survey stations. An additional 700 feet of resurvey was needed to fix some loop closure problems. There were a total of 16 in-cave survey trips, spread roughly equally over the June, July, and Labor Day expeditions. Surface surveys were done to tie in some new small sinkholes near the cabin, and to measure the growth of the several year old Pebble Pile sinkhole. A diver explored Big Spring to a depth of about 70 ft. and surveyed a traverse length of 165 feet. Deeper penetration was blocked by sand.

The new passages in Lilburn were in the Attic area, above the Lake Room, near Davis Exit (the Mushroom Passage), near the Hex Room, and down River Pit. Although it is getting significantly harder to find new cave passage, as reflected by the shorter total compared to previous year, there are still many leads left to check out, especially in the wetter or muddier parts of the cave, such as River Pit and Hog Heaven. Several interesting climbs are also waiting to be done. The total cave length at the end of 1991 was 20.53 km (12.76 miles) using 5355 survey stations.

Progress was made on drawing up the 11 x 17" quadrangles of Lilburn. These portray different levels in more detail than is possible on the main map, including features such as cross sections, permanent survey station locations and elevations, and notes on features of interest. About 20 quads have been started in pencil and five have been made into finished products. Rather than the traditional ink and mylar the final quads are produced using the drawing program Canvas on a Mac IIsi computer. This program allows the use of multiple layers, so that several versions of the quad can be produced, depending on the layers chosen. The first layer has the line plot, the second layer the passage outline, the third layer the details and cross sections, the fourth layer has the border, north arrow, scale, and location, and the fifth layer is a filled-in version of the passage outline. The fifth layers are designed to be combined together from different quads so that the relationships among different levels can be visualized. So far, it has taken an average of two hours to produce each Canvas quad. With an estimated 50 more quads to go, it will take several years to complete this project.

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Lilburn Cave Diving Activities

by W. H. Farr

Labor Day Expedition

Exploration of the Lilburn resurgence at Big Springs in the 70's by Bill Kruise and others reached a limit of exploration at -170 feet depth and approximately 600 feet penetration, whereupon a major constriction was encountered. Access to the spring at that time was relatively easy as the road was still open, but limitations of equipment and technique inhibited further exploration.

The dive objective for the Labor Day expedition was to reach the constriction at the limit of exploration and pass it if possible. However, progress was halted by a sand blockage at -70 feet, a possible product of the Pebble Pile Creek sinkhole collapse and the drought conditions of the last several years. Here, passage previously sketched as six feet high by eight feet wide with one to two inches of sand on the floor was filled to within four inches of the ceiling.

During two dives, liquefaction of the sand floor near the constriction was observed to create a sand-slide that further occluded the passage, resulting in an increase in the local flow rate and a subsequent "sand-blow". This effect warrants further study as a possible chaotic trigger event for the flushing behavior observed at Big Springs.

All dives were conducted solo, not an unusual practice for initial sump exploration. A dry-suit and twin, fully independent, side-mounted Accurex composite tanks of 105 cubic foot capacity with air were utilized on all dives, with a 30 cubic foot tank of Nitrox-50 available for decompression. A survey to the current constriction was completed during the last dive, netting 170 feet of underwater passage to -70 feet depth. During this dive, a 15 cubic foot bottle of argon was used to provide the dry-suit fill gas with a noticeable decrease in thermal loss over the use of air as the fill gas, especially during decompression. Bühlmann 2000 m air tables were used to calculate decompression.

Columbus Day Expedition

The dive objective for the Columbus Day expedition was an initial reconnaissance of the South Seas sump pool, using tanks remaining from the Labor Day expedition.

Using a ¼ inch farmer-john style wetsuit with and additional 3/16 inch vest and two sidemount 30 cubic foot tanks, the initial dive explored the underwater extension of the now-flooded South Seas terminus, estimating the room to be 50 feet wide, 100 feet long, by 100 feet deep, although the maximum depth for the dive was limited to 50 feet due to the gas mixture (Nitrox-50) in one tank. A second submerged chamber was also entered from the southwest corner of the room, ascending from 30 feet to 12 feet depth, of undetermined size due to the silty conditions encountered (one foot visibility). Visibility in the main chamber was 20 to 50 feet.

A second dive the next day, using the same wetsuit and two 80 cubic foot tanks, located a passage 8 feet wide and 12 feet high heading down and south from the northeast corner of the room. Exploration was halted at -100 feet due to insufficient thermal protection at that depth. The passage could be seen continuing on and down beyond -130 feet depth. A survey out was attempted but abandoned due to excessive shivering. The 40 minute dive in 47°F water was chilly! Future dives will require use of a dry-suit.

The trip to and from the sump was quite reasonable, averaging 2-½ to 3 hours each way, fully loaded with gear. Note that all equipment was backpacked to/from the cabin for a total of 90 tank-miles. *Thanks to all the sherpas during both expeditions!!*

General Resources Inventory at Lava Beds National Monument

by Janet Sowers and Bill Devereaux

The project hit its stride this past year as we attempted to complete the inventory of twenty-four caves at Lava Beds National Monument. With the development of the inventory form and handbook behind us and nine caves under our belt, the remaining fifteen caves have gone fairly smoothly. This report will present some of our preliminary findings.

The general cave resources inventory is the third step in a three step process. The first is location of the cave and brief documentation using the Reconnaissance Cave Inventory Card, which provides spaces to record location, entrance characteristics, length, and contents. (A copy of this card is printed in the 1990 CRF Annual Report.) For many caves, especially the smaller or more remote caves, this will be all the documentation the cave receives. If the cave is seen to be significant or of some interest, the second step is to survey the cave and make a map.

The third step, and the subject of this report, is the General Resources Inventory, which is conducted on a subset of the caves mapped. This is a thorough documentation of the cave including its history, geologic features, biology, hydrology, cultural features, access problems, and degree of visitor impact. Resource ratings are assigned and recommendations for management made. The completed inventory form is nine pages in length.

A group of twenty-four caves with specific resource or use concerns was selected by CRF and monument staff for initial General Resources Inventory. After data for these twenty-four are collected, the monument will evaluate the data and add caves to the list as the need is perceived. Ideally, every cave would be thoroughly inventoried, but due to time and personnel limits, only a subset of the approximately 200 known caves are likely to be inventoried in this manner.

The General Cave Resources Inventory is a relatively time consuming process. For the average cave it takes two teams of three people each 6-8 hours to complete the field portion of the cave inventory. An additional four hours are required for two to three people to complete the office portion of the inventory, check the field data, and assign resource ratings and recommendations. Thus, the average cave requires about 60 person-hours of work. Small caves take much less time, and large caves much more time. In 1991, 712 person-hours were expended on this project (Figure 3).

Below are listed selected preliminary data, which together give a brief description of Lava Beds caves and a feel for the types of data we are collecting. All numbers are based on a total of 24 caves.

Characteristic	**No. of caves** (of 24)
More than one entrance	8
Cave over 500 feet long	16
Primarily intact lava tube	11
Primarily breakdown	14
Contains lava stalagmites	6
Contains lava stalactites	16
Woodrat nests in cave	12
Twilight zone over 200 feet	16
Slime (bacteria) on walls	16
Significant bat use (>100 bats)	5
Cave temperature above 50°F	4
Contains ice	10
Contains ice <100 sq. ft.	7
Prehistoric pictographs	2
Historic signatures or signs	18
Trail or rock work built by the Civilian Cons'vn Corps	11
Parking lot, cave sign, and trail to cave	8
Moderately to heavily impacted by visitors	12
Recommend special management	11

These data are a small fraction of those collected. Inventory data are being entered into a database structure written in Dbase III+ by Walter Sydoriak of the National Park Service. When the data entry is complete we will have a very powerful tool for research and cave management. For example, we could:
— List all caves that have owl nests in the entrance
— List caves with over 50 sq ft. of standing water
— List the direction the entrance faces for all caves having ferns at the entrance.
— List all caves located in Section 26, T23S, R5E.
— List caves in order of total length of passage.
— Make a table showing cave name, temperature, and number of bats present.

Figure 3: Kora Jordan taking notes at a cave entrance. (*Photo by Jonathan Jordan*).

The possibilities are endless!

Monument staff will begin using and evaluating the data this summer. We plan to train them in inventory procedures so they will understand how the data were collected and can conduct a cave inventory themselves if needed. If the information obtained seems worthy of the time spent, we look forward to inventorying caves on a continuing basis.

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Cave Mapping at Lava Beds National Monument

by Mike Sims and Bruce Rogers

The objectives of this project are to survey and map the caves that are expected to be of most significance for purposes of cave inventory and cave management. Caves of more than 100 feet in length or that have significant contents or features will be mapped. A minimum of twelve caves were to be mapped in the scope of this project.

To date, 55 caves have been surveyed as part of this project. Final maps have been completed for 24 caves. In addition, maps and sketches were made of two archaeological sites and detailed maps and sketches were made of pictograph caves. Field checks will be completed in early 1992 and final maps for all caves surveyed will be drawn and reproducible copies submitted to the National Park Service at the close of the mapping project in June 1992.

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Guadalupe Escarpment Programs

by Ron Bridgemon

Exploration, mapping, ridgewalking and biological/geological research are continuing at Carlsbad Caverns National Park (CaCa).

Seven Expeditions were scheduled at CaCa with a total of 8,159 feet of new survey and 3,926 JV-hours completed in Carlsbad Caverns. New areas in the New Mexico Room (North-west Pit Series), Mystery Room (Western Pit) and Guadalupe Room (62180 Room) are showing great promise. These areas contain unexplored/unmapped passage, boneyard and pits which we hope will move the existing known cave to the northwest, a trend in which, for the past decade, we have been trying to connect into "supposed missing part of Carlsbad Cavern". This trend also puts the Cavern in a line closer to Spider Cave, which is approximately 1 1/2 miles NW of Carlsbad Cavern.

Spider Cave also continues to give up more of its hidden passages. Approximately 3,300 feet Or new passage has been discovered and a promise of more unknown cave exists. Each Carlsbad expedition sends at least two (2) teams to check (un)known leads.

Ridgewalking in the Park boundaries has also shown promise. A few small caves have been located, but nothing significant has yet been found. We will continue in areas northwest of Lechuguilla Cave in the future.

Two (2) Guadalupe Mountains National Park (GUMO) expeditions were completed in 1991.

Ridgewalking, known cave relocating with steplogs, mapping and scientific research are continuing. Three (3) new caves were located and mapped extensively. The GUMO area is showing great promise for cave speleogenesis, along with the beauty and "stark" vertical relief which is common for this part Or the Guadalupe Mountains. We will continue with more expeditions (from Ship-on-the Desert) next year.

The Carlsbad Caverns Restoration Field Camp completed its week-long cleanup and restoration with a total restored area of 7,250 sq. ft. and 1,360 volunteer-hours. Areas in the Old Lunchroom, Big Room Junction and boneyard along visitors trail prior to entering the Big Room were completed.

Our Restoration Crew has gained a great deal of knowledge in the "how-to" (bring back) restore "blast-pit" areas, used to build the original visitors trail (circa 1929).

The Volunteers "blend" cave debris, clay and associated material from the surrounding area, to form new "cave floor", which pictorially resembles the areas "untrod (untouched)" by human encroachment. Areas, once covered by debris "blasted-out" for the elevator shafts excavation, are also being uncovered (near New Lunchroom). Rimstone dams, popcorn, stalagmites, pits and flowstone flooring are also being exposed by this excavation.

A restoration video has also been started and will be completed at next year's Field Camp (1992). The video has been authorized by the National Park Service and Carlsbad Cavern National Park, to be used as a interpretative video for both the visitor and cave related interest groups on "How to Restore a Cave".

CRF Future Plans: Guadalupe Escarpment and Lincoln National Forest

New ridgewalking, cave (location) hunting, biological and geological research will continue at CaCa and will also begin October, 1991 (1992 fiscal year) at Lincoln National Forest near Lincoln New Mexico. This will be a week long, campout expedition in and around areas near Capitan Peak, New Mexico.

Biological inventories, cave monitoring and exploration at Carlsbad Cavern National Park backcountry caves and caves in the Ft. Stanton (Ruidoso) and Chosa Draw, Carlsbad area New Mexico (in sponsorship by the Bureau of Land Management, Roswell and Carlsbad offices), will also be completed in fiscal 1992.

The 1992 CRF Guadalupe Escarpment Expedition Year plans to be one of the most extensive and intensively focused exploration/scientific research programs ever undertaken for the past few years. It will cover a larger (and broader) area of the Guadalupe, Lincoln and Capitan Mountains of New Mexico and Texas. It is hoped this program will broaden our knowledge of the speleogenesis and bio-environment/inventory of the caves in these areas.

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Missouri Cave Inventory and Mapping

by Scott House

As in the last two years, much of the CRF work in Missouri focused on the Mark Twain National Forest. Work trips outside of the Forest were either on private lands or were associated with two other major projects, one of which is finally completed.

Mark Twain National Forest

Several caves were mapped and inventoried as part of a project to do assessments and baseline data in a proposed lead mine study area. The study area is in southern Shannon and northern Oregon Counties in the heart of the southern Ozark karst region where several of the nation's largest springs have their recharge areas. (See article elsewhere.)

Two trips were taken to Davis Cave, Shannon County, a fairly complex cave with two entrances and over a thousand feet of passage. Camp House Cave in Oregon County (at 150 ft.) was surveyed as were McCormack Trail Pit, Tusher Hill Cave (Figure 4, 5), and Saltpeter Cave, all less than 200 ft. long and all in Oregon County. Four trips were taken to finish the survey of Kelly Hollow Cave (Oregon County) which totalled 6540 ft. of survey; two trips finished the survey of Barrett Spring Cave (Oregon County) at 3470 ft.

Elsewhere on the Forest four trips were taken to continue the survey of Cave Hollow Cave, an Indiana Bat hibernaculum in Iron County. The cave totals 4020 ft. but the survey is not yet finished.

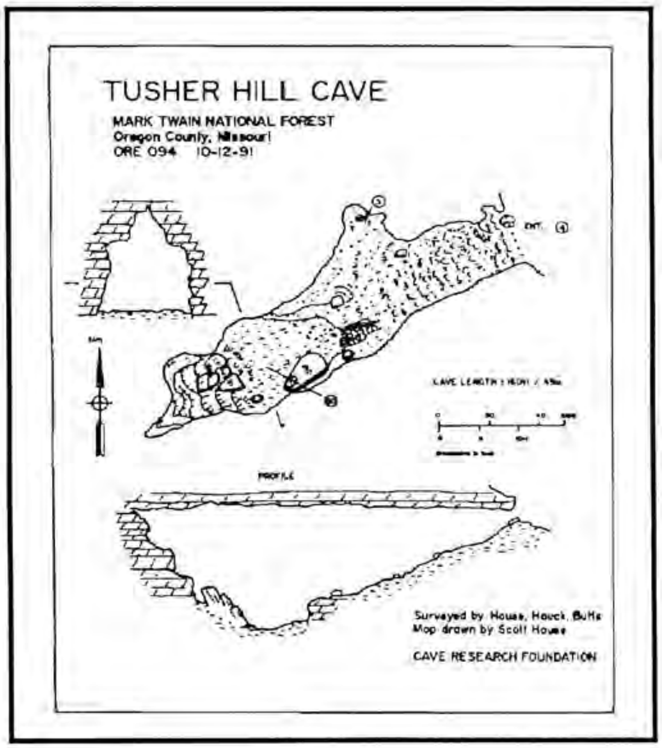

Figure 4: Tusher Hill Cave was surveyed as part of ongoing CRF work in the Mark Twain National Forest, Oregon County, Missouri.

The largest cave on the Forest, Douglas County's Still Spring Cave, continues to grow longer. Seven trips were taken to Still Spring this year and the survey length is now in excess of 15,000 ft. The new areas mapped are

Figure 5: Scott House doing a biological inventory "bug hunt" in Tusher Hill Cave, Oregon County, Missouri. (*Photo by Leonard Butts*).

far upstream but are most easily accessed via a dry crawlway. The upstream "end" has not yet been reached and a number of leads are still left in rooms and side passages.

Ozark National Scenic Riverways

The survey of Allens Branch Cave, a large stream cave in Shannon County, was completed this year. The cave, just outside of the authorized boundaries of the Riverways, sports the longest crawlway (a watercrawl) known in Missouri. Four trips, totalling 3400 ft. of survey, were taken this year and the cave's final surveyed length was nearly 14,000 ft. The cave is an important hydrologic and biologic resource and second in length among caves of Shannon County. The longest, Powder Mill Creek Cave, is within the Riverways boundaries but is on land owned by the Missouri Department of Conservation.

Missouri Department of Conservation

The survey of Powder Mill Creek Cave continued this year with seven trips fielded and 2700 ft. surveyed. Most of this was in the canyons of the Hellhole section where leads abound and virgin walking passage awaits a survey. This area of the cave is accessed via a very low watercrawl and an extremely tight squeeze both of which have managed to filter people out to a large degree. One trip continued the survey of the main passage, the Third Watercrawl, which still goes on. The surveyed length of the cave is now in excess of five miles and shows no signs of quitting in any of the three areas of the cave that leads remain.

Field work on the Great Scott Cave project was put off this year so that joint venturers could focus on completing other projects.

Personnel

Most of the above work was coordinated by Mick Sutton, Doug Baker, or Scott House. Other JV's who have helped with the drafting, or administrative duties include Bob Osburn, Jim Kaufmann, Sue Hagan, Paul Hauck, Steve Irvine, and Leonard Butts. Numerous others participated in the field work.

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Missouri Long Caves List

by Scott House and Doug Baker

This is a continuation of an ongoing attempt by the authors to document the long caves of Missouri. The differences in this year's list are that Still Spring Cave in Douglas County and Powder Mill Creek Cave in Shannon County moved up on the list and Allens Branch Cave appeared within the top twenty caves (Table 1). All of these were due to CRF survey efforts in those caves.

Most of the length information was gained by the authors through personal contact although some was obtained through files maintained jointly by the Missouri Department of Natural Resources and the Missouri Speleological Survey.

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Table 1: Twenty Longest Caves in Missouri

Rank	Cave	County	Acc. #	Length/ft	Miles	Kilo's
1	Crevice Cave	PRY	010	148902	28.2	45.4
2	Moore Cave System	PRY	045	87362	16.5	26.6
3	Mystery Cave System	PRY	054	83645	15.8	25.5
4	Rimstone River Cave	PRY	099	74110	14.0	22.6
5	Carroll Cave	CAM	001	59400	11.2	18.1
6	Devil's Icebox	BNE	001	29801	5.6	9.1
7	Powder Mill Creek Cave	SHN	021	26694	5.1	8.1
8	Piquet Cave	PUL	111	25681	4.9	7.8
9	Cameron Cave	MIO	002	24395	4.6	7.4
10	Meramec Caverns	FRA	004	21173	4.0	6.5
11	Hot Caverns	PRY	173	16400	3.1	5.0
12	Cathedral Cave	CFD	002	15639	3.0	4.8
13	Still Spring Cave	DGL	036	15176	2.9	4.6
14	Mark Twain Cave	MIO	001	14889	2.8	4.5
15	Great Scott Cave	WSH	001	14524	2.8	4.4
16	Allen Branch Cave	SHN	347	13897	2.6	4.2
17	Maple Leaf Cave	PRY	085	13334	2.5	4.1
18	Zahner Cave	PRY	557	11723	2.2	3.6
19	Meisner Crevice Cave	PRY	451	11616	2.2	3.5
20	Indian Creek Caverns	STN	013	11200	2.1	3.4

Counties: PRY=Prior; CAM=Camden; BNE=Boone; SHN=Shannon; PUL=Pulaski; MIO=Marion; FRA=Franklin; DGL=Douglas; CFD=Crawford; WSH=Washington; STN=Stone

Fitton Cave Survey Project - 1991

by Pete Lindsley

The goal of this special survey project is make a precision survey of Fitton Cave, Arkansas, located in the Buffalo National River and managed by the National Park Service. Six survey expeditions held during the year are supported by JV's primarily from Missouri, Oklahoma, Texas and Arkansas. We had an interesting year for 1991. Not only did we survey in various parts of Fitton Cave, but also accomplished some significant work topside as well as in Fitton Spring, a resurgence of the streams found in the cave.

Major emphasis was placed on surveys in the New Maze area, the complex three dimensional zone between Jurgen's Leap and the Tennouri Passage. The Inverted Bell Room is the joining point of several surveys leading to the Keyhole route to the Jurgen's Leap passage (via the "Flint Ridge this way" sign which points in the opposite direction), numerous pits (at least one of which still needs to be checked and surveyed in 1992), and at least two routes to the Tennouri Passage. Jack Regal is acting as the area cartographer for the New Maze area and will be providing us with additional tasks in 1992 to check tie points, provide cross sections, and clean up remaining passages.

A preliminary geological survey of selected front portions of the cave was made during the August expedition by Carol Hill, from Albuquerque. We hope to see Carol and several other "interested" geologists in the future; our preliminary quadrangle maps (which we updated in April, 1991) offer good opportunities for supporting future scientific work in Fitton Cave.

An October wet suit trip into Fitton Spring continued a survey started in 1979 by Ron Bridgemon, Bob and Debbie Buecher. The length of the surveyed part of Fitton Spring cave doubled with a push to "almost the bitter end". An interesting pit and breakdown area continue to intrigue us and another trip into the Spring is planned for summer 1992. Surface walks downstream (along Cecil Cove) from the Fitton Spring resurgence revealed another (smaller) spring and a shallow sinkhole above, but no hot leads suggesting more cave.

A major push was started at the Bat Cave entrance with surveys well past the "47 Foot Waterfall", which we found had shrunk to 41 feet since Jim Schermerhorn's late-1950's vintage map. Surveyors headed downstream towards the Chute area. Pushing upstream above the 5 Foot Waterfall, we discovered quite a bit more passage than the old timers remembered. Some very interesting layers of gravels were noted, indicating an ancient connection with Cecil Cove upstream from the Bat Cave entrance. Small surface fish and plant material also indicate a surface connection. The Bat Cave area is open only between May 15th and August 15th due to the endangered Indiana Bat (*Myotis sodalis*) that uses the Water Passage as a hibernating area.

Missouri cavers continued some rather complex passage cross sections in various parts of the cave. The East Passage is very complex when you look beyond the elephant footpath along the trunk, and the passage cross sections are going to be a major contribution to the quality of the map as well as enhancing our understanding of this multi-level cave. Arkansas cavers made their mark in Lower East Passage. The MOLES joined us for an expedition and started the Lower East Passage survey downstream from the T-Room. The survey was carried to a point just below the Needle's Eye.

A surface transit survey was made from Fitton Spring following the road up the hill. A tie point was established to the "1505" benchmark just off the road (at the top of the bench) and to the shallow sinks and pond just north of the same area. The survey line was carried to the Chestnut Cabin area where it is tied to several permanent stations. During the 4-day August expedition a true north alignment was made using a sun shot made with a transit. The survey line was also carried down the hill, via the road, and connected with Fitton entrance.

With all the interest in the surface survey and Fitton Spring, we began to speculate about correlations between the cave and surface features. Late in 1991 plans were made to perform a cave radio location at several points. A new topographic overlay was made at 500 feet to the inch over our existing survey database. Then, on the first weekend in 1992, Father Paul Wightman met a small crew at Fitton with a car full of cave radio gear. Radio locations were established over four locations in the cave, thanks to Chuck Bitting's help setting up preliminary locations the previous day. Locations were made over the T-Room Junction, the Needle's Eye, the Out Rock and the Jurgen's Leap benchmark. We now have an "Out Tree", which is directly over the Out Rock brass cap location. The Out Tree was tied to the surface benchmark (about 1000 feet north) via transit survey. Surface to cave depth triangulations with the radio gear indicated a cave depth of approximately 250-325 feet at the four locations.

We are limited to a maximum of 21 people in Fitton Cave at any one time, so if there are additional personnel at the expedition they will be assigned to survey duties in other caves or on the surface. It is very important to notify Pete Lindsley or Jack Regal, the Arkansas CRF Area Manager, one week (or more) prior to attending an expedition. This will also allow us to notify participants of any last minute road access problems or combination lock changes.

The 4-day summer expedition (usually in early August) is a good opportunity for scientists and "long distance" cavers to make long range plans to visit the cave. There are five other weekend expeditions usually scheduled from March through October. There are several potential projects including mineralogy, geology, hydrology and biology that will be of interest to qualified scientists and researchers. Interested primary investigators should contact Pete Lindsley, Project Manager, or Jack Regal, CRF Arkansas Area Manager, for additional information.

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Survey, Exploration, and Cartography of the Caves of Mammoth Cave National Park

by Scott House

Big discoveries up the river, perseverance on maps, and success with surface surveys marked the 1991 effort in Mammoth Cave National Park. Visible base map progress continues to be good and projects are moving to completion.

FIELD WORK

Morrison and Proctor Cave (Hawkins River Area)

A methodical, persistent pushing of all leads resulted in several miles of passage being discovered in 1991. Sometime previous, Lee Avenue (the L survey) and side passages off of the T Survey had been connected and over the last two years leads off of them were being carefully surveyed to their end. One of these led to a series of canyons that eventually connected up to a long tube now known as Coons Trail; this eventually reconnected to a side passage of the T Survey via a series of shafts. A long crawl off of Coons Trail broke out into a trunk similar in size and length to Cleaveland Avenue. This passage, named Kaemper Avenue after the cartographer of the 1908 Mammoth map, has side passages that continue and are still being surveyed (Figure 6). The new areas are rather remote but by utilizing the shaft route travel time to them has been cut to 3 - 4 hours from the Doyel Valley entrance.

Some limited resurvey and resketching was also done in the river this year as well as a number of leads in other areas off of the river proper.

Mammoth Cave Ridge

Mammoth Cave continues to receive the brunt of the survey effort with a substantial amount of resurvey done and 1.5 miles of new passages surveyed. The Kentucky Avenue sheet is virtually finished and mop-up work there centered on the Lower Robertson, Woodbury Pass and Sansoms Domes areas which accounted for over 2000 feet of new survey. Efforts on the Marion Avenue area were mostly resurvey but mop-up efforts uncovered more than 600 feet of new and overlooked passages with many leads left unexplored. Detailed lead-checking on the Cathedral Domes sheet (also nearing completion) turned up nearly 1600 feet of new passages. Resurvey and lead-checking work on the Stevenson Avenue and Roaring River areas turned up over 1600 feet of new survey and substantially improved the main line surveys (Figure 7). Work on the Alberts Dome sheet resulted in 500 feet of new survey along and off of Ganter Avenue and more than 1500 feet of new passages in and around the immediate area of Alberts Domes (Figure 8). Lastly, more than 4000 feet of Mystic River has been resurveyed in preparation for a new map sheet of that area.

Flint Ridge

Most of the 1991 work involved resurvey of major passages in the Colossal - Salts survey network. This resulted in nearly 14000 feet of high-quality replacement survey. In Unknown Cave, continued investigation of the Union Shaft and Unknown Pit areas turned up another 400 feet of new passages. One survey trip to Crystal Cave netted 100 feet of new survey near Ebb and Flow Falls.

Surface Surveys

A small amount of surface survey was done late in the year to tie in the entrances of Roppel to the system survey net. A level survey was run from a benchmark in the Rotunda to an azimuth mark outside the Historic Entrance that lacked a recorded elevation.

Other Caves in the Park

1991 very nearly saw the completion of the Running Branch Cave survey (Figure 9). Despite 500 feet of new survey being done leads remain to be finished. The cave is now about 1 mile in length. The long-dormant Johnson Cave project was revived and is nearly finished after two additional trips netted 500 feet of survey. A cave near Dennison Ferry was surveyed for more than 300 feet, two small sandstone caves on Joppa Ridge were mapped, and a cave on Joppa Ridge with a fault running through it was surveyed.

Length of the System

The Mammoth Cave System is now nearly 336 miles long. New mileage comes mostly from the Proctor/ Morrison area.

Cave	Miles	Kilometers
Colossal Cave	29.19	46.98
Crystal Cave	14.15	22.77
Salts Cave	19.50	31.38
Unknown Cave	45.40	73.06
Flint Ridge Total	**108.24**	**174.19**

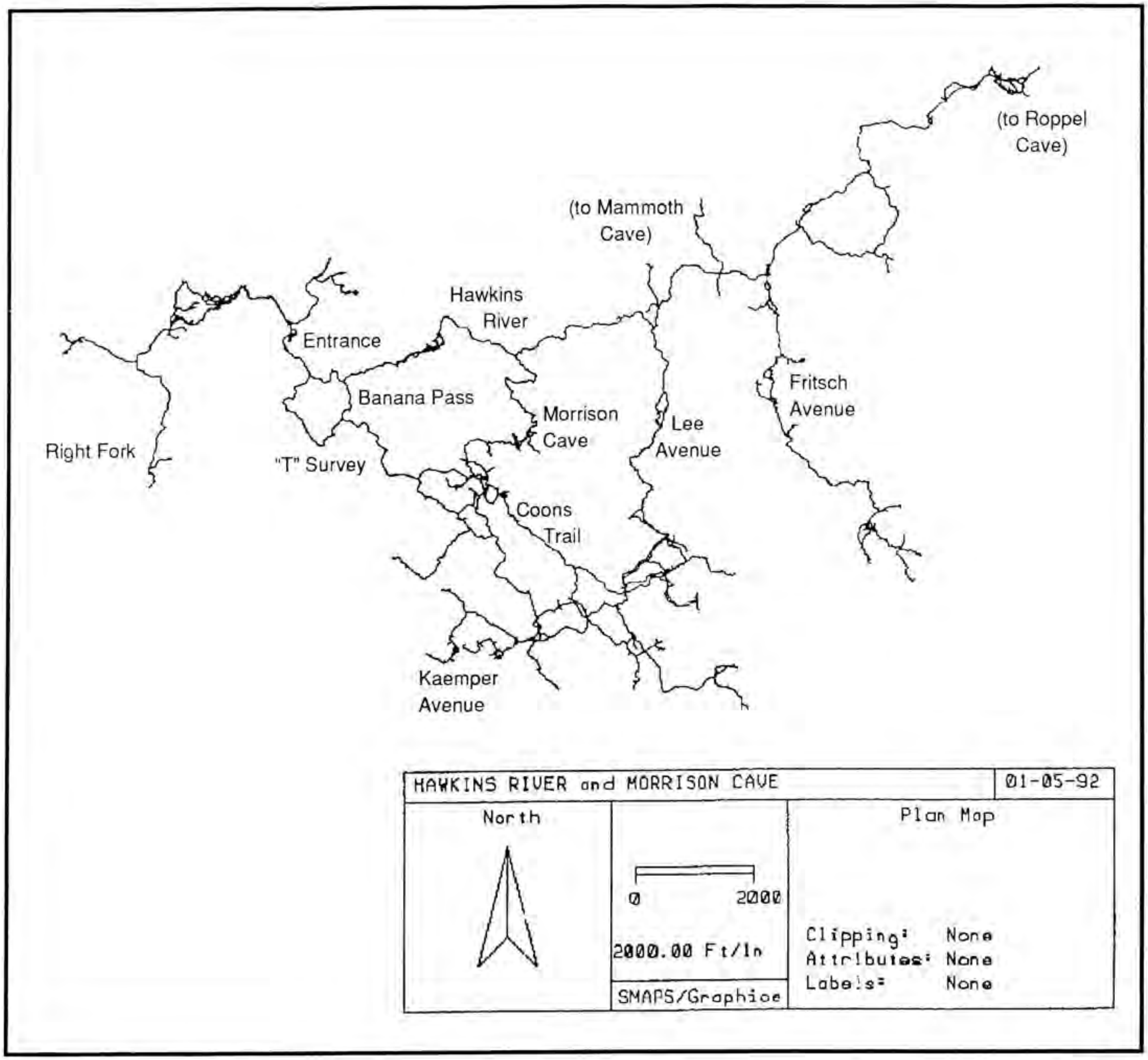

Figure 6: Computer-generated SMAPS map of the Hawkins River and Morrison Cave areas of Mammoth Cave.

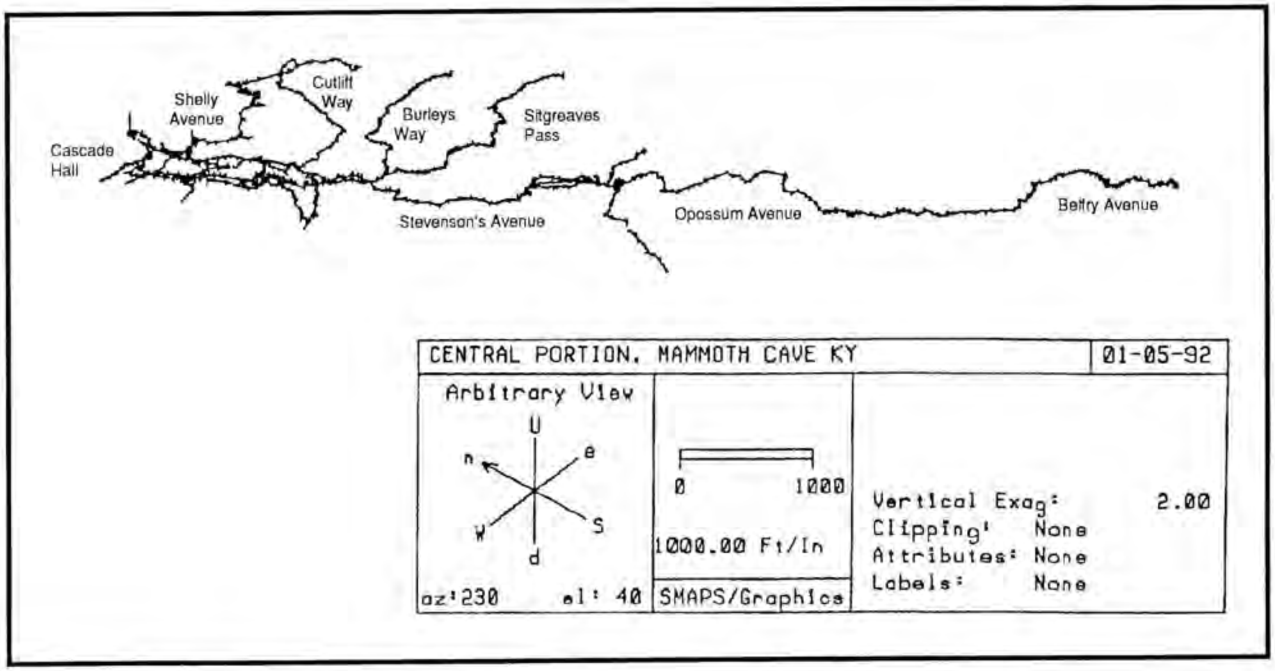

Figure 7: SMAPS-generated map of a central portion of Mammoth Cave.

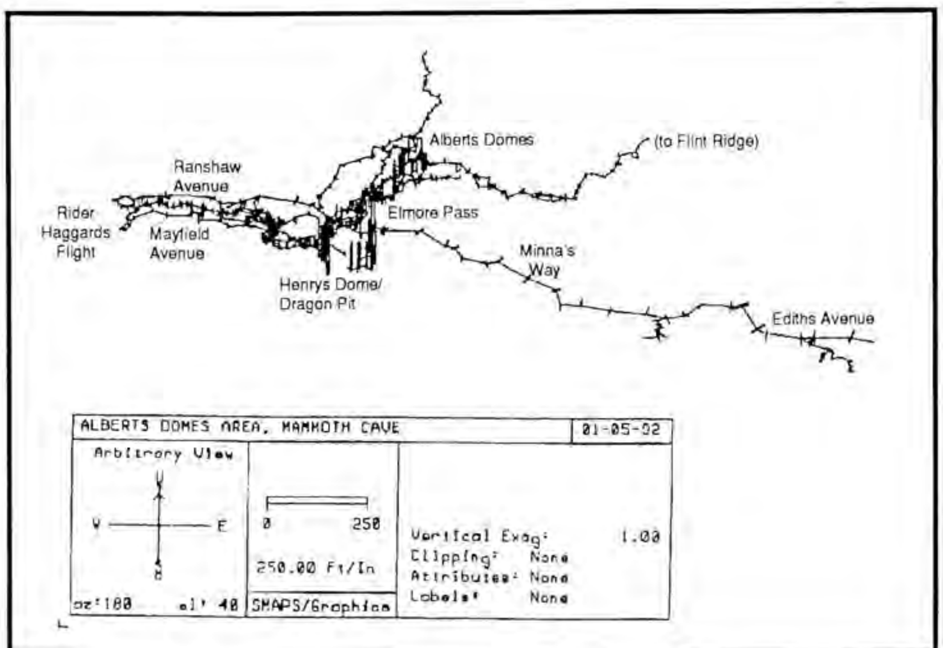

Figure 8: SMAPS-generated map of the Alberts Domes area of Mammoth Cave.

Figure 9: CRF Survey crew at the entrance of Running Branch Cave, Mammoth Cave National Park (*Photo by Scott House*).

Mammoth Cave	131.22	211.18
Proctor/ Morrison	37.17	59.82
Roppel Cave	59.16	95.21
System Total	**335.79**	**540.40**

This represents an increase of 7.95 miles over last years total. 7.08 miles of that is new survey and the rest (0.87 mile) represents mileage "found" in the data mass.

DATA REDUCTION

CRF's Cave Map Language (CML), developed by Mel Park, continues to improve our capabilities at reduction and archiving of a variety of survey data. This will be the Foundation's long-term data archival and retrieval system and it is increasingly sporting new features. Eventually we hope to rely on it for maintaining virtually all types of data records that could be obtained from the data set. Its reduction capabilities are very advanced and have been used for solving various difficult problems (such as fixing an area of Cathedral Domes.) Its major test was passed when it easily reduced the entire Roppel Cave net and its ability to read and decipher older data was proved through a reduction of southeastern Mammoth Cave (Cocklebur and East Bransford Avenues.)

At present, most of the data is entered through Doug Dotson's commercial SMAPS program and then "dumped" into CML for archiving. SMAPS is compatible with the park's GIS system (also developed by Dotson.) SMAPS does not always work on data in the way that we prefer and we have made numerous suggestions for improvement; a new version of SMAPS is coming out and we anticipate that CRF will be provided access to it through a park license.

The database of CRF survey books now has over 2800 entries and continues to be a very useful product. Additionally, CRF, the National Park Service (NPS) and the Central Kentucky Karst Coalition (CKKC) are working on a merger of survey book databases which will also include work done over the years by NPS teams. The eventual goal is to integrate all these available survey networks into one.

CARTOGRAPHY

Work continues on finishing some of our 1:600 base maps. The Kentucky Avenue sheet is essentially done and is being inked. The Cathedral Domes sheet is coming along nicely but awaits finishing of leads in difficult places. The Bishops Dome and Frozen Niagara sheets are in good shape and may actually be finished within the next year. The Cleaveland Avenue, Blue Springs Branch, and Marion Avenue sheets are all dependent on the underlying Mystic River section being finished before they are inked. Similarly, the Main Cave sheet is mostly done but awaits the finishing of Roaring River before it is completed. Most of the survey work on the Alberts Domes sheet is finished but drafting on that complex area is going to take some considerable time. The following list names various sheets in pencil on mylar format and the cartographer.

Sheet	Cartographer
Main Cave	Scott House
Blue Springs Branch	Roberta Burnes
Marion Avenue	Bob Osburn
Cleaveland Avenue	Doug Baker
Bishops Domes	Kevin Downs
Cathedral Domes	Scott House
Kentucky Avenue	Mick Sutton
Frozen Niagara	Scott House

Work on the river sheets is coming along nicely but with much new cave being found and the detailed maps providing new information on possible leads it is difficult to imagine being done with these any time soon. All of the sheets (4 so far) are being drawn by Bob Osburn.

In Flint Ridge the Pohl Avenue sheet (drawn by Paul Hauck), in all its complexity, continues to near completion as pencil on mylar. Several other sheets in Unknown Cave exist on vellum but will be redrawn as time permits. Crystal Cave, drawn by Art Palmer, continues to show progress. Work is now beginning on several sheets in the Colossal/Salts area as surface surveys are closed. Most of these will be drawn by Jim Borden while Upper Salts will be drawn by Mick Sutton.

Good progress has been made on other caves within the park. We still have a 25-year-old backlog of surveys that were never turned into final maps but we are catching up by training new cartographers. Several maps were completed and inked this year: Sturgeon Cave (Figure 10), Fault Cave, France Sandstone Cave #2, France Pit #2, Hunts Sink Pit, and Sloans Crossing Cave #3. Several more caves are currently finished (or nearly finished) and are being drafted by the indicated cartographers:

Cave	**Cartographer**
Mouse Cave	Bob Osburn
Rigdon Pit	B. Osburn and Phil Bodanza
Dickey Pit	B. Osburn and Phil Bodanza
Curd Cave	Jim Greer
Little Proctor	Jim Greer
Little Lower Proctor	Jim Greer
Lawton Cave	Jim Greer
Church Talus Cave	Tom Brucker
Johnson Cave	Gerry Estes
Cripple Creek Cave	Gerry Estes

The following are still being surveyed:

Running Branch Cave	Scott House
Crow/Hackett Caves	Scott House
Dry Prong Cave	Stan Sides
Long Cave	Tim Schafstall
Smith Valley Caves	Tim Schafstall

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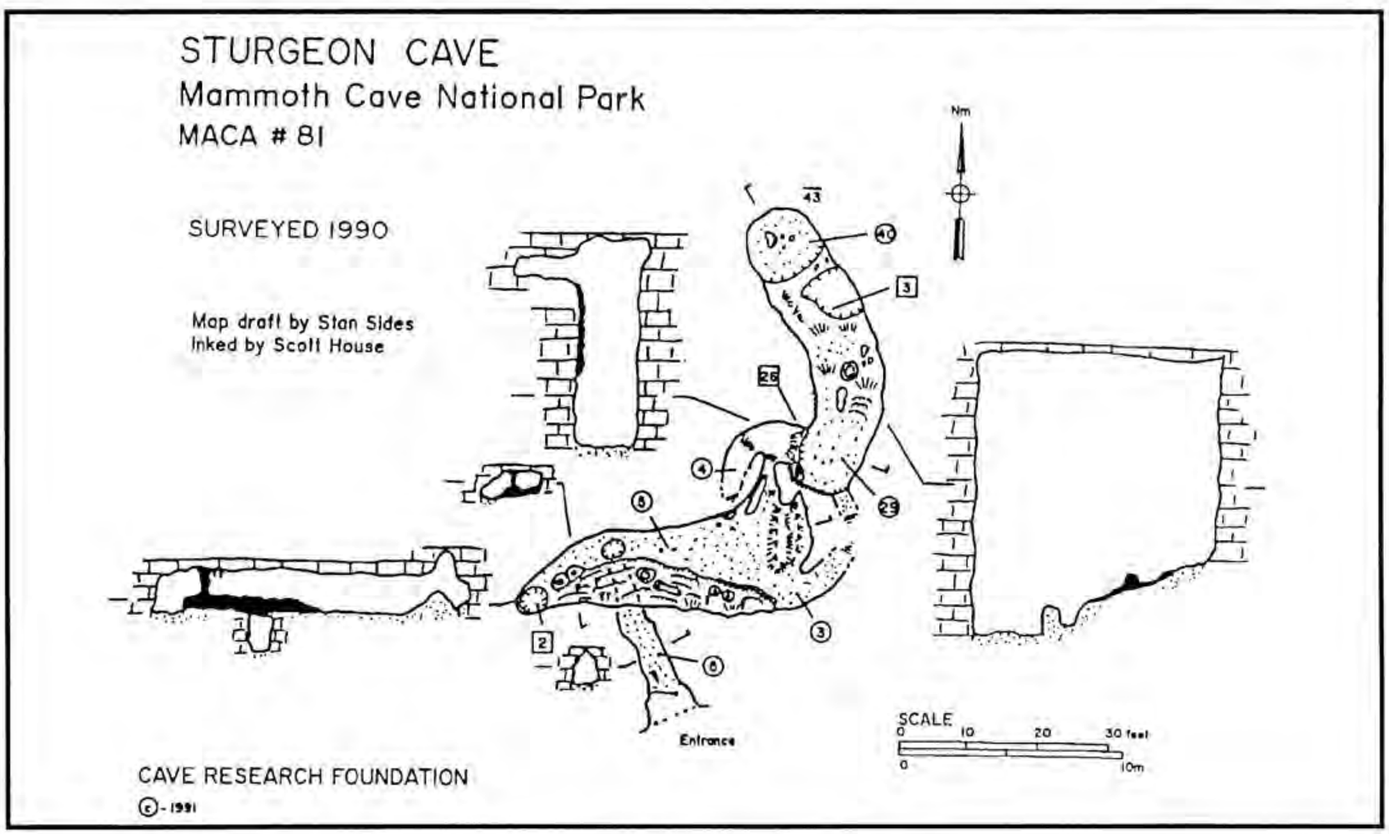

Figure 10: Completed map of Sturgeon Cave, located in Mammoth Cave National Park.

THE SCIENCES

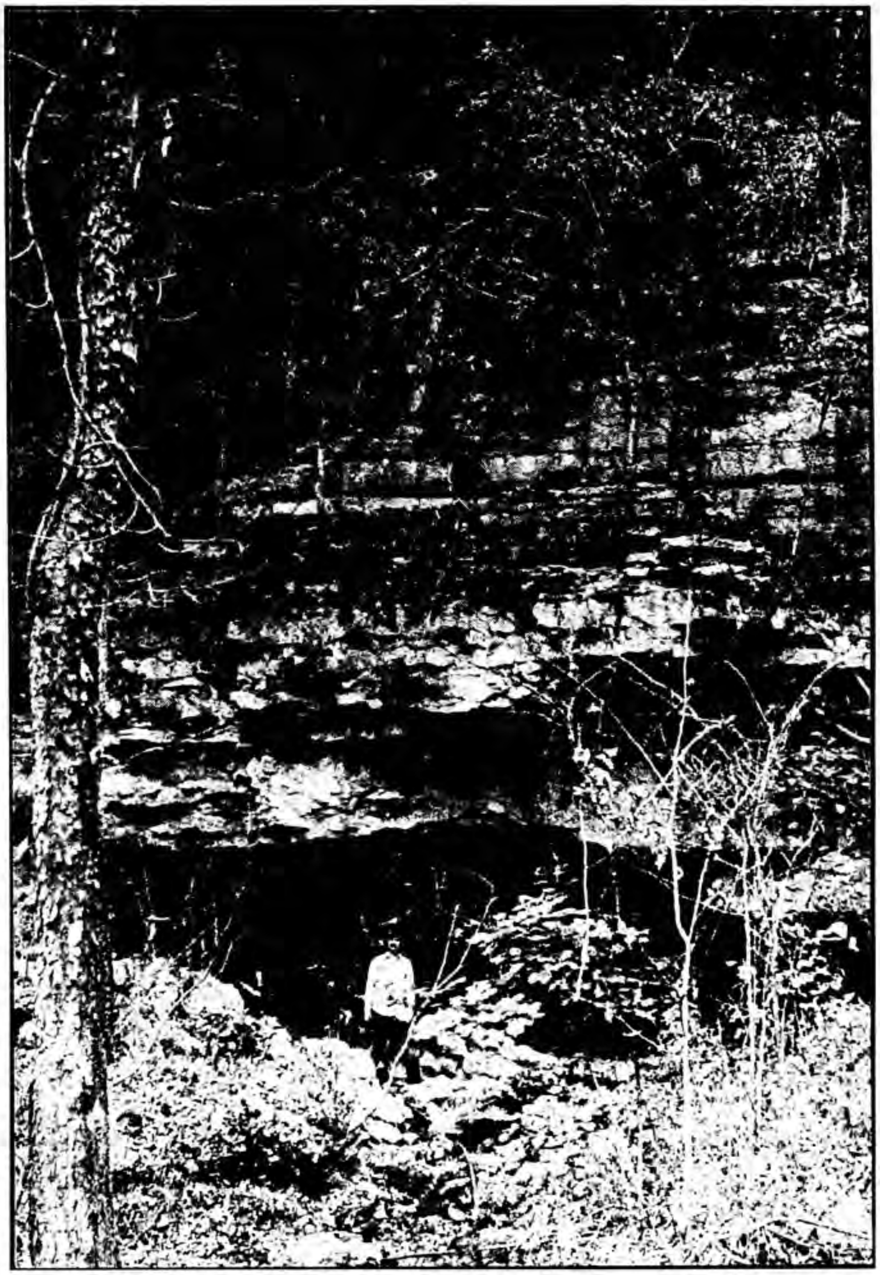

Figure 11: Caver Mike Pearson stands in the entrance to Fitton Spring Cave, the resurgence of Fitton Cave. (*Photo by Pete Lindsley*).

GEOSCIENCES

Geology and Mineralogy of Lava Tube Caves in Medicine Lake Volcano, California

by Bruce W. Rogers and Patricia H. Rice

Lava Beds National Monument is located on the northern shoulder of Medicine Lake volcano in the northeast comer of California, just south of the California-Oregon border. This Pleistocene to Holocene volcano is located in the southeastern portion of the Cascade Geomorphic Province where it adjoins the northern end of the Sierra Nevada-Klamath Mountains Province and the western edge of the Great Basin Province. The volcano has developed as a large shield over 33 km in diameter which attains an elevation of 2417 m. The north slope of the mountain is covered with bunch grasses and sage at the lower elevations adjacent to highly alkaline Tule Lake. Further up slope a mixed sage and pinyon pine-juniper woodland is present while a ponderosa and lodgepole pine forest covers the upper third of the volcano. Except for Medicine Lake, a caldera lake, and short-lived ephemeral streams, the volcano lacks permanent surface water. The eruptive rocks range in composition from basalt to rhyolite. More mafic flows and breccia comprise the bulk of the volcano with a thin covering of more silicic pumice, ash, and obsidian flows. Many of the basaltic lavas have compositionally changed throughout their eruptive history such that the earliest lava is lower in silica (approximately 47% SiO_2) and the latest more silicic (approximately 53% SiO_2). This results in lava fields which change composition along their length. The age of the exposed flows vary from very recent—85—to pre-Holocene—nearly 11,000 ybp.

In a zone on the northern flank of the volcano at approximately 1370 m in elevation are many cinder and composite cones from which long, tube-bearing lava flows emanate. Approximately 18% of the lava tubes, nearly 200 caves, are preserved in these flows and flow segments within the Monument. The caves range from short grottos under 10 m long to braided systems nearly 7 km long. Passage sizes range from 0.25 m high crawlways a meter wide to "dirigible passages" up to 25 m in diameter. Vertical pits up to 20 m deep are common where passages either stopped their way to the surface or collapse between overlying levels occurred. While breakdown is pervasive, small to large areas of original pahoehoe floors with differing surface textures are found in nearly every cave. Wall and roof decorations of lava glaze are very common even in the smallest of surface tubes (Figure 12). However, in many of the moderate- to large-sized caves, the consecutive collapse of the linings have removed most of the tube's original glaze.

Over 50 caves were sampled for secondary minerals. Nearly 120 samples 0.5 to 2 cc in volume were collected from the caves. These small samples were carefully removed from inconspicuous localities and brought to the U.S. Geological Survey's Menlo Park campus for laboratory analysis. In several cases samples from glaciers were collected, transported, and held under refrigerated until analysis could be performed. Many samples were not collected because these deposits were found to be extremely thin coatings—under 0.1 mm thick—on the cave walls. The samples that were collected were inspected under a microscope and then hand-picked to free them from impurities. Each sample was ground, combined with a sodium chloride internal standard, and applied to a glass slide in an acetone slurry. These slides were then scanned on a Norelco x-ray diffractometer at either 1° or 2°/minute. The resulting diffractograms were then interpreted by either comparison with known mineral diffractograms or indexing with the ASTM powder pattern indexes. Where warranted, some minerals were subjected to more detailed scans made at ¼°/minute. Several samples were mounted on aluminum targets, gold or carbon plated, and inspected under an electron microscope. EDAX qualitative analysis was made of several samples on the electron microscope as well.

Eleven secondary minerals, mineraloids, and rocks were found as speleothems in the Monument's caves. These include: ice - H_2O (common, especially seasonally), gypsum - $CaSO_4{\cdot}2H_2O$ (uncommon), calcite -

$CaCO_3$ (very common), two unnamed sulfite and sulfo-carbonate salts - $Na_2SO_3 \cdot 7H_2O$ and $Na \cdot SO_4 \cdot CO_3 \cdot nH_2O$ (rare), cristobalite - SiO_2 (very common), "amorphous" silica - SiO_2 (moderately common), uric acid (moderately common), amberat (common), and basalt and andesitic basalt (ubiquitous). The sources of these minerals are varied.

The silicate minerals have had their origins as leachates from the volcanic rocks. Basalt itself is a rather insoluble rock. Its feldspars only undergo solution to any extent in humid tropical environments where the ground water has both a high carbonic acid content and is at an elevated temperature. In the cool, arid Monument environment little of the basalt has undergone solution. Thus the weathering of the basalt has contributed little to the silicate cave minerals. Rather, the ubiquitous and unstable pumice and glassy volcanic ashes found carpeting the Monument's ground surface have readily weathered thus providing the silica needed for the formation of the silicate minerals found in the tubes. Slightly acidic ground water has dissolved the silica from the glass and ash in the soil, transported it into the tubes, and precipitated it out where it has formed the speleothems. It is probable that most of the silicate minerals have formed by simple evaporation of silica-bearing solutions rather than solution degassing and subsequent precipitation. Often silicate speleothems will show a pearlescent or dully iridescent surface color. The term "amorphous" silica is used here to refer to silica which has a crystallite size only slightly larger than an x-ray wave length. The characteristic cristobalite "bump" on an x-ray diffractogram of such material is usually very poorly defined indicating that the material, while crystalline, is exceedingly fine grained and almost beyond the resolving power of the x-ray diffractometer. Chemical analysis of this material has shown that it is composed of silica.

The calcite, gypsum, and unnamed salts have drawn their carbonate and sulfate from two sources. The ultimate sources of these minerals are the primary sulfate and carbonate minerals deposited as sublimate deposits associated with waning volcanism. Much of this carbonate and sulfate, however, has been reworked physiochemically and biogenically and has been deposited in the Tule Lake sediments. The Tule Lake Basin has had an over 600 m thick deposit of carbonate-rich sediment deposited on its lava floor. Although relatively large- scale leaching of this carbonate occurred when Tule Lake was filled, large amounts of carbonate and sulfate minerals remained in the basin. These have been deposited as rather fluffy, seasonal, lake side "beach rock" at the carbonate lake margins and as seams in the more porous volcanic rocks. Aeolian transport to the surrounding soils, solution by acid ground water, and redeposition as speleothems followed. In most of these cases it is probable that carbonic acid solution transport and subsequent degassing in the caves themselves played a more significant part in the speleothem deposition than in the simple evaporation of the solutions in the case of the silicate minerals.

Gypsum mineralization in the Monument's caves deserves special mention. Gypsum is found in several of the ice caves of the Monument as a very fine, fluffy, white to tan colored powder on ice deposits, usually flowstone. It appears that the gypsum is carried in solution in the ground water, then literally "squeezed" out of solution by the freezing of the water into ice. This phenomena has also been reported in several other lava tubes and gypsum caves in New Mexico. In the drier Monument caves the gypsum speleothems all appear old and undergoing corrosion, and, in several locations, adjacent redeposition. It may be that this gypsum is a relic of earlier, drier Holocene time. Gypsum can be identified in the field by its extreme softness (it can be scratched by one's fingernail) and its sugary texture on broken surfaces.

The two unnamed sulfo-carbonate and sulfite salts are only found in the deepest parts of several lava tubes in the Monument, most notably in Sentinel Cave. These caves are very wet, have high humidity, and are, at least seasonally, ice caves. It may be that these salts are only stable in very high humidity, low temperature environments.

Ice has been derived by freezing of ground water seeping into the lava tubes. Ice is present as permanent deposits in at least 20 caves and appears as seasonal decorations in a great number of caves. Many of the ice speleothems are grossly crystalline, indicating at least partial recrystallization. Seasonal forms in several caves are apparently unique to those caves. Necked stalactites resembling frozen "dripping" water droplets, stalactites of stacked 2 cm diameter hexagonal plates resembling stacks of pancakes, and other bizarre speleothems await further study. The grossly crystalline, variable diameter stalagmites will be reported on in an upcoming paper by Sims and Denbo. Studies have shown that the location, extent, and volume of both permanent and seasonal ice are strongly affected by the soil temperature, the relative ground water temperature, and the seasonally changing relative humidity of the cave atmosphere. There are some indications that some of the banded ice found in several glaciers may be relic ice from the last Pleistocene glacial epochs.

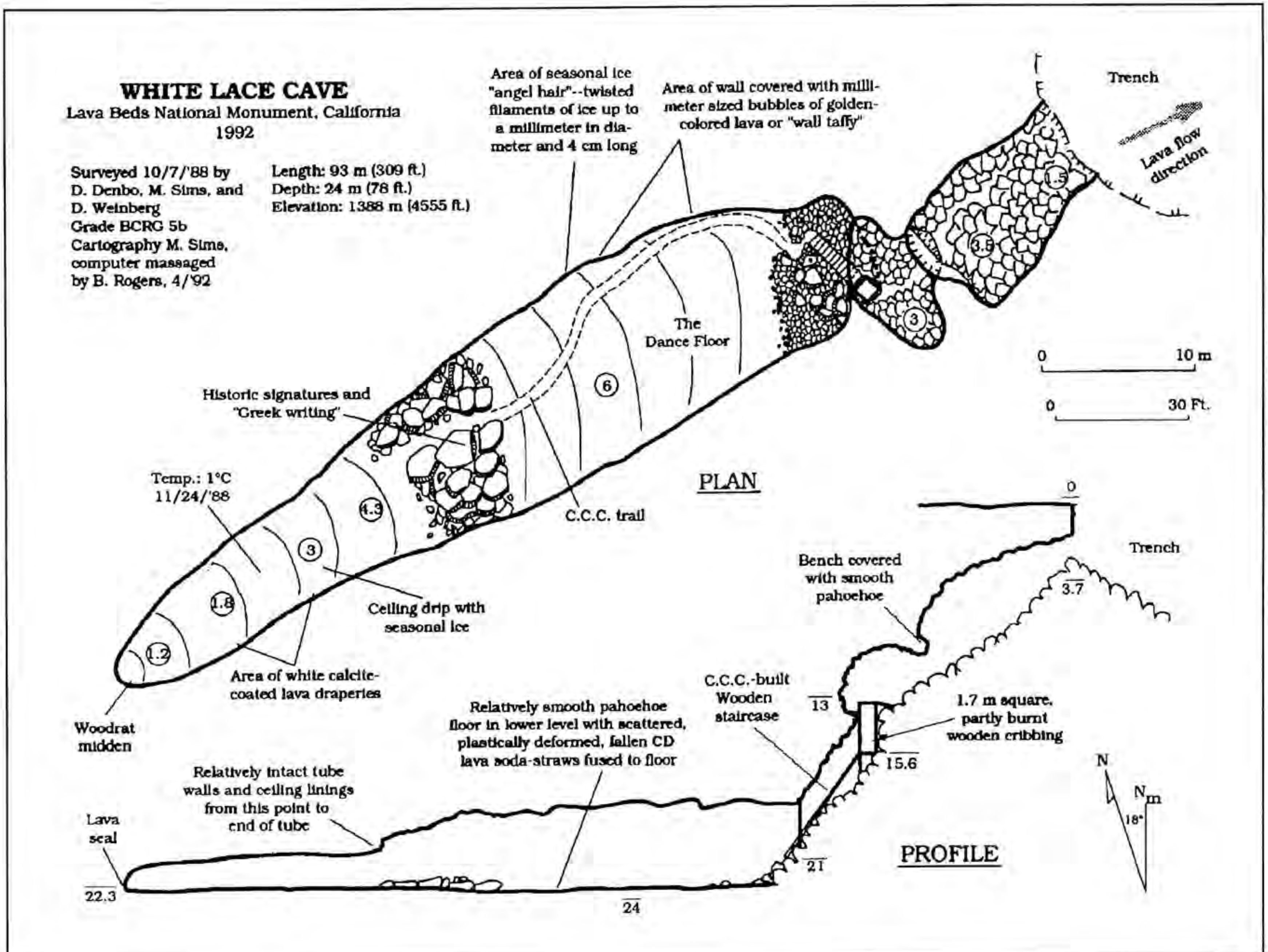

Figure 12: Map of White Lace Cave, Lava Beds National Monument, California.

The uric acid and amberat speleothems found in the Monument's caves are located in relatively dry and biologically active caves and have resulted from mostly either avian or rodent activity. Basalt and andesitic basalt speleothems are a problematic group. While they usually form after the primary cave passages form, they are also formed during the passages' consolidation. Thus they can be considered as either primary features or as speleothems. In either case they form from partial melting of the ceilings and walls of the cave due to increased heating of the linings by gasses coursing through the caves or from small driblets of invading magma.

Reports of elemental sulfur crystals coating walls of such caves as Golden Dome, Hopkins Chocolate, and the back parts of The Catacombs are actually thin films of lava tube slime. The several types of bacteria present on the walls are hydrophobic thus forcing the seepage or condensate water present to bead on the uncolonized parts of the walls. The light from the explorer's lamp is reflected such that the slime appears as a golden or silver coating on the cave walls. No native elements are known to occur in the Monuments caves.

There is a rough zonation of the secondary mineralization in the lava tubes controlled primarily by elevation. This zonation appears to follow the availability of ground water, soil composition, and vegetation patterns. On the flanks of the volcano, the less mobile amorphous silica mineraloid forms in the caves higher on the volcano where soils are well developed and the rainfall—and thus resulting ground water—is greater. The higher elevation, more humid caves both discourage evaporation of the seeping ground water, thus retarding deposition of speleothems, and allow greater leaching and transport of the minerals held in solution. The more mobile silicate, carbonate, and sulfate minerals are found further down slope in areas of thinner soils and less rainfall, thus less ground water. The drier cave environment here allows greater evaporation and therefore more speleothem deposition. It also allows preservation of some of the more soluble minerals such as gypsum and mineraloids such as uric acid. Although one might expect more ice to form in higher, thus colder lava tubes, ice speleothems are found throughout the elevational range of the caves studied. It appears that availability of ground water and cave configuration are more important than elevation. Basalt and andesitic basalt speleothems are also found throughout the cave areas studied.

The speleothems present in the lava tubes include coatings, crusts, columns, conulites, coralloids of many differing types, crystals, draperies, flowstone, helictites, moonmilk, spathites, stalactites of several differing types, and stalagmites. The speleothems are predominantly caused by either permanent or seasonal drips or seepage films.

Nearly every cave in the Monument will show some development of secondary mineral coatings. In several caves such as Craig Cave, the walls and ceilings are nearly completely covered with white films. The bulk of these coatings are either calcite, amorphous silica, or, to a lesser degree, cristobalite. Many of the coatings are very thin, some only fractions of a millimeter thick. They are often associated with seasonal seeps on the walls or ceilings.

Crusts of calcite, gypsum, or the unnamed salts are present throughout the Monument. The crusts of gypsum in such caves as Tichner's Cave and, to a lesser degree, calcite, are relatively thick, some approaching a centimeter in thickness. The other minerals generally form thinner crusts of several millimeters in thickness.

Columns composed of ice are seasonally present in many of the Monument caves. In several of the glaciers, such as Crystal Cave, ice forms massive columns up to a meter in diameter and several meters high. Some of these grow to a critical size then undergo either ablation or catastrophic collapse.

On the floor of Fern Cave are several patches of fine silt deposited by infiltration through ceiling cracks. Dripping water has also drilled small, circular pits into these floor deposits. The surface of these sediments and the linings of the pits have been armored by coatings of amorphous silica up to several millimeters thick. The drip pits themselves are called conulites.

A great variety of coralloids are present in the caves in the Monument. The forms range from the common bunches of grapes to miniature broccoli to mushrooms and peas-on-a-stalk. In a few instances, such as in The Catacombs, the "heads" never form and unusual straight, single fingers form. In other caves, such as Pumice Railway Cave, headless multi-stalked forms result. The great majority of these forms are stalked variants rather than mammiform in shape. None of the coralloids present attain great size. Most forms present are in the tens of millimeters to centimeter-in-height size. Some of the coralloids in the Monument's caves apparently show a range of forms depending on the developmental stage of the speleothem. After initial deposition as a bud on an irregularity of the lava substrate, the speleothem grows into a branched form. The angles of the "branches" and the "trunk" of the form commonly reflect known crystallographic structural elements. As these branches enlarge they begin to hold small droplets of seepage water and thus accelerate their growth. As the overall diameter of the coralloid approaches the limits of an ordinary water drop—approximately 2 to 5 mm in diameter—the ends of the coralloids begin to thicken. This happens because the maximum deposition will be at the surface of the water droplet either where it loses its dissolved gasses and must then deposit its load of minerals or where simple evaporation is greatest thus causing the precipitation of the carried minerals. As deposition continues, the coralloid forms resemble miniature stalks of broccoli. Eventually the interstices will fill in and a hemispherical rounded or mushroom-shaped coralloid will result.

Crystals are nowhere common. The most well developed crystals are those composed of ice. In Crystal Ice Cave are stalactites covered with aborescent acicular ice crystals. Stalactites made of stacks of 1 to 3 cm diameter hexagonal crystal plates up to 14 cm long have been recorded. In the central canal of some partly hollow, tubular lavacicles amber-colored crystals of plagioclase 1 to 2 mm long have formed. In several caves deposits of amberat show incipient crystal faces on their surfaces.

Draperies are sparingly present in the Monument's caves. Ice draperies are most common and attain their maxima in late summer when ground water is most abundant. Draperies of tan-colored cristobalite several tens of centimeters long are known from Fern Cave.

Flowstone is very sparsely present throughout the Monument. It intergrades with coatings and crusts of calcite, cristobalite, and gypsum. The largest concentrations of flowstone are comprised of ice and are found in the major glaciers such as Crystal Ice Cave. In several other minor glaciers ice flowstone is apparently old enough to have recrystallized into large prismatic crystals up to 3 cm in diameter. A small sheet of gypsum flowstone, with coralloids and stalactites, has formed in Heppes Grotto.

Helictites are found in lava tubes with intact ceilings. They are composed of lava, are remarkably intricate in form, and are sometimes at least partly hollow. Their exact method of development is still imperfectly understood. They apparently have formed when pockets of liquid magma collect behind the cooling skin of the lava tube. In the pocket of liquid lava degassing occurs and the increased gas pressure forces the lava out through the surface of the tube lining. They grow relatively fast, propelled from the base as in squeezing toothpaste from a tube. Their beaded surfaces probably reflects the varying amount of lava supplied to the helictites.

Moonmilk is a soft, cream-cheese-like deposit when wet and similar to dry cake frosting when dehydrated. In the Monument moonmilk is present in several caves and is comprised of extremely fine-grained crystals of either calcite, cristobalite, or either of the unnamed salts. The calcite has apparently nucleated on *Actinomycetes hypha*, forming soft masses of white micro-crystals. In Fern Cave a 12 mm thick sheet of tan-colored moonmilk nearly 1.5 meters square is composed of cristobalite. Moss rootlets and fungi hypha permeate the moonmilk and apparently serve as nucleation centers for the growth of the cristobalite.

In several caves, notably Post Office Cave and The Catacombs, are cristobalite spathites. These speleothems appear similar to stalactites but are composed of several nested, leaf-like tubular blades. They have formed along ceiling cracks where silica-rich water has dripped into the cave.

Stalactites of several types have formed in the Monument's caves. Tubular stalactites of basalt are most common. These "soda straws" form much like lava helictites except that the flow is much more even so that the resulting stalactite is relatively uniform in diameter, relatively straight, and may grow to lengths of several tens of centimeters. They are usually at least partially hollow. Craig, Valentine, Arch, Silver, and Post Office Caves have large numbers of these forms. Cristobalite forms many stubby—3 to 5 mm in diameter—and short—up to 3 cm long, white to tan-colored soda straws. These form from degassing of silica-rich solutions and subsequent deposition of the minerals. Often they will form on the end of a similarly sized lava soda straw stalactite. They have been observed in The Catacombs, Valentine, Craig, Post Office, and other caves. Gypsum has formed a few stubby soda straw stalactites in Heppes Grotto.

Tapered stalactites are only found in a few caves. These stalactites are usually cristobalite although several of calcite are known. In the Venturi of Post Office Cave a small number of these stalactites are present. Basalt forms a similar-looking type known as a lavacicle. It differs, however, in having a base which smoothly contours into the ceiling of the tube. Also similar are the slightly webbed-base, bladed shark's tooth stalactites. Both of these basaltic stalactites are primary features, not secondary, solution-derived forms.

Stalagmites of ice are common in the Monument, whereas basalt only forms stalagmites sparingly. Forms comprised of ice are present in many caves and may grow and ablate seasonally. They commonly intergrade with flowstone. Basalt has formed both low, conical "spattermites" and relatively tall, uniform diameter drip stalagmites in several caves. These stalagmites are usually composed of 5 to 15 mm diameter droplets of lava piled on each other so the stalagmite looks like a remarkably uniform bunch of small grapes. Stalagmites in Post Office and Craig Caves are perhaps the best of both types in the Monument.

The color of the speleothems in the Monument are a result of several processes. Calcite, cristobalite, amorphous silica, gypsum, and the unnamed salts are usually white. Traces of soil humic and fluvic acids, iron oxides, and included clay particles, in descending order of importance, all add colors to these minerals. The blue wall coatings in Blue Grotto and in Pumice Railway Cave are actually thin clay films which are gray to slightly bluish in color. Most silicate speleothems can be tentatively identified in the field by their slightly pearlescent luster. This is the result of the surface being comprised of many small spherical crystallites packed tightly together, the same structure as the outer surface of natural pearls and common reflective highway paint. Basalt speleothems may be colored green, mustard yellow, orange, or red. The green tends to indicate either a high olivine crystal content or a large amount of ferric iron or that the form is very thin, thus allowing light to be partly transmitted through the speleothem. The yellow, orange, and red colors indicate that the cave passage was open to the outside at the time the speleothems were forming and that small amounts of free oxygen were present to oxidize their surfaces. The uric acid stalactites and flowstone tend to be white or, in some cases, slightly pinkish. Amberat is usually some shade of brown or dull to very shiny black. In rare instances it can be bright orange, yellow, or even red.

Although virtually no systematic atmospheric studies have been made in the Monuments caves, save Crystal Ice Cave, as a result of this preliminary mineral inventory we can draw some conclusions about what sort of minerals one might expect in the various cave environments present in the Monument. In very cold and wet lava tubes or glaciers one might expect ice, the unnamed sulfite and sulfo-carbonate salts, calcite, gypsum, and amorphous silica to be present. Cristobalite would be much more common as coralloids than calcite or amorphous silica. The unnamed salts could be expected as crusts and moonmilk. Powder found on ice speleothems or in locations where ice floors have formed would commonly be calcite or cristobalite, less commonly, gypsum. In the slightly warmer but equally wet caves nearly any mineral might be found. In the warmer, drier caves coralloids composed of cristobalite would be more common than calcite which, in turn, would be more common than amorphous silica. Crusts of gypsum and calcite would be equally common. Seasonally, ice could be expected nearly anywhere.

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Dust Monitoring and Sedimentology of Selected Caves at Lava Beds National Monument

by John Tinsley, Ken Miller, and Robert Johnson

Skull Cave, a frequently-visited lava tube at Lava Beds National Monument (LABE), appears to be accumulating clastic sediment in consequence of human visitation. The pattern of dust accumulation as measured by an array of collectors within the cave indicates that the rate and quantity of particulate matter collected varies inversely with the distance from the trail tread and the distance above the trail tread. The trail tread was constructed years ago and consists of a vitric pumice which tends to pulverize under the footfalls of visitors. While the tread makes for smooth walking, the fine particulates are suspended as dust and are dispersed to settle on flat or sloping surfaces throughout the cave. Near the trail, the coating of dust discolors the lava and is an unsightly feature of the otherwise impressive former conduit for lava of Medicine Lake volcano.

Possible remedies include removal of the present trail materials and reconstructing the trail using crushed basalt or other material which will not pulverize to aerosolic dust under the footfalls of visitors. With the source of the particulates eliminated, cleaning of the rock faces adjacent to the trail would successfully restore a more pristine appearance to this remarkable feature of Lava Beds National Monument

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Flow Behavior of Big Spring, Redwood Canyon Karst Area, Kings Canyon National Park, California

by John W. Hess, Linda Urzendowski, Michael Spiess, John C. Tinsley and Brad F. Lyles

Introduction

Hydrogeologic investigations of the Redwood Canyon Karst are aimed at a better understanding of the hydrology of the area including the ebb and flow behavior of Big Spring. In the Fall of 1988, the recording station at Big Spring was up-graded from a strip chart recorder to a digital data logger and sensors and a heated recording rain gage was installed in the headwaters of Redwood Creek. Data collection was sporadic during the winter and spring of 1989 until problems were worked out with the recording system. Data collection has been almost continuous since early summer 1989. Parameters recorded at Big Spring include stage (discharge), water temperature and electrical conductivity (EC).

In November 1991, a second digital data logger was installed within Lilburn Cave. Sensors measuring stage, water temperature and EC were installed in the Z-Room. Sensors measuring stage and water temperature were also installed in River Pit approximately 800 ft. up stream from the Z-Room. The data loggers are programmed to collect data once a hour or when there is a significant change in stage, temperature, or EC. A Manning automatic sediment sampler was also installed at Big Spring in November 1991. The sediment sampler is controlled by the data logger to collect samples when the stage at the spring is greater than 1 ft. This indicates a period of flushing. The sampler will continue to collect samples every 10 minutes until the stage drops below 1 ft. Analysis of these samples may suggest the type, amount and size distribution of sediments being moved through the cave system during the flushing period.

Example Records

Twelve days of the Big Spring stage and temperature hydrography (April 1991) are shown in Figure 13. The ebb and flow behavior can be observed beginning on day 93 and continuing through day 99. During this period the water temperature drops from approximately 7.2° C to approximately 5.3° C indicating a pulse on snow melt water moving through the cave system.

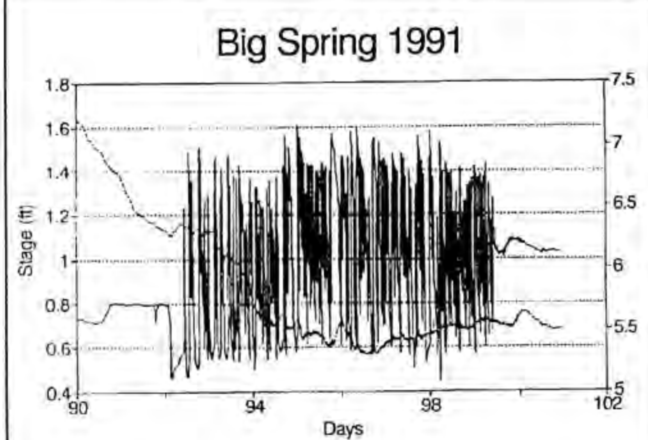

Figure 13: Big Spring stage variations for 12 days during the 1991 snowmelt showing cyclic ebb and flow behavior (CRF, unpublished data).

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Sedimentology of the Redwood Canyon Karst Area, Kings Canyon National Park, California

by John C. Tinsley III

Introduction

This research monitors rates of sediment yield and processes of sediment transport among the karst features of Redwood Canyon in order to improve understanding of the karst as a physical system and to gain insight into the region's natural history using a sedimentological perspective. The results of the studies offer some interesting applications, one of which is described below. In 1990 and 1991, using some of the latest technology available to cave divers, Bill Farr conducted several exploratory dives within Lilburn Cave with the intent of boldly going where no one has gone before. He discovered that the Big Spring resurgence, a single orifice ebb-and-flow spring that was previously entered by divers during the early 1970's, was blocked by sediment at a point well short of previous limits of exploration. While the observations of water flow and sediment stability were of interest to hydrologists studying the hydrology of ebb-and-flow springs (see reports by Bill Farr and Jack Hess elsewhere in this volume), the logistics required to conduct staged cave dives at 5000 feet altitude in 7° C water are so demanding of equipment and personnel that we would like to schedule future dives when the conduit would be open. Thus, a means to ascertain if the Big Spring conduit is clear or if it is likely to contain an excessive volume of sediment would help us to schedule dives when conditions of sediment load favor further exploration. I have interpreted some stratigraphic observations obtained from Redwood Creek and data obtained from sediment profiles located at appropriate points within Lilburn Cave and have devised simple criteria we will use to evaluate the feasibility of conducting additional exploratory SCUBA dives in principal subterranean conduits of the karst.

Background

In the spring of 1989, CRF joint venturers observed a large new sinkhole in the channel of Pebble Pile Creek, a tributary to Redwood Creek which traverses above the southern 1/4 of Lilburn Cave. The sinkhole represented about 140 cubic yards of sediment input to the cave upstream of the terminal siphon. The influx of sediment was manifested in the Z-Room as sediment waves 10 to 20 meters high during episodes of snowmelt-fed runoff; aggradation of the floor of the stream passage amounted to 3 to 5 meters compared to observations made prior to development of the sinkhole. This was enough aggradation to occlude the water passage traditionally traversed by cavers enroute to the South Seas, the terminal siphon at the southern end of the traversable cave. Water levels at the South Seas are about 18 feet higher than they were prior to the sinkhole's opening.

A monitoring program was instituted. On the surface, we have used sediment profiling and photography to track the development and evolution of the Pebble Pile sinkhole and recent stream terraces of Redwood Creek downstream of Big Spring and simultaneously we have recorded the sediment supply in transit within the cave using sediment profiling. Ideally, relative stability of the sinkhole above the cave would be indicated by an absence of active collapse features on the floor of the sink and by a progressive infilling of sediment. Underground, the decrease in sediment supplied to the cave would show up as a dearth or absence of sediment in storage within the cave. A runoff year characterized by a high volume of fluid discharge and relatively low sediment concentration would favor the spring becoming flushed of its sediment plug. The effects of clear-water discharge should show up as erosion of the 0.7 to 1.0 m thick fill terraces formed of medium- and fine-grained sand deposited by Redwood Creek downstream of Big Spring since the Pebble Pile sinkhole opened in 1989.

Observations and Trends

In 1989 and 1990, within the cave, the active sinkhole in Pebble Pile Creek supplied copious sediment in transit through the Z-Room; the traditional route along the free-surface stream leading to the terminal siphon at the South Seas was plugged; access to the siphon area was available through higher-level passages. Meanwhile, above ground and owing to the drought, runoff was not especially voluminous and a net aggradation of sandy fill characterized the reach of Redwood Creek below Big Spring. Exposed in a series of slit trenches, each season's accumulation of sand was delimited at its base by an accumulation of oak leaves, pine needles and forest duff.

In the winter of 1990-1991, conditions changed as a major late-season storm struck the southern Sierra Nevada. The Pebble Pile sinkhole became plugged and overflowed at its downstream lip, an impressive natural bathtub, however chilly. Within the cave, by the end of 1991 the water route at the Z-Room was again open to the South Seas, reflecting the decreased sediment supply from the sinkhole. Water levels in the South Seas have remained elevated compared to water levels from 1976-1989 (pre-sinkhole) period; the observation suggests that one or more conduits leading to Big Spring remain plugged with sediment.

In September, 1991, Farr's exploratory dive showed that the spring conduit was occluded at a point 71 feet below the resurgence. Downstream of Big Spring, the 1989 and 1990 accumulations of sand were scoured away and replaced by a single accumulation of sand of comparable thickness (0.5-0.8 m) to that of the 1989-1990 deposits.

As we await the 1992 field season, the picture is incomplete but encouraging. At this writing (3/92), the sinkhole has stayed plugged, the prospects for decent runoff are the best since the latest cycle of drought beset California in 1986. Reconnaissance trips in April, 1992, will visit the Z-Room, the South Seas, and Redwood Creek to observe the state of sediment in transit through the system. Erosion of the recent terrace and bars in the channel of Redwood Creek below the resurgence will be taken as evidence indicating clearing of the spring orifice. The cave divers will be the ultimate arbiters of the success of this approach.

Conclusions

Observations of water and sediment levels made by project cavers as far back as 1966 and by CRF observers since 1977 provide a baseline against which the events of 1989-1992 may be interpreted. The increased sediment flux within Lilburn Cave owing to the large slug of sediment derived from an overlying a sinkhole provides an opportunity to study process-response within karst conduits. If the model proposed here has useful validity, cave diving is not likely to be productive at Big Spring until dwindling sediment deposits within the cave are accompanied by a dearth of sediment emanating from the orifice of Big Spring, a condition evidenced by the erosion of recent deposits of sand presently stored as terraces and bars in the channel of Redwood Creek.

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Nitrocalcite in Kartchner Caverns, Kartchner Caverns State Park, Arizona

by Carol A. Hill and Robert H. Buecher

Nitrocalcite ($Ca(NO_3)_2 \cdot 4H_2O$) is a deliquescent mineral, efflorescent only under very low humidity conditions (around 50% for a normal range of cave temperatures; Hill and Forti, 1986; Figure 14). Nitrocalcite has been mentioned as occurring in a number of eastern United States caves, but these are pre-1900 citings which are erroneous since eastern caves have relative humidities approaching 100%. Brief mention of nitrocalcite as a cave mineral has been given for one cave in the southwestern United States and one cave in Italy (Hill and Forti, 1986). This is the first authenticated, detailed description of nitrocalcite as a cave mineral.

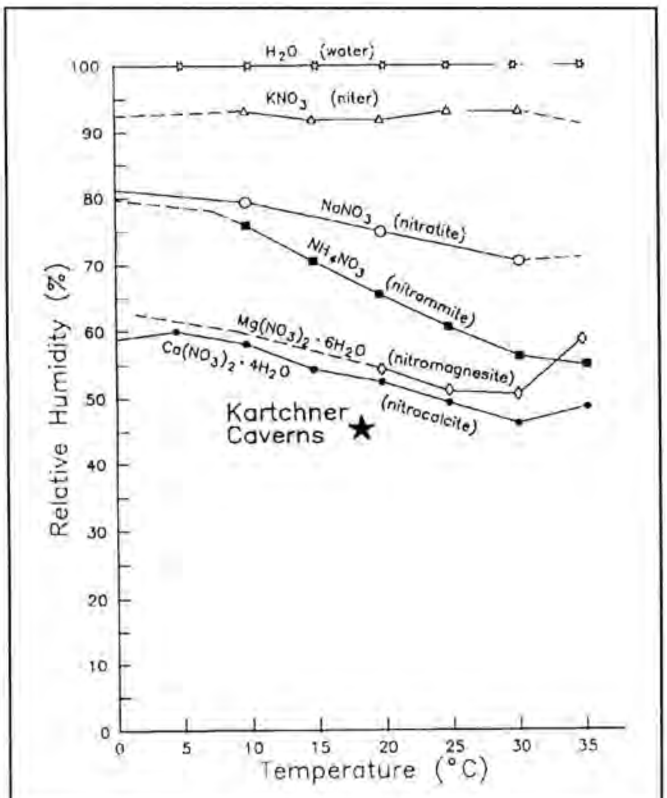

Figure 14: Stability of nitrate minerals in a cave environment with respect to temperature and humidity, showing the Kartchner Caverns nitrocalcite (star) plotted below the nitrocalcite line in the zone of efflorescence. After Hill and Forti (1986).

Nitrocalcite occurs in Kartchner Caverns as cave cotton growing from sediment in scattered areas along the entrance Passage (e.g., Babbitt Hole and L.E.M. Room, Figure 15) where cold, dry, winter air flows into the Entrance Passage from the surface. Mineralization occurs as efflorescent cotton mats, consisting of colorless to milky-white, silky-to-transparent, slender needle crystals up to 0.5 mm in length and <0.1 mm in width (Figure 16). Birefringence is high: third order yellows, pinks and greens. One optical indice measured <1.50, another >1.50. Some of the needle crystals look eaten-away along their edges and many have a thin coating of clay on their surfaces. The mineral has a strong, bitter-cool taste.

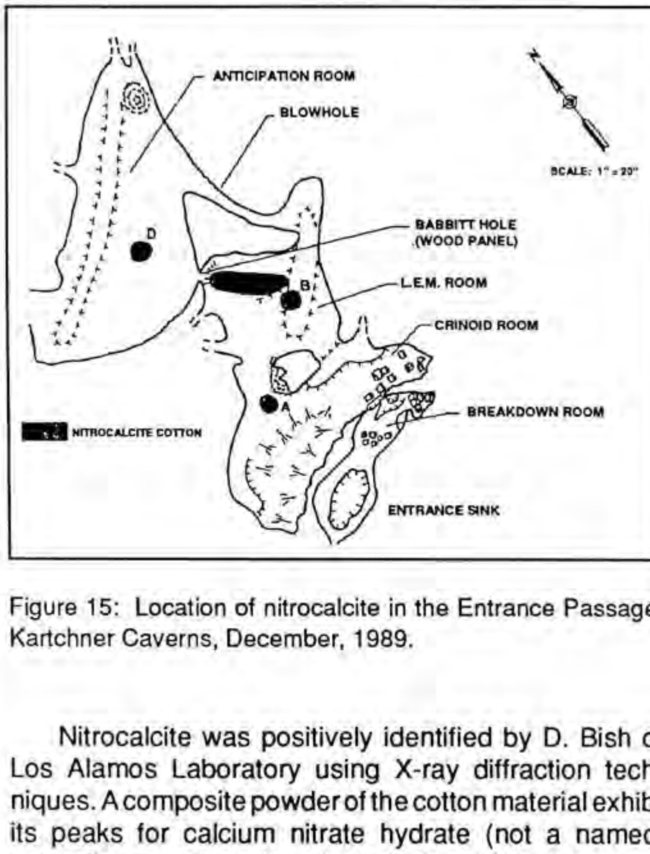

Figure 15: Location of nitrocalcite in the Entrance Passage, Kartchner Caverns, December, 1989.

Nitrocalcite was positively identified by D. Bish of Los Alamos Laboratory using X-ray diffraction techniques. A composite powder of the cotton material exhibits peaks for calcium nitrate hydrate (not a named, naturally-occurring mineral species), calcite, and quartz; in addition, a possible peak for a clay mineral was detected. The calcite is probably normal secondary mineralization within the sediment, the quartz is probably detrital (tiny pieces of needle quartz in the sediment?), and the clay mineral is probably clay coating the nitrocalcite crystals. It is seems probable that the calcium nitrate hydrate (two waters of hydration) is a dehydration product of nitrocalcite (four waters of hydration). The mineral was kept in a closed container containing desiccant since its collection (December, 1989) and the diffractometer was kept below 10% relative humidity during X-ray analysis, so the dehydrated form of nitrocalcite was not unexpected.

Figure 16: An efflorescent mat of nitrocalcite cotton, Entrance Passage. (*Photo by R. Buecher*)

The growth of nitrocalcite in the Entrance Passage was monitored by a data logging system which recorded cave temperature and relative humidity on an hourly basis. A weather station was also operated on the surface near the cave entrance. From December 10, 1989 to December 16, 1989 the weather on the surface was unusually dry and cold, with the outside humidity dropping to 23%. The cotton was first noticed on December 14 in front of the Babbitt Hole, two days after the significant drop in surface humidity. Maximum growth was noted on December 12th at Babbitt Hole as a loose mat 1-2 cm thick when the cave humidity and temperature measured 45.3% and 15.6°C, respectively (star, Figure 14). When both surface and cave humidity rose a few days later the nitrocalcite slowly deliquesced and disappeared back into the floor sediment. A humidity of 49-50% or below appears to be needed for crystallization, and the humidity needs to remain low for a few days before significant cotton effloresces. This corresponds to a time when the cave is "breathing in"—that is, when cold, dry air is coming into the cave from the outside. When the cave "breathes out," warm moist cave air quickly causes the mineral to deliquesce and disappear back into the cave sediment.

Interestingly, maximum nitrocalcite growth does not occur in undisturbed dirt off the trail, but it occurs where dry sediment of the Entrance Passage becomes compacted and smeared with mud by crawling cavers returning from the wet, muddy interior of the cave. It may be that, where sediment becomes compacted, nitrocalcite cannot crystallize within sediment pore spaces but must crystallize at the surface of the sediment. It has been noted that crystallization obliterates boot and knee-pad marks in the sediment within a few days time; evidently, sediment particles are forced upward by crystallization within sediment Pore spaces. Scattered patches of dark bat guano can be seen all along the Entrance Passage where the trail has not been crawled over. Cave rat trails can also be seen along the passage walls. Bat and rat guano could both be Possible sources of nitrate for the nitrocalcite mineralization.

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Mineralogy of Diente Cave, Guadalupe Mountains National Park

by Cyndi Mosch and Carol A. Hill

Diente Cave, Guadalupe Mountains National Park, Culberson County, Texas, was discovered by firefighters in 1990 and explored by Cave Research Foundation cavers in March of 1991. The cave has an entrance about 3 m high and 6 m wide, and two short branching passages each about 10 m long. The cave was named Diente Cave for the calcite dogtooth spar crystals which cover the cave walls and ceiling ("diente" is Spanish for "tooth"). The cave is developed at the contact between the massive and forereef facies of the Capitan Limestone. Crinoids, fusulinids, brachiopods, and bryozoa were noted in the Capitan at the cave entrance. Also noted in the cave was a roosting Townsend's big-eared bat (*Plecotus*), net-like spider webs, flies, pack-rat droppings, acorn shells, black beetle carapaces, and a 26 cm by 8 cm skull, probably of a deer. On the cave floor is a reddish-brown to buff-colored, hackly clay containing detrital calcite crystals. Desiccation cracks and drip pits up to 17.5 cm deep can be seen in the floor clay about 5 m in from the entrance along the right-hand branch.

A variety of speleothems occur in the cave but most of these are dry and inactive. Cave pearls up to 7.5 cm in diameter are present, some of which may have nuclei consisting of broken spar pieces. Rimstone dams and popcorn coralloids occur on sloping walls and floor breakdown. Other speleothem types include stalactites (up to 25 cm long), soda straws, stalagmites, columns, draperies (serrated and ribbon), and canopies.

Approximately 60% of the cave is lined with euhedral to subhedral dogtooth spar crystals up to 5 cm in length (2-3 cm average). Carbonate speleothem material (popcorn, flowstone, or moonmilk) coats the exteriors of some of these spar linings. Laminated clay, similar in appearance to the floor clay, is locally "packed" in between the individual spar crystals and also fills spar-lined wall pockets. The cave may have been filled with clay at one time, subsequent to the deposition of the spar, but is now being reexcavated; the clay packing may have helped to preserve the spar crystals from erosion. Occasionally, interstices between spar crystals are filled with yellow-orange to blue to black, submetallic-looking material which is seemingly associated with etched and resolutioned spar.

A sample of spar was collected (by C. Hill) in order to determine the carbon-oxygen isotopic value of the calcite and to compare this value with other spar types in the Guadalupe, Delaware, Apache, and Glass Mountains, Delaware basin. A $\delta^{13}C$ value of +1.2 and a $\delta^{18}O$ value of -13.4 was obtained for the spar piece, values that place it in the thermal-spar episode of Hill (1992). Diente Cave, like other spar caves in the Guadalupe Mountains and spar-lined passages in caves such as Carlsbad and Lechuguilla is probably a thermal cave which formed in the Miocene epoch (25-5 Ma) from hot solutions (40-80°C).

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Acknowledgments

The isotopic work of Carol A. Hill was funded by the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico. Carbon-oxygen analyses were performed by Andrew Campbell, New Mexico Tech, Socorro, New Mexico.

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Mineralogy and Geology of Fitton Cave, Arkansas: Preliminary Findings

by Carol A. Hill

INTRODUCTION

Fitton Cave is located in the Ozark Mountains, Buffalo National River, approximately 120 km north-northwest of Russellville, Arkansas and about 25 km southwest of Harrison, Arkansas. The cave is developed in the Boone Formation of Mississippian age, which formation is overlain by the Batesville Sandstone, also of Mississippian age. The Boone is an alternately cherty and fossiliferous (crinoids, bryozoans, brachiopods) limestone. Geology and mineralogy were noted during a 10 hour cave trip taken on August 17, 1991 during a Cave Research Foundation expedition led by Pete Lindsley.

MINERALOGY

Carbonates

The carbonate minerals calcite ($CaCO_3$) and its polymorph aragonite ($CaCO_3$) were both identified from Fitton Cave. Speleothem types and subtypes noted were: stalactites (soda-straw, carrot, anemolite), stalagmites, columns, flowstone (microcrystalline, macrocrystalline), draperies, shelfstone, rimstone dams, shields (palette, welt, "angel-wing"), helictites, spar (pool), coralloids (subaerial popcorn, subaqueous), anthodites (frostwork), and moonmilk. Of these, it is estimated that over 95% of the speleothemic material is composed of calcite, the remainder of aragonite. Especially impressive are the shield and welt-shield in the Shield Room. The shield is about 5 m in diameter and occurs isolated from the left wall of the passage (going in). The welt-shield protrudes from a prominent bedding plane for about 10 m along the right side of the passage; dripstone hangs from the bottom of the linear welt and helictites grow along its top.

Travertine is not evenly distributed throughout the cave but seems to be concentrated in specific areas (e.g., the Entrance Room). This distribution may (or may not) correlate with sections of overburden where the Batesville sandstone cap has been eroded away. Travertine also seems to be concentrated along major joints and/or fractures, an example of which is in the Entrance Room where a line of stalactites, stalagmites, and columns are oriented approximately 160° along a major joint or fracture. Other travertine is bedding-plane controlled: in these cases solutions have issued forth along horizontal bedding planes and deposited "waterfall"-type flowstone directly beneath the bedding plane. Most of the speleothems in Fitton display smooth, microcrystalline surfaces, but locally speleothems display sparkling ("sugar-candy") macrocrystalline surfaces.

Where flowstone and dripstone travertine is sparse (in areas covered by the sandstone caprock?), evaporative-type speleothems such as popcorn and aragonite frostwork decorate the lower walls of the cave, while corrosion of limestone occurs on the upper walls and ceiling. This phenomena, called "condensation-corrosion" by Hill (1987), demonstrates the effects of cold, dry, evaporative air moving into the cave along the floor (depositing popcorn), and warm, humid, acidic air moving out of the cave near the ceiling (corroding the ceiling limestone).

Sulfate minerals in Fitton Cave are gypsum ($CaSO_4.2H_2O$), and possibly epsomite ($MgSO_4.7H_2O$) or mirabilite ($NaSO_4.10H_2O$). Sulfate speleothem types and subtypes are: crusts (coatings, snowball), flowers, selenite needles, cotton, and rope. (Gypsum rope was present the last time I visited the cave in 1968, but reportedly has been vandalized. I also saw the selenite needles in 1968, but many of these have also been vandalized and are "off limits" so were not visited on this trip.) Beautiful gypsum flowers in ceilings alcoves were observed on the way to the Tennouri Room.

An efflorescent cotton mineral–very clear, transparent, and with a bitter taste–occurs in the Tennouri Passage area (F. Glock, personal communication). This is probably epsomite or, less likely, mirabilite. Both epsomite and mirabilite are stable below 88% humidity at cave temperatures (10-15°C) (see Hill and Forti, 1986, their Figure 89 for stability curves of epsomite and mirabilite). This means that when the humidity drops below 88% these minerals will "sprout up" as an efflorescent cotton, but when the humidity rises above 88% these minerals will deliquesce (i.e., dissolve in their own waters of hydration, turn to liquid, and "sink" back into the soil). In this manner the very soluble, deliquescent minerals epsomite and mirabilite pull "disappearing acts" in the spring when the humidity increases slightly, and "appearing acts" in the fall-winter when the humidity lowers below the critical 88% relative humidity value. Fitton Cave has a measured humidity range of 86% to 91% (Table 2), so the minerals epsomite and mirabilite should be able to crystallize in the dry, upper cave passages .

Table 2: Temperature and Relative Humidity, Fitton Cave. Measurements taken 17 August, 1991.

Location in Cave	Temp °F	Temp °C	RH	Notes
Entrance Room	57.5	14.2	88%	Travertine along 160° joint/fracture
Manhole	57.5	14.2	91%	Macrocrystalline speleothems noted 200 ft. from Manhole toward Entrance
No-Name Room (just beyond stream)	57.5	14.2	86%	Popcorn line, condensation-corrosion noted here
West of T-Junction	57.0	13.9	89%	—
Shield Room	56.0	13.3	91%	Shield 15 ft. in diameter; 30 ft. long welt-shield
Beyond the Keyhole	57.0	13.9	98%	Pool Room; shelfstone, pool spar, subaqueous, coralloids, travertine

GEOLOGY

Probably the most significant geologic feature of Fitton Cave are its gravels. Well-indurated remnant gravels in the upper large passages of the cave indicate a time when northern Arkansas was receiving significantly more water than it receives today–water that had the load capacity to carry gravel clasts up to 5 cm or so in diameter. It is possible that this wetter time may correspond to Pleistocene glacials, interglacials, and climate (the Illinoian glacial and Sangamon interglacial?), but this hypothesis needs to be verified by an in-depth study. If such is the case, the gravels in Fitton Cave are important to the understanding of regional geology as well as cave geology.

The following preliminary observations were made on the gravels and sediments in Fitton Cave:

(l) The gravel clasts are very well-rounded (5-6 on Powers roundness scale). This means that they were either transported a very long distance from their source or they are reworked material (i.e., derived from a nearby, older conglomeratic unit).

(2) The gravels are composed of mostly siliceous clasts, such as jasperoid. These hard and resistant clasts also indicate a long distance of transport or reworked origin.

(3) The gravels seem to be mostly in the Pebble to granule size (6.4 cm to 2.4 mm; Folk's grain size scale). According to Hjulstron's diagram, deposition of this size sediment requires a stream/river velocity of between about 10-100 cm/sec (about 0.3-3 ft/sec).

(4) The gravels seem to exhibit graded bedding, which means that different bedded layers contain different size clasts. This graded bedding is not pronounced but may be an important indicator of the conditions of sedimentation.

(5) Gravel remnants are found high up along the cave walls, which may indicate that the passages were at one time almost filled with gravel before being later excavated.

(6) The gravels are well-indurated (i.e., they have hardened into a resistant unit). Downcutting of the gravels has left steep-sided exposures of the gravel unit along many sections of the cave, both along cave walls and in the middle of passages. The well-indurated nature of the gravels suggests that the gravel unit is very old, dating from earlier in the Pleistocene (200,000 years or more ago?).

(7) The gravels are overlain (unconformably?) by fine-grained sediment. This fine-grained sediment is Probably not a upper fine of graded bedding, but may represent a later episode of sedimentation in the cave.

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Minimum Conditions for Cave Development

by Christopher G. Groves and Alan D. Howard

One of the early enigmas posed by a theoretical look at the initiation of cave development could be called the "penetration problem." Initially undersaturated water entering small fractures within carbonate rocks was shown to approach saturation within a short distance, and thus be unable to do much work beyond this point in enlarging the fracture (Weyl, 1958). Various mechanisms have since been proposed that might give these waters a boost in their limestone dissolving capabilities, including local acid production by oxidation of organic material or sulfide minerals, *Mischungscorrosion*, and mechanical pumping of undersaturated fluids by diurnal variations in earth tides (Howard, 1964; Dreybrodt, 1981; Atkinson, 1968).

As understanding of the calcite dissolution process has become more sophisticated, it has become clear that the most likely answer to the problem seems to be White's (1977) "kinetic trigger" idea. However, there still must be a set of minimum conditions under which conduits can form, below which the waters at work forming them will actually achieve saturation and thus be unable to develop caves. For example, some minimum head gradient must exist for any set of initial geometric flowpath conditions that will allow the throughflowing fluids to leave the lower end of the flow system before the waters can reach complete saturation.

A series of runs using our newly developed FORTRAN simulation model KARST (Groves, 1991) was performed in order to investigate the magnitudes of these conditions. Starting with very small initial diameters for which saturation was achieved during the growth of the conduit, subsequent simulations starting with larger and larger initial conduit diameters were run. In this way, the minimum diameters at which conduit growth is successfully achieved was determined as a function of head gradient for various conduit lengths (Figure 17) and initial PCO2's (Figure 18).

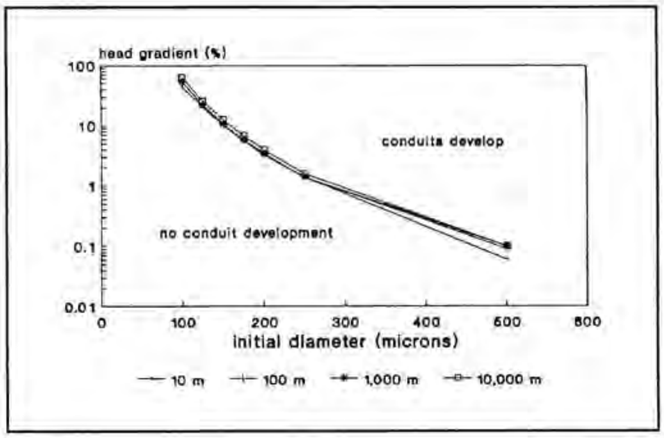

Figure 17: Calculated minimum initial diameters of successfully developing conduits, as a function of head gradient for various lengths.

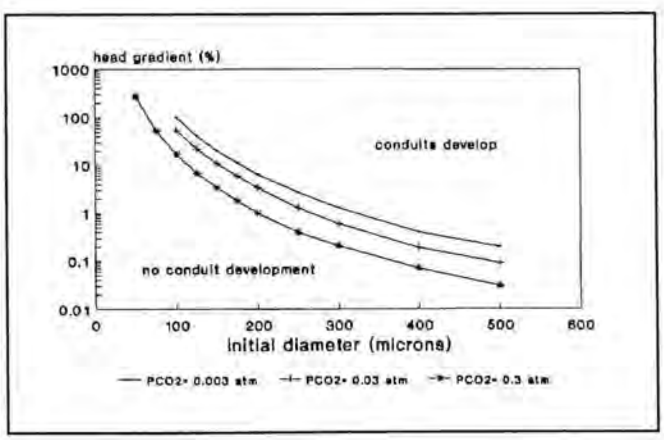

Figure 18: Calculated minimum initial diameters of successfully developing conduits, as a function of head gradient for various initial PCO2's.

Results of these experiments indicate that under the influence of realistic PCO2's and head gradients, the minimum initial diameters in which conduits will be able to successfully develop is on the order of 100-200 microns. This is the case even for water with PCO2's as high as 0.3 atm, which is higher than any values which should normally be expected to be found within karst systems. For these waters, a conduit with an initial diameter of 100 microns required a head gradient of about 11%. The world's deepest known karst flow system, Sistema Cuicateco in Oaxaca, Mexico, with a total vertical drop of 2,580 meters, has an average flow gradient of only about 9% (Smith, 1991).

The minimum initial size required for conduit development by waters with a PCO2 of 0.03 atmospheres, a more realistic value for karst waters (Atkinson, 1977), appears to be independent of the initial length for conduits between 10 and 10,000 meters in length. Flowpaths with initial diameters of less than 100-200 microns once again require unrealistic head gradients to develop into cave passages.

Water with initial PCO2's of 0.03 atmospheres were able to successfully develop conduits within initial flowpaths of about 500 microns, even under the influence of head gradients as low as 0.1%. This means that there is only a factor of two or three between the initial diameters of flowpaths that cannot form conduits because of their small size, and those in which conduits will form easily. In addition to providing information on the magnitude of the sizes of initial flow paths that may be able to form caves, these results suggest that competition between initial flowpaths may be a strong function of initial size.

An important feature of KARST is the flexibility of its design, so that it can be used to study a variety of problems concerning early karst aquifer development. A number of additional aspects of this process have been investigated using the model, including the varying kinetic controls on early limestone dissolution rates, thresholds in conduit growth rates, and effects of passage constrictions on growth behavior. Acknowledgments Appreciation is especially expressed to Deana Groves, Carol Wicks, and Janet Herman for assistance with this research. Financial support has been provided by the Cave Research Foundation, the National Speleological Society, and the University of Virginia.

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ECOLOGY

Evolution and Biogeographic History of Edwards Plateau Cave and Spring Salamanders (*Eurycea* and *Typhlomolge*): A Molecular Approach

by Paul Chippindale

The Edwards Plateau region of central Texas is a large area of uplifted Cretaceous limestones, bounded along its southern and eastern edges by the escarpment associated with the Balcones Fault Zone. The many springs and subterranean water systems of the region represent a group of "islands" of aquatic habitat in an area that is otherwise inhospitable for many aquatic organisms. Among the organisms that are dependent on the waters of this area are the salamanders of the genera *Eurycea* and *Typhlomolge,* in the tribe Hemidactyliini of the family Plethodontidae. Almost all populations of these salamanders are neotenic, retaining an aquatic larval body form throughout their lives instead of transforming into terrestrial adults as do many other salamanders. This group of salamanders exhibits a bewildering array of morphologies. These range from mainly surface-dwelling forms such as *E. neotenes* (the Texas salamander, Fig. 19) to seemingly bizarre troglobitic forms, exemplified by the Texas blind salamander *Typhlomolge rathbuni* (Fig. 20). With the support of the 1991 Cave Research Foundation Karst Fellowship, I am investigating relationships, evolution, and biogeographic history of the Texas neotenic salamanders, using a variety of molecular-level approaches to test previous hypotheses that have primarily been based on morphological studies of the group. This research represents a large part of my dissertation work at the University of Texas at Austin, in which I am studying relationships and evolutionary history of the entire group of hemidactyliine plethodontid salamanders.

Based on geological evidence and studies of morphology (for example, body proportions and features of the eyes, skulls, skeletons, and teeth), Sweet (1978, 1982, 1984) concluded that many subterranean populations of hemidactyliine salamanders in central Texas were independently derived from surface populations, which moved underground when springs failed or stream capture occurred. He suggested that shared morphological features among many of the cave populations reflected repeated instances of convergent or parallel evolution associated with the move to life underground, and regarded most cave populations as isolates within the species *E. neotenes*. Sweet (1978, 1982, 1984) recognized most spring and cave populations of *Eurycea* throughout central Texas as *E. neotenes*, and also concluded that the following species were valid: *E. tridentifera*, the Comal blind salamander (known from caves in the "Cibolo sinkhole plain" of Comal, Kendall, and Bexar counties); *E. nana* (from San Marcos Springs in Hays Co.), and *E.* sp. (from the subterranean system beneath Barton Springs in the city of Austin).

The status of the enigmatic genus *Typhlomolge* has been especially controversial. This genus was viewed by Wake (1966) as a relict of an early invasion of hemidactyliine salamanders into central Texas; Potter and Sweet (1981) also regarded *Typhlomolge* as a lineage distinct from the *Eurycea* of the region. In contrast, Mitchell and Reddell (1965) and Mitchell and Smith (1972) viewed *Typhlomolge* as simply the extreme in a continuum of cave-associated morphological changes in the Texas *Eurycea*. The affinities of *Typhlomolge* have continued to be problematic, but my work is shedding new light on this problem and others.

The research and hypotheses described above raise many questions about evolution and relationships of the Texas neotenic salamanders. Given that most of these salamanders retain a "generalized" larval morphology, and that there may have been repeated instances of colonization of subterranean habitat accompanied by parallel morphological change, inferences of relationships based on morphology alone are problematic. Many of the springs and underground water systems that are inhabited by these salamanders are almost certainly isolated; thus, there may have been the opportunity for substantial genetic divergence in the group. How many

Figure 19: Texas salamander (*Eurycea neotenes*) from the type locality for the species, a spring in Bexar Co. Note the visible external gills that are present in these neotenic (permanently larval) salamanders. Note also the well-developed eyes, characteristic of surface-dwelling populations of Texas neotenic salamanders.

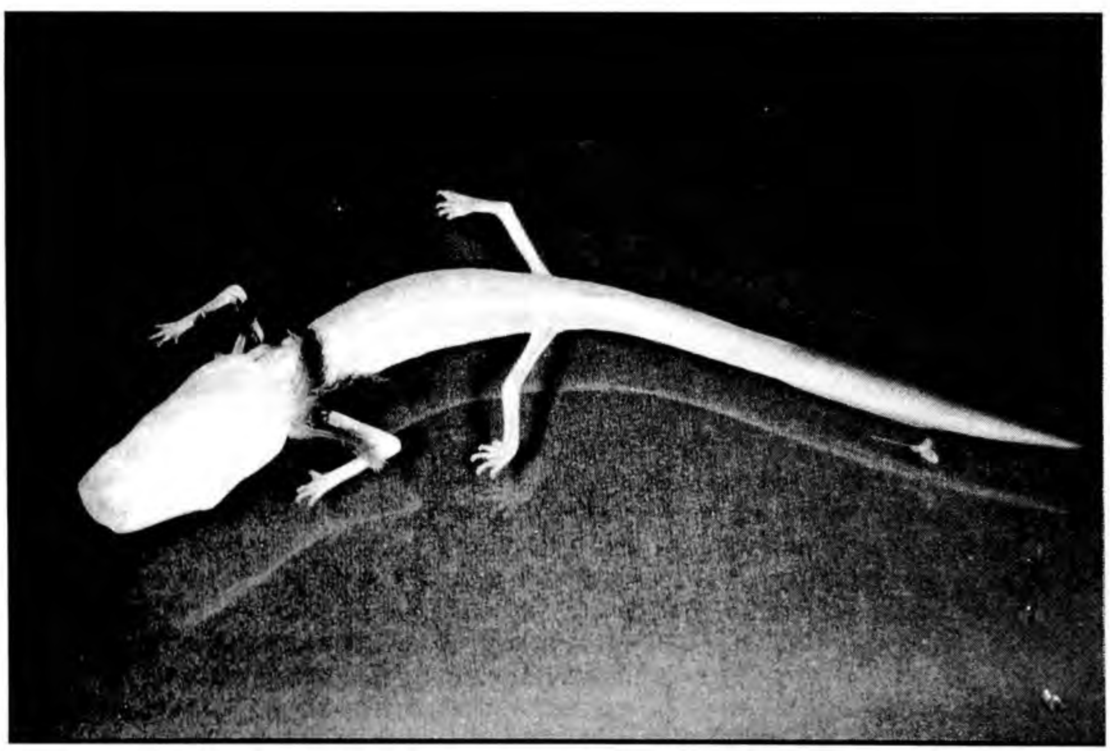

Figure 20. Texas blind salamander (*Typhlomolge rathbuni*). This species, which inhabits the pool of the Edwards Aquifer that lies beneath the city of San Marcos in Hays Co., exhibits one of the most extreme troglobitic morphologies among vertebrates. Note the almost complete lack of eyes, the lack of dark pigmentation, and the highly modified head and elongate limbs.

species of Texas neotenic salamanders are there? How has the geological and biogeographical history of the Edwards Plateau region influenced genetic differentiation and evolution in the group? How many times has cave-dwelling arisen independently? To answer these questions, and to obtain a comprehensive understanding of the evolution and historical relationships of the Texas neotenic salamanders, I am using a variety of morphology-independent molecular approaches.

These methods involve analysis of variation in the proteins and DNA of the salamanders. Using starch-gel electrophoresis of proteins, different forms of enzyme proteins ("allozymes") can be identified that migrate differentially through a starch gel under the influence of an electrical current. These differences represent variations in the genetic code for the proteins; by determining which allozymes are shared among populations and species, relationships among them can be reconstructed. I am also using two different levels of analysis to investigate DNA sequence variation: restriction site analysis and DNA sequencing. Restriction-site analysis involves determination of the presence or absence of specific short sequences of DNA at particular locations in the genes. I am using this approach to study variation in genes of both the cell nuclei, and the mitochondria (the "energy factories" of the cells). DNA restriction site analysis, like allozymes, allows large numbers of individuals from many different populations to be screened for genetic variation. DNA sequencing provides more detailed information on variation in specific regions of the DNA, but fewer individuals can be surveyed. I am working to determine the DNA sequence for regions of two mitochondrial genes (12S ribosomal and cytochrome b) to reconstruct relationships among the Texas neotenic salamanders, and to determine how they are related to other members of the tribe Hemidactyliini. In collaboration with Dr. Leslie Lowcock at the University of Toronto, I am also measuring the total amount of DNA in the nuclei of the cells of these salamanders, to provide an additional independent data set for investigating the evolution of the group. In conjunction with these molecular-level methods, I am carrying out analyses of the morphology of these salamanders to investigate the degree of correspondence between morphological and molecular divergence in the group.

My results so far, based on samples from 46 spring and cave populations, support some hypotheses of relationships among the Texas neotenic salamanders, and strongly contradict others. Allozymes, genome size measurements, and preliminary DNA restriction site data have identified major divisions within *E. neotenes* that correspond to major geographic barriers. This "species", currently regarded as widespread in the Edwards Plateau region, appears to represent a group of species that exhibit varying degrees of morphological differentiation. Some populations that are almost indistinguishable from one another based on morphology are vastly different at the molecular level, and clearly represent cryptic ("hidden") species. Conversely, some cave populations that are morphologically distinct from surface populations appear on the basis of the molecular evidence to be very closely related to nearby surface populations, rather than to more geographically distant cave populations with which they share some morphological features. This supports Sweet's (1978, 1982) hypothesis of repeated, independent invasions of subterranean habitat by surface populations of Texas *Eurycea*. Perhaps the most striking result of my work so far is the position of the enigmatic genus *Typhlomolge*. Rather than representing a group distinct from the Texas *Eurycea*, as some have concluded based on its extreme troglobitic morphology, *Typhlomolge* appears on the basis of the molecular data to be more closely related to some populations of "*E. neotenes*" than those populations are to some other populations of "*E. neotenes*". My work indicates that while there is a great deal of genetic diversity in the Texas neotenic salamanders, the degree of genetic divergence detected by molecular techniques does not necessarily correspond to degree of morphological divergence. Analysis of both the molecular and morphological data is allowing me to trace the evolution of this group, and obtain a better understanding of the influences of cave-dwelling on morphological evolution.

My research has proven to be of more than academic interest. The Texas Parks and Wildlife Department (TPWD) and the U.S. Fish and Wildlife Service have provided considerable support for this project, and are using the information that I am gathering to formulate strategies for conservation of these salamanders and their spring and cave habitats. Together with Dr. David Hillis (one of my PhD advisors) and Dr. Andy Price (TPWD) I am currently preparing formal descriptions of several new species of Texas salamanders. These include the Barton Springs salamander, which has become a symbol for conservation of endangered species and water resources in the Austin area. Only by recognizing the genetic diversity in the group and identifying species boundaries will it be possible to adequately protect the Texas neotenic salamanders and the vulnerable aquifer waters in which they occur.

I still have considerable work to do. In particular, there are several key caves that have so far been difficult to access, or have failed to yield salamanders. I have trips to many caves planned for this spring, and hope to fill most of the gaps in sampling in the near future. The mitochondrial DNA work is still in its early stages, but preliminary results indicate that this approach will be very useful for detailed investigation of relationships among the Texas neotenic salamanders. DNA sequence data are likely to be very informative regarding relationships within the Texas group, and will also allow me to investigate the relationships of the Texas neotenic salamanders to other hemidactyliines (these include cave dwelling forms such as the Ozark blind salamander, *Typhlotriton spelaeus*, and the Georgia blind salamander, *Haideotriton wallacei*). My work to date has shed much new light on relationships and biogeographic history of the Texas neotenic salamanders. This research continues to yield exciting results that contribute to a better understanding of the evolution of this group in particular, and the effects of the cave environment on subterranean organisms in general. I thank the Cave Research Foundation for their generous support of this project, and look forward to providing further updates on my research as it progresses.

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Baseline Biological Inventory of Caves Near the Hardrock Mineral Prospecting Area, Oregon and Shannon Counties, Missouri

by Mick Sutton

In August 1990, CRF signed a contract with the Missouri Department of Natural Resources (MoDNR) to map and inventory caves in an area of the southern Missouri Ozarks which the U.S. Forest Service is considering opening up for lead mining (see 1990 *Annual Report*). In February 1991, the project ran into a roadblock when the MoDNR legal staff ruled that the contract had been set up incorrectly, and was invalid. Attempts to rework the contract proved prohibitively difficult, and eventually the project was restarted under the direct supervision of the U.S. Forest Service, the major funding organization. The project was set up as a cost share agreement, rather than a formal contract, cutting a lot of bureaucratic corners. This was possible since CRF crews are donating more than half the total cost of the project in donated work.

Survey work continued at a low level during the hiatus, resulting in the completion of two major surveys, those of Kelly Hollow Cave (about 2 km long), and Barrett Spring Cave (about 1 km). Field work restarted in earnest in September. By the end of the year, mapping of ten additional caves had been completed. These ranged in length from tiny (8 m. long Connors Cave) to moderate (400 m long Davis Cave). Biological inventories were completed on all of the mapped caves and on two others. Some of these were newly reported sites, discovered while searching for known caves. As before, variety in cave community make-up seemed to be the rule. At the end of 1991 an estimated 65% of the field work had been completed. The project is scheduled to run through June 1992. Brief summaries on the sites examined in 1991 follow.

Adams Cave #1

The Adams Caves are in the Hurricane Creek valley. The stream passage in Adams #1 consists of 170 m of meandering canyon. Use of the cave by beavers has a profound effect on the cave's wildlife, though beaver use is probably limited to periods of high water (for most of the year, there is no surface flow in Hurricane Creek near the cave). The stream is partly filled with beaver-cut sticks, supporting large populations of epigean amphipods, predatory diving beetles, and larval salamanders. This community extended throughout the stream, well beyond the debris zone. In the deeper pools were epigean crayfish (*Cambarus punctimanus*); this species occurs abundantly in the nearby spring branch of Barrett Spring. The small pools in the terminal room contained at least 100 Dytiscid beetles (*Agabus* sp.), crammed in amazing concentration into small gaps beneath the rocks. A few troglobitic isopods somehow coexist with the more exotic wildlife.

Adams Cave #2

This is very similar to Adams Cave #1, 100 m down-valley, but on a smaller scale. The cave is basically a hands and knees crawl over the shallow stream bed. The biota closely parallels that of the Adams Cave #1. Mapping is incomplete, and will require a thin survey crew.

Barrett Spring Cave

The Barrett Spring survey was completed in two trips, giving a total length of 1060 m, with a vertical range of 30 m. The main stream was followed through a complex breakdown zone to an effective end in a breakdown choke. The main stream below a prominent waterfall contains eyed, pigmented amphipods. These have presumably invaded the cave stream from the spring branch, where they occur in large numbers. The waterfall evidently provides an effective barrier to their dispersal farther upstream, since only troglobitic amphipods were collected beyond the fall. As usual, isopods predominate, with amphipods in much lower numbers. The usual three species of salamander share the habitat: long-tailed (*Eurycea longicauda*), cave (*E. lucifuga*) and grotto (*Typhlotriton spelaeus*) salamanders. One unusual albino (or very pale-colored) cave salamander was seen. Although small aquatic snails were collected from the spring outlet in August 1990, no snails were found in the cave stream.

The population of hibernating pipistrelles numbered at least 100. Beyond the stream banks, the cave floor is very sparsely populated. Food sources are scant, consisting of a very diffuse scattering of bat guano and a few dried scats. In March 1991, a fresh beaver den was noted near the upstream end of the entrance crawl, and fresh wooden debris at the downstream end was backing up the water more than usual. If this trend continues, the cave may become inaccessible.

Brawley Cave

This is a low, moderately wet cave near the valley floor of Hurricane Creek. It is subject to flooding from Hurricane Creek in high run-off. The cave was extended significantly beyond the previous 50 m limit to a section of free-running stream (flow rate approximately 8 liters/sec). Gardner (1979) reported a single cave fish (*Typhlicthys subterraneus*) in the ponded section of the cave stream. During the survey trip in December 1991, no fish were present in the pool, but amphipods and isopods, not reported by Gardner, were collected from the stream. Additions were also made to the terrestrial fauna. Mapping of the cave continues.

Camp House Cave

This small, shelter type cave was mapped. It is situated in Camp House Hollow, a side valley of Spring Creek, and had been previously inventoried by Gardner (1986).

Connors Cave

This is a small, previously unreported cave only 8 m long. It is dry, and does not contain an accessible dark zone.

Davis Cave

Davis Cave is in the Hurricane Creek valley, about 1 km east of the proposed mineral lease area boundary. It contains about 400 m of mostly dry passage. Surface conditions are felt deep into the cave. The twilight zone is large, and includes the impressive 50 m wide central room.

A very small stream (<0.1 liters/sec) flows through a narrow canyon passage. No life was seen in most of it, but near the upstream limit a section with a chert cobble substrate had a high population of isopods and amphipods, in equal numbers. Terrestrial fauna included a number of big brown bats (*Eptesicus fuscus*) in the cool entrance passage. In a low room terminating one passage was a latrine of raccoon or skunk scat in various states of decomposition; this proved a rich site for pseudoscorpions, Sphaerocerid flies, mites, and springtails.

Kelly Hollow Cave

Mapping of the longest known cave within the study area was completed with the survey of an extension-ladder lead which proved to be a short stream crawl, the drawing of a profile of the Main Trunk, and a surface survey to define the topography above the major passages. The surveyed length of the cave is almost 2 km. Surprisingly, the breakdown chokes ending the twin trunks are unrelated to the land surface. The Main Trunk terminus occurs beneath a topographic high.

The Western Trunk stream was measured as only 0.04 liters /sec.; the stream is an obvious misfit for so large a passage, and no doubt represents a recent invasion by current drainage. It is relatively devoid of life, but isopods occur in scattered patches of suitable habitat. Several minor streams intersect the Main Trunk but they do not, at least within the explorable cave, form an integrated drainage net. The twilight zone drip pools have a population of large, white amphipods. This is an undescribed species of *Bactrurus* (J. Hollsinger, pers. comm.). Although situated almost 100 m inside the cave, the pools are susceptible to surface conditions. They receive dim light, and in January, 1991, the water temperature was a cool 10° C. A small stream flowing over the terminal breakdown has a fairly dense population of isopods in the tiny rimstone pools.

The cave is a significant hibernation site for pipistrelles, and terrestrial life is relatively rich. Among the more interesting finds were large numbers of tiny, white orb-weaver spiders. These weave irregular webs in small crevices.

Many Springs Cave

This small, dry cave was discovered while searching for Statue Cave. It is situated high on a hillside above a cluster of small springs emerging from a talus slope. The cave consists of 30 m of dry to moist passage. The terrestrial fauna was fairly rich and included a population of small orb-weaver spiders. These are apparently not the same species as those collected from Kelly Hollow Cave and a few other sites; the Many Springs spiders are pigmented, and build their untidy webs in the open. Another unusual finding was a slimy salamander (*Plethodon glutinosus*) carrying three young on its back.

"Mark's Cave"

This site was known only from a 1966 report in Missouri Speleological Survey files, describing a small spring near the top of a bluff. Closer examination showed that the spring outlet can be entered for only 3-4 m before becoming too tight. A brief examination showed no cave-adapted fauna in the small stream.

McCormack Trail Cave

This minor cave was mapped and inventoried. Contrary to earlier reports, this pit entrance did not require vertical equipment. The dark zone was very limited in extent, but yielded the common cave Heliomyzid fly, *Amoebaleria defessa*.

Saltpeter Cave

It is not certain that the cave mapped and inventoried under this name is the same site as the "Saltpeter Cave" reported with a vague location in the Missouri Speleological Survey files. It does apparently contain saltpeter in the dry dirt floor, based on a simple carbide flame test. It is also possible that "Saltpeter Cave" is a synonym for the nearby Davis Cave, in which case, the present site represents an unreported cave.

It consists of a single low, wide room with a dry and dusty floor, and only a very limited dark zone. The total length is about 50 m. There were several hundred cave crickets (*Ceuthophilus* sp.) distributed over the ceiling, almost all of them juveniles. Many mosquitos shared the ceiling with the crickets, as did at least a dozen Heliomyzid flies.

Skunk Den Cave

This small (10 m), dry cave lacks a dark, constant temperature zone. The cave was named from the strong odor of skunk, and the rear of the cave appeared to be a skunk latrine area.

Statue Cave

Two trips were needed to locate the site that Gardner (1986) reported as "Statue Cave". It is not certain that this is the cave known locally as Statue Cave—further research is needed. The cave, which was inventoried but not yet mapped, consists of a small stream passage (flow rate approximately 1 liter/sec.), about 150 m long; the outer 50 m is a comfortable crouchway in the shallow stream; the inner section is much less pleasant to traverse. The cave ends where the stream emerges from a tight collapse area.

The stream has a dense population of troglobitic isopods (*Caecidotea antricola*) in suitable habitat and, in keeping with most cave streams in the study area, troglobitic amphipods (probably *Stygobromus onondagaensis*) in much lower numbers. Also in common with most of the area's cave streams, grotto salamanders (*Typhlotriton spelaeus*) were present. Two species of Heliomyzid fly were collected, *Amoebaleria defessa* and *Heliomyza brachypterna.* It is noteworthy that parasitic mites have been found on 30% of *Heliomyza* specimens collected, but on none of the much larger number of *Amoebaleria* examined.

Tusher Hill Cave

This cave is high on a hillside, and consists of 120 m of dry, comfortable passage developed along a prominent joint, most of it within the twilight zone. There is little moisture, and only a very limited dark, constant temperature zone. It was mapped and inventoried.

Walter's Spring Cave

Walter's Spring is a large stream cave (1070 m long) in the Hurricane Creek valley, which has been described in detail by Baker (1989). Walter's Spring was used historically to power a grist mill. It was mapped some years ago by Doug Baker *et al.* The watershed of the stream is unknown; since the stream gains little in elevation, it is possible that water from farther upstream in Hurricane Creek contributes to the flow.

The community make-up of the stream is unusual, in that the population of long-tailed salamanders (*Eurycea longicauda*) is exceptionally high, while the population of troglobitic crustaceans is very low. The other two common cave-dwelling salamanders, *E. lucifuga* and *Typhlotriton spelaeus* are present in much lower numbers. The low population of isopods (only 4-5 seen after extensive examination of 400-500 meters of stream) may be in part because much of the habitat which looks superficially suitable—chert cobbles in the stream bed—is in fact heavily cemented, leaving little interstitial space for shelter. The terrestrial fauna includes common cave-adapted insects (Heliomyzid flies, *Spelobia* flies, *Ptomophagus* beetles, etc.). Two diplurans were recovered, floating dead but intact on a backwater pool.

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Effects of Recent and Future Climate Change on Terrestrial Cave Communities at Mammoth Cave

by Thomas L. Poulson

Over 25 years the cave cricket and communities that depend on cricket eggs and guano have shown fluctuations that seem to depend on changes in weather. During a series of dry years of 1985-1988, crickets and cricket guano communities declined; cricket numbers are up again in 1991 but guano communities have not yet recovered. During the same time period the cricket egg-sand beetle feces community was shifted along a passage by expansion of the gypsum "desert." I conclude that community change may be a sensitive indicator of global warming.

Caves are "time traps" in the sense that they preserve records of past climate at different temporal scales. Because of the protective caprock over much of the Chester Uplands, erosion has not destroyed the oldest upper level passages in Mammoth Cave and so the time record in speleothems (e.g. Harmon) and paleomagnetic signatures in the sediments (Schmidt) goes back to the beginning of the Pleistocene. The time resolution for these dates is on the order of 1000's of years. The cave record for the Holocene is better with radiometric dating giving resolutions on the order of 100's of years. Dating of humic/fulvic acid banding in speleothems (White personal communication), of fossils of groups that now have more northerly or southerly distributions (e.g. Wilson), and of archaeological plant material (Watson et al.) suggest the timing of past fluctuations in temperatures and precipitation patterns associated with glacial and interglacial periods. These inferences about past climate can be strengthened using climate inferred from dated pollen records of surface vegetation (Delcourt and Delcourt). At a still finer time scale, on the order of tenths of years to 10's of years, changes in the distribution and abundance of the living terrestrial cave species are allowing me to make inferences about periodic fluctuations in regional climate.

Current fluctuations in distribution and abundance of terrestrial cave species gives us hints of changes to be expected with global warming. Any changes in terrestrial cave communities in MCNP are likely due to weather and are not confounded by local or regional anthropogenic stressors. MCNP caves are protected against impacts of agricultural and urban areas and are buffered against regional ozone and acid deposition so their faunas are potentially sensitive indicators of climatic change. My students and I have made periodic censuses of different terrestrial communities for the past 25 years with especially detailed study for 1972-1975 and 1985-1988. In retrospect this timing was serendipitous because, over the past 100 years, 1972-1975 were the wettest four consecutive years (17% more precipitation than average) and 1985-1988 were the driest four consecutive years (23% less precipitation than average) on record in the central Tennessee and Green River basins. In the summer drought of 1988 my field notes document severe wilting of understory tree saplings and shrubs in the shaded old growth forest around Mammoth Dome Sink and the cricket guano community in nearby White Cave was almost non existent. At the time I was worried that the decline in the White Cave guano community, that started in 1986, might be due to the "trogs" program for pre-teens, but it now seems that the progressive drying from 1985-1988 may have been the explanation because the guano slope fauna in Little Beauty Cave was also declining. The guano community had not recovered to pre 1986 levels by 1991 in either White or Little Beauty Cave but the cricket population in Little Beauty was 2-3x as dense as in the late 80's. This suggests that there was a problem for cricket foraging outside due to warmer and/or dryer nights in the late 80s which resulted in less guano deposition. Data on rates of weight loss (Studier and Lavoie) suggest that 22ºC may start to be problematic for crickets and that 25ºC is close to lethal. Dry conditions are definitely a problem for the cave cricket because of its thin exoskeleton (Studier and Lavoie). Dry conditions of the guano slopes are a problem for those species that require damp substrates, such as springtails, snails, and millipedes. These were the first species to decline in the mid 80's and have not yet returned. So far only the species that are favored by dryish conditions are still common, especially the "fuzzy" mite. Time series analyses of cricket census data and the guano community in relation to the Mammoth Cave National Park weather data will resolve the extent of the lag time between changes in weather changes and responses of cave organisms.

Shifts in the border between dry gypsum with no organisms and damp silt-sand with cave organisms along Edwards Avenue of Great Onyx Cave appear to lag 3-5 years behind changes in surface climate. There has been a clear change in moisture conditions, from wet to normal to dry and back to wet from our first data in the early 70's to present. We have both biosassays and physico-chemical assays of moisture conditions (see Biological Deserts Under the Cap Rock, pages 24-25 in 1985 CRF Annual Report). Bioassays of change are egg-laying activities of cave crickets, survival of enclosed cricket eggs in and sand beetles on the substrate, growth of fungi on sticks, and distributions and abundances of crickets and sand beetles compared to springtails, bristletails, pseudoscorpions, spiders, and daddy-long-legs which all require even moister conditions. Physico-chemical assays are of relative humidity of the air (indicative of drying power since temperature is constant) moisture content of the substrate (estimated relatively by feel and ease of sifting without clogging a sieve and measured absolutely by matrix potential), and growth of epsomite from the mud-silt trail in gypsum areas well under the caprock. Of these measures of moisture only a few were noted on every trip into the cave from the 70's to present. We always noted whether crickets were laying eggs in a 1m² beetle exclusion ring at the entrance end of the passage (damp enough or not), whether epsomite was growing from the trail half way back (dry enough or not), and how far beetles ventured toward the gypsum "desert" at the back end (damp enough or not). The reappearance of egg-laying and disappearance of epsomite in 1990-1991 alerted me to a change and subsequent review of my field notes showed that there had been a fluctuation in these measures, from 1970 to 1991, that is consistent with the 1972-1975 wet years and the 1985-1988 dry years discussed above (note the value of long-term data sets!!).

All of these fluctuations in distributions and abundances of cave organisms suggest the kinds of changes that might occur with global warming. That the wettest and dryest periods in 100 years of record occurred in the last 20 years is consistent with some global warming scenarios that project increasing frequencies of extreme weather periods and synoptic events such as El Niños. The most serious effect of global warming for the Mammoth Cave terrestrial communities would be the loss of cave crickets upon which most of the other cave species depend for "import" of energy from outside to inside the cave. In retrospect the physiological tolerance data of Studier and Lavoie are consistent with the narrow latitudinal distribution of cave crickets; crickets disappear in northern Tennessee to the south and toward the Ohio River to the north.

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Energetic Advantage of Interference competition in *Neaphaenops t. tellkampfi*

by Thomas L. Poulson, David M. Griffith & Kenneth Schmidt

We review the observations and inductive logic that led to our hypothesis that it should be energetically advantageous to usurp holes started by other beetles or to steal cave cricket eggs already dug up by other beetles. And, we summarize field and laboratory studies aimed at testing the predictions of our hypothesis of interference competition for holes and eggs (Table 3).

Observations in the field suggested that beetles fight over eggs especially at high beetle densities. Over 20 years we have often seen beetles running with an egg in their mandibles and have occasionally seen fights over holes from which a beetle subsequently extracted an egg. Both sets of observations led us to hypothesize that interference competition is important and so we predicted that the ability to find eggs should decline with increased beetle density. In the laboratory per beetle success at finding 10 eggs, buried under artificial cricket oviposition mounds, declined as beetle density increased. With increased density beetles foraged for shorter periods of time and dug fewer and shallower holes. The average hole depth was deep enough to reach the top of a buried egg (11mm) only in the 1 beetle per bowl density.

In the field the depth of holes was shallower at high beetle densities (6.9mm at 5-6 beetles per m^2) than at low beetle densities (10.2mm at 0.3-1.0 beetles per m2). At the higher beetle densities only about 10 percent of the holes were deep enough to reach the top of a buried cricket egg. Once a beetle extracts an egg from a hole in the field it invariably runs at high speed until it stumbles into a rock, and crawls under it, or runs into a wall, and climbs up onto the ceiling. In areas of high beetle density >80 percent of beetles that have eaten within a week are under rocks or on the ceiling. This observation is consistent with our hypothesis that beetles carrying eggs run and hide, before eating the egg, to avoid having the egg stolen by another beetle.

In addition to the above observations, inferences about and calculations of the energetic cost of hole digging are consistent with our hypothesis that there should be interference competition by stealing eggs and/or usurping partially dug holes. We inferred that digging might be expensive because continuous digging by pocket gophers is 300 times as expensive as non-digging and periodic digging by spadefoot toads is 20 times as expensive as non-digging. In addition it is known that the difference between routine metabolic rate and cost of transport and work increases allometrically with decreasing body size and our beetles are only 7mg compared to 700,000 mg for a pocket gopher. Thus our calculations that digging is 63 times as expensive as walking do not seem out of line. Both laboratory and field data suggest that an average beetle digs one hole per day in about one hour and so digging comprises 74 percent of a beetle's total energy budget.

The high cost of digging and our earlier field observations led us to predict that beetles should usurp holes started by other beetles and that they should fight hardest for deeper holes. So far our results are consistent with this prediction. For example at a time of low

Table 3: Interference Competition with Finding Cricket Eggs

Beetle Density Per Bowl	Time Foraging %	Holes Per Beetle Per Day	Hole Depth mm	Eggs Eaten Per Beetle
1	75	0.52	11.3	1.00*
2	50	0.24	8.4	0.69
4	38	0.11	6.1	0.09

* a beetle can eat a maximum of 1 egg in the two week experiment.

cricket egg availability in September, we watched 159 beetles for 30 seconds each and classified their behaviors. "Walking" involved almost continuous locomotion, "searching" involved regular alternation between periods of slow walking with 1-2 second pauses and regular changes of direction, "intensive searching" involved periods of very slow walking interrupted by periods when the beetle was stopped and investigating with its antennae, and "digging" is self-explanatory. In addition we recorded incidents of agonistic behavior in which there were definite chases or fights. If an agonistic act was observed then we followed the interaction to its conclusion. Of 159 beetles 17 were "walking", 66 were "searching", 66 were "intensively searching", and 10 were "digging" in holes. Of the 9 agonistic interactions 3 involved a beetle intensively searching and 6 involved a digging beetle. All of the four fights over holes involved holes >6mm deep. The agonistic interactions continued for 1-35 minutes with 1-7 separate encounters each. In the two most spectacular interaction sequences the holes being dug were already 7 and 9 mm deep when we came on the scene. In one case a searching teneral encountered, fought with, and displaced a digging adult and subsequently chased three other beetles away; during one of the chases another beetle entered the hole and the teneral pulled the intruder from the hole and threw it! In the other encounter the original digger chased away and/or wrestled with four other beetles, dug between encounters, and 25 minutes after our first observation extracted an egg, ran with it for about 5 meters, and disappeared under a rock.

In the course of field observations on beetle interactions we noted a distinct difference between agonistic and presumed sexual behavior which we followed up in the laboratory. Our preliminary laboratory results (N=9 beetles in 21 separate kinds of pairings) involved sand arenas in which numbers of resting holes and foraging holes were not well controlled but the results are interesting none-the-less. In sexual interactions a male invariably jumped on a female and grabbed her by the neck with his mandibles as he attempted to pin her to the ground; about half the time he was successful in mating and half the time the female shook him off. This was distinct from agonistic interactions in which one beetle chased, bit, or wrestled with another beetle. Thus there was a clear sex effect; males fought with males and females with females but males never fought with females. Also, there was a clear residency effect; beetles that had been in a bowl for > a week and had dug resting holes were usually the aggressors. But, there were two individuals that were always the aggressors whether they were residents or not. One of these cases can be explained energetically since the aggressor was a teneral. New tenerals weigh only 4.3 mg, compared to 7.0 mg for an average adult, and so there is a great premium on tenerals getting enough food to complete their development. Recall that our one case of a non-digging beetle usurping a digging beetle's hole was by a teneral.

The lab bowl residency effect and the existence of "resting holes" suggest the possibility of territoriality as one explanation for differences in agonistic behavior in the field. In the field about 5 percent of holes are along walls or rocks and >= 5 mm deeper than the 11mm needed to dig up a cricket egg and in the lab beetles regularly dig 16-25 mm deep holes at the edges of bowls and spend long times in the hole especially if not fed for a while. An intriguing possibility is that the high CO_2 concentrations in deep holes should depress a beetle's metabolic rate and so prolong survival at times of year when cricket eggs are scarce and beetles on average get an egg only every 70 days. The potential energy savings of staying in a deep hole coupled with the high cost of digging such a deep hole could make it advantageous to defend the hole. If the hole is dug in microsites which have deep and slightly moist sand and so are optimal for cricket egg-laying then there would be a double reason for defending the hole and the area nearby. The beetle could mark its own territory by a pheromone and thus delimit the area for itself and for others. This hypothesis requires that beetles can recognize their own scents. We have not yet tested this possibility.

Thus the saga of beetle predator vs cricket egg prey continues. For the history of these studies and references to the literature see the CRF Annual Reports for 1973, 74, 76, 81, 83, 85, 89, and 90.

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Assessing Groundwater Quality in Caves Using Indices of Biological Integrity*

by Thomas L. Poulson

The states of populations and communities give an integrated record of past and ongoing pollution whereas toxicity bioassays and chemical analyses may detect pollution occurring only at the moment of sampling. Of the population and community biocriteria that are derived from field data, indicator species, diversity indices, and community similarity metrics are either totally flawed or have more disadvantages than advantages. The preferred biocriterion is an Index of Biological Integrity (IBI) which combines habitat data with population and community data. In caves there are few species and so most must be censused to develop an IBI baseline. For fish, salamanders, and crayfish all individuals are located on a map, measured, and examined for fat stores, reproductive condition, and lesions or tumors. The smaller species and habitat characteristics are sampled at random stations. Since surface waters enter cave by different routes, I sample communities from diffuse input formation areas, from mixed input areas like terminal breakdowns, and from concentrated inputs associated with sinking streams, vertical shafts, and backflooding from surface rivers. Over 30 years of study, mainly in the Mammoth Cave Region, I have used the natural variation in pristine areas to demonstrate or infer the non-lethal effects of anthropogenic stressors. For example, there are different negative effects due to homogenizing of substrate by siltation, favoring of facultative over obligate cave species by excess food input, and compromising reproduction and growth of very long-lived species by bioaccumulation and biomagnification of toxins along food chains.

* Abstract of paper presented at The Karst Conference of The American Groundwater Association, Nashville, TN, 6 December 1991. The full paper will appear in the Proceedings which are in press.

ARCHAEOLOGY

CRF Archaeological Project

by Patty Jo Watson

The archaeobotanical material from the world's longest cave is unparalleled in quantity and quality as evidence for the earliest (ca. 1000 - 500 B.C.) fully-fledged agricultural economy north of Mexico. Now that the Accelerator Mass Spectrometer ("direct") dating system is accessible, very small samples (e.g., a single seed) can be placed rather precisely in time. We already have available some 35 traditional 14C determinations (Kennedy, 1990), and have begun a second phase of chronological investigation making use of this new refinement. In September, 1991, 3 specimens from Salts Cave and Mammoth Cave were submitted for AMS dating, as follows:

1) a small core taken from a climbing pole, also thought to be prehistoric, in Dismal Valley, Upper Salts Cave: 2496 +/- 60 BP (545 BC), Beta-47472 (Figure 21).

2) a small piece of the bark lashing that attaches a crosspiece to the possibly prehistoric ladder in Star Chamber, Mammoth Cave: 2500 +/- 55BP (550 BC), Beta-47470 (Figure 22).

3) stick snapped off in a sediment bank in Upper Salts Cave: 2490 +/- 60 BP (540 BC), Beta-47471 (Figure 23).

Hence, all three items are indeed prehistoric. A fourth specimen (from Mammoth Cave) was submitted separately by Park Historian, Robert Ward, with results that will also be published soon.

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Watson, Patty Jo, and Kennedy, Mary C., 1991, The development of horticulture in the eastern woodlands of North America: women's role. In "Engendering archaeology: women and prehistory" (J. Gero and M. Conkey, Eds.), pp. 255-275. Basil Blackwell, Oxford, England. ∞

Figure 21: George Crothers examining a climbing pole found in Dismal Valley, Upper Salts Cave. (*Photo by Sam Frushour*).

Figure 22: Bark lashing attaching a crosspiece on what is believed to be a prehistoric ladder in Star Chamber, Mammoth Cave. (*Photo by Sam Frushour*).

Figure 23: The tip of what was probably a prehistoric digging stick remains embedded in a sediment bank in Upper Salts Cave. (*Photo by Sam Frushour*).

CRF FELLOWSHIP AND GRANT SUPPORT DURING 1991

Each academic year, the Cave Research Foundation sponsors a graduate Fellowship competition supported by an endowment fund. The Foundation may award as much as $6000 as one or more Karst Research Fellowships or as one or more grants for graduate research in karst-related fields of study. The truly exceptional proposal may receive a Karst Research Fellowship (limit $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, some of whom may also serve on the CRF Science Committee and some of whom may not be affiliated with the Cave Research Foundation. These judges seek promising or innovative topics, supported by evidence that the student has command of the literature and of the methodology. Proposals are judged on the basis of relevance and timeliness, technical quality of the proposal, and use of resources.

The Fellowship competition is cyclic and is in phase with the academic year. An announcement of the competition is mailed in early Autumn and states the requirements for applications, including the contents of the proposal package; the deadline for receipt of the proposal, supporting documents, and letters of reference is January 31. Awards are made in mid-April.

The Cave Research Foundation received 5 proposals in 1991. Of these, one proposal was awarded a Fellowship; two proposals received grants. The recipient of the award, the recipient's graduate school, the title of the proposal and a synopsis of the research are given below for each funded proposal.

1. For his proposed research entitled ***Evolution and biogeographic history of Edwards Plateau cave and spring salamanders (Eurycea and Typhlomolge): a molecular approach***, Mr. Paul Chippindale, Department of Zoology, The University of Texas at Austin, Austin, Texas, 78712-1064, was awarded a 1991 CRF Karst Research Fellowship in the amount of $3500.00.

   Mr. Chippindale's study will test various hypotheses concerning relations among cave- and spring-dwelling salamanders of the Edwards Plateau that have been advanced on the basis of morphology; a high incidence of parallel morphological evolution is suspected to characterize the group. He will employ a variety of primarily molecular methods, including protein electrophoresis, restriction site analysis of nuclear ribosomal and mitochondrial DNA, sequencing of portions of two mitochondrial genes, and flow cytometric analysis of nuclear DNA content. The results of the study are expected to help resolve questions about the biogeographical and evolutionary history of members of the group. Once the biological issues are sorted out, there are additional, practical and conservation implications: some cave populations that may have represented distinct species appear to have already been destroyed owing to human activities; other populations are threatened by development, pollution, and overuse of aquifer waters.

2. For his proposed research entitled ***Hydrogeological and hydrochemical characterization of the Matozinhos-Pedro Leopoldo Karst of Brazil***, Mr. Augusto Auler, Center for Cave and Karst Studies, Western Kentucky University, Bowling Green, Kentucky, 42101, was awarded a 1991 CRF Karst Research Grant in the amount of $750.00.

   Mr. Auler's research is intended to characterize the paleohydrology and existing hydrogeology of a poorly understood karst, the Matozinhos-Pedro karst area of southeastern Brazil. The study will entail an inventory of swallets and resurgences; dye tracing will be used to characterize patterns of ground water flow; seasonal variations in basic ground water chemistry will be measured and analyzed at selected sites; paleoflow indicators compiled from in-cave studies will be used to infer present and former flow directions among components of the karst. A general model of cave development formulated on the basis of this study will provide a scientific basis for improved planning of the on-going urbanization of Belo Horizonte (population about 3 million inhabitants located about 40 km away).

3. For his proposed research entitled ***Groundwater contaminant pathways in the dolostone karst of southwestern Wisconsin***, Mr. Philip Paul Reeder, Department of Geography, University of Wisconsin, Sabin Hall, P. O. Box 413, Milwaukee, Wisconsin, 53201, was awarded a 1991 CRF Karst Research Grant in the amount of $750.00.

   Mr. Reeder's study will assess the extent of groundwater pollution in the dolostone karst of southwestern Wisconsin and define the flow attributes of the routes by which contaminants reach the aquifer. Although the study emphasizes agricultural pollution (nitrates, chlorides, pesticides, and bacteria), 14 other chemical and physical parameters will be used to assess the hydrogeologic characteristics of the aquifer and other relationships pertaining to groundwater contamination. Dye-tracing will be used to identify subsurface flow routes and characteristics of contaminant pathways. Research on agricultural soil taxae and groundwater contamination has been conducted previously in the region The results of these studies will lead to development of a predictive model of contaminant behavior applicable to selecting appropriate practices for management of contaminants.

Research summaries and progress reports authored by these recipients and reports by other CRF investigators are published elsewhere in this volume. Please refer to those summaries for a perspective on the diverse scientific activities of the Foundation and feel free to contact the respective authors (see addresses of contributors, this volume) to obtain additional details concerning their research.

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INTERPRETATION AND EDUCATION

Figure 24: Lillian Novella "pulls chain" (caver terminology for the job of pulling a measuring tape from one station to the next station to take distance measurements) in Fitton Spring Cave in Arkansas. Note the carbide dot placed on the ceiling to mark that station.

Below, Susie Pierce takes a compass bearing between two stations using a Suunto compass. Fitton Spring Cave in Arkansas. (*Photos by Mike Pearson*).

INTERPRETATION

Lava Beds Photo Monitoring Project

by Bill Frantz

The Lava Beds National Monument photo monitoring project's objective is to set up a program to monitor cave resources in the monument. Since the start of the project in September 1989, we have set up 32 monitoring sites in 15 caves. These sites have been chosen to monitor breakage of formations; changes in the growth of ferns, ice and, "cave slime"; the extent of dust transport; and the condition of pictographs and graffiti. Each site has been photographed with a color slide, color print, and black and white print films (Figure 25). For each site, the location on a map of the cave has been marked, and a detailed survey has been prepared showing the location, bearing and inclination of the camera and strobe (Figure 26).

All the field work for the project is now completed. The only major remaining work is the final report.

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Figure 25: Bill Frantz photographing a monitor site in Postoffice Cave. (*Photo by Mark Bendickson and Bill Frantz*).

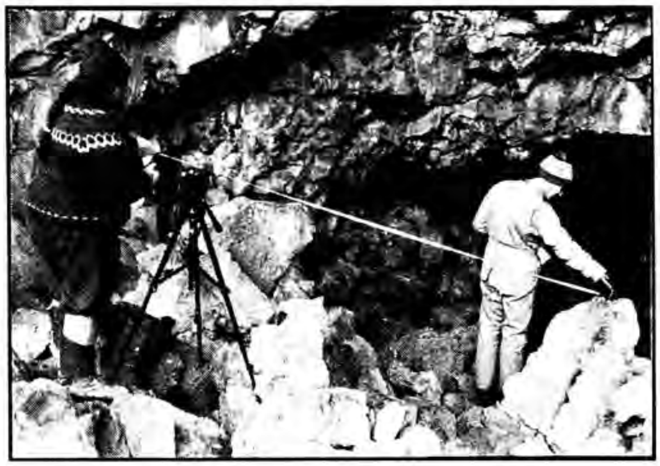

Figure 26: Peri and Ethan Frantz locating a survey site in Symbol Bridge. (*Photo by Bill Frantz*).

Reconnaissance Inventory of Lava Beds National Monument

by Mike Sims and Dan Weinberg

The objectives of this project are to develop a reconnaissance inventory card and define a procedure to provide basic documentation on caves, and to locate as many caves as possible and prepare inventory cards on each cave.

The first objective was completed in 1990. A reconnaissance card was designed and approved by the National Park Service. Procedures for filling in the information on the card were written. The reconnaissance inventory card serves to briefly record features of the caves and to alert Lava Beds staff and cave researchers of any features of note for each cave. Cavers carry reconnaissance cards as they explore the monument and should complete cards on any caves they visit. Completion of the cards is mostly self-explanatory. If a feature is observed on a particular trip, it is indicated by a "Y". Bearings to the cave entrance are taken with a compass to the high points of the major buttes used for triangulation.

During 1990 and 1991, reconnaissance cards were prepared for 89 caves. The major caves of the major cave trenches have been located. For 1992, reconnaissance will be concentrated on the more remote lava trenches in the Lava Beds wilderness area and the roadless areas.

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Ice Level Monitoring at Lava Beds National Monument

by Mike Sims

The objective of this project is to monitor the level and condition of the ice in six caves that have permanent ice floors. Continuous long-term data on ice levels will help the National Park Service staff in decisions which will help perpetuate these resources.

During 1990 and 1991, ice level monitoring stations were established in eight caves. Ice level and temperature measurements were taken in late winter and in late summer. Sketches were made on the appropriate cave maps to indicate the locations of the ice monitoring stations and the level markers.

The winter monitoring found all ice floors solidly frozen. The average winter temperature was about -3° C. Summer monitoring found liquid water on the ice floor surface in only two caves, and the only substantial water was, as is normal, in Big Painted Cave (Figure 27) where the water was about 0.4 ft. deep. The average summer temperature was from +0.2° C to +1° C in the caves.

Upon completion of this project in 1992, written procedures for continued monitoring will be provided to the National Park Service, along with the final report which will give detailed data and graphical representation of the results.

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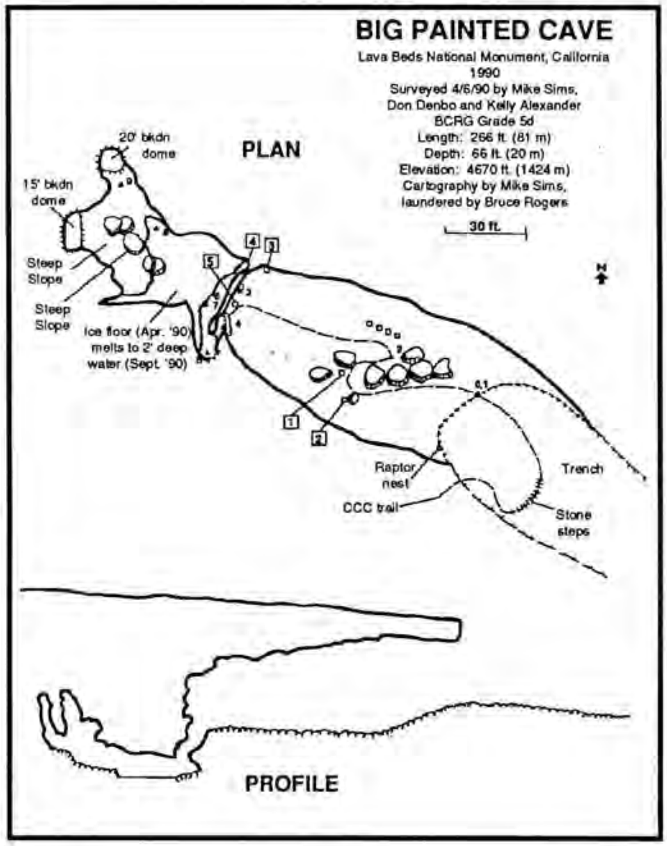

Figure 27: Map of Big Painted Cave in Lava Beds National Monument, California. This cave is one of eight caves with ice floors being monitored.

Results of Precise Relative Humidity Measurements at Kartchner Caverns and Lechuguilla Cave

by Robert H. Buecher

Knowledge of the relative humidity is useful in understanding many facets of the cave environment. Relative humidity and evaporation from cave surfaces is an important aspect of the biologic microclimate and a controlling factor in determining the morphology of speleothems. Relative humidity is also an indication of the rate of evaporation and the subsequent removal of moisture from the cave by air exchange. Within a cave, temperatures are remarkably constant and air movement is generally very slight. Under these conditions, evaporation from cave surfaces is largely determined by the relative humidity of the cave air. Evaporation rates are expected to be inversely proportional to the relative humidity; i.e. the higher the relative humidity, the less evaporation. At a uniform 100% relative humidity, there would be no evaporation.

Relative humidity is a measure of the amount of moisture contained in the air compared to the maximum amount of moisture that the air could hold at a given temperature. Most caves have high relative humidities, often approaching 100%. Accurate measurement of relative humidity becomes increasingly difficult at the high relative humidities typically found in caves.

Relative humidity measurements in caves have typically been done with sling psychrometers. At the high humidity levels usually found in caves, the accuracy of a sling psychrometer is dependent upon the resolution of the temperature measurements. For temperatures accurate to half a degree Fahrenheit, the relative humidity measurement has a resolution of ±3.5%. With a temperature resolution of a tenth of a degree, the resolution is increased to ±0.7%. Our experience has shown that this method is not accurate enough to determine the variations in relative humidity that typically occur throughout a cave. The relative humidities determined from sling psychrometers almost invariably turn out to be 100%. Without better accuracy the relative humidity measurements merely confirm a very high relative humidity without giving sufficient accuracy to allow correlations to be made with other measurements.

In recent years, a number of solid state relative humidity sensors have been developed. Unfortunately, these all suffer from large errors at the high relative humidities found in most caves. Typical accuracy for these sensors is ±3% at relative humidities above 95%.

An unusual device, the soil psychrometer was suggested as a method of measuring high relative humidities by Chuck Graf and Dr. Todd Rasmussen. The soil psychrometer is capable of measuring relative humidity from 93% to 99.9% with an accuracy of 0.05%. Furthermore, the soil psychrometer measures the relative humidity by two independent methods. One is by directly measuring the dewpoint temperature while the second measures the wet bulb depression. While ideal in many respects, the soil psychrometer has several disadvantages. To obtain the maximum accuracy, probes must be allowed to stabilize for 30 to 60 minutes. Also, relative humidity can only be determined in areas of very stable temperatures. Additionally, the equipment is moderately bulky and requires some experience in use.

An extensive series of relative humidity measurements have been made at Kartchner Caverns. Figure 28 illustrates the distribution of 318 precise relative humidity measurements throughout the cave. The average relative humidity for all measurements is 99.42% but is highly skewed toward the higher values; 84% of the readings fall above 99% relative humidity.

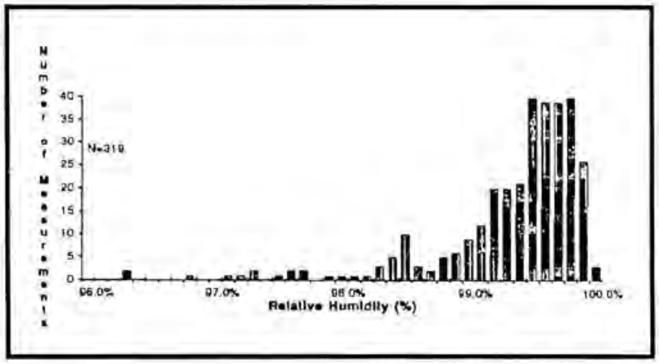

Figure 28: Distribution of Precise Relative Humidity Measurements, Kartchner Caverns, Arizona.

Another series of relative humidity measurements were made in Lechuguilla Cave during several science expeditions. The distribution of 41 measurements is shown in Figure 29. The average relative humidity is 99.26% with 88% of all measurements being above 99% relative humidity.

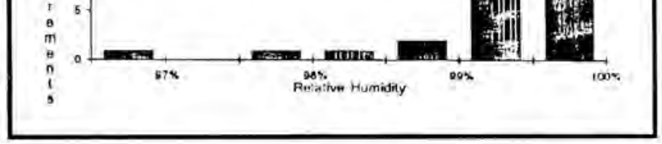

Figure 29: Distribution of Relative Humidity in Lechuguilla Cave, New Mexico.

These measurements show that the relative humidity in Kartchner Caverns and Lechuguilla Cave is almost always above 99%, except near the entrances. Traditional methods of measuring relative humidity would be unable to make meaningful measurements at the high relative humidities encountered in these caves. The skewed distributions may be the result of decreasing accuracy of the soil psychrometer at relative humidities above 99.7%.

At Kartchner Caverns, evaporation rates have been measured at 22 monitoring stations on a monthly basis and at a number of other locations adjacent to the natural entrance. At each location, a 9 in. diameter aluminum pan (surface area 382 cm^2) was filled with a volume of exactly 750 ml of distilled water. The volume of water was carefully measured each month and the evaporation rate (or, in a few instances, a gain from condensation) was determined from the change in volume. The distribution of 400 monthly evaporation rates is shown in Figure 30. This represents the observed distribution at 19 stations which are at least 150 meters from the entrance to the cave. The average evaporation rate is 5.3 ml/m^2/day and the distribution is skewed toward very low rates of evaporation. Experience indicates that the evaporation rate can be determined with an accuracy of 1.5 ml/m^2/day with the methods used. Approximately 93% of the monthly measurements show evaporation taking place. The remaining 7% show an increase in the volume of water due to condensation onto the surface of the water. The measured increases are not due to drips splashing into the pans. Those pans which were found to have been placed near actively splashing drips were not included in this analysis. Also, graphs of the data from individual stations show a smooth transition from periods of evaporation to periods of condensation.

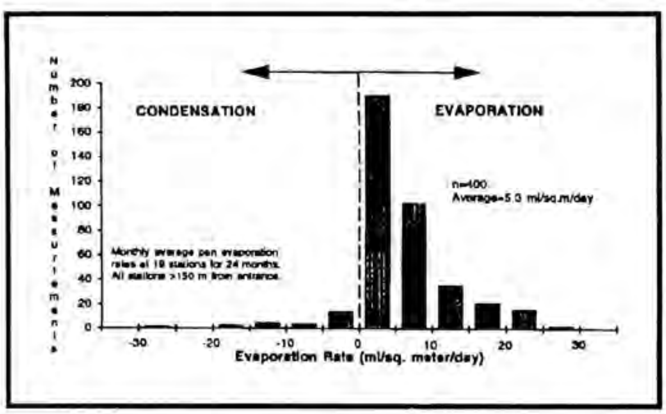

Figure: 30: Distribution of Pan Evaporation Rates in Kartchner Caverns, Arizona.

Historically, evaporation rates have been estimated from empirical equations based on the differences in vapor pressure. For the high relative humidity (99.4%) observed in Kartchner Caverns, these equations would predict evaporation rates of 50 ml/m^2/day. This is about 3 times greater than has been observed. Most likely, the empirical equations, which were developed from surface experiments, are not completely valid for the cave environment.

The expected evaporation rate within the cave can also be predicted by assuming that the mechanism is entirely due to molecular diffusion. At 99.4% relative humidity, the evaporation rate due to diffusion is calculated to be 8.4 ml/m^2/day by the integrated form of Stefan's law. This is very close to the 5.3 ml/m^2/day average for stations removed from the natural entrance. Water loss by diffusion represents a lower limit of the expected rates of evaporation. Diffusion will occur in totally still air with no temperature gradients, as it is dependent only on the water vapor pressure gradient. The presence of moving air, convective currents and temperature fluctuations will all act to increase the rate of evaporation. This indicates that, for a majority of the cave, molecular diffusion may be the predominant mechanism for evaporation. This also implies that air movement is very slight and that temperatures are very stable.

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EDUCATION

Names and Places in Mammoth Cave

by Mick Sutton and Sue Hagan

Gazetteer

The Mammoth Cave gazetteer continues to make steady progress, with the database now standing at approximately 1850 entries. A crop of new names arose from the recent explorations in the Southern Highlands area off Logsdon River, and from less extensive discoveries within Mammoth Cave Ridge. These range from the historic, such as Kaemper Avenue, named for Mammoth Cave's most renowned cartographer, to the imaginative, such as the Nervous Breakdown Room, named for the somewhat airy route into it. Most of the major place names for the Roppel Cave section have now been added from standard sources, though a great many of the more obscure Roppel names are still missing.

Bob Salika's extensive collection of Mammoth Cave postcards was a rich source of material; the advantage of these is that features which would otherwise be a complete mystery (the Masterpiece, the Climbing Bear,...) can be field checked against the illustrations. The old Crystal Cave tour trail map provided another whole series of names, including such wonders as the Onyx Pig and False Teeth Hall—these may be difficult to positively identify! Another interesting source turned up last year was a copy of the standard Hovey and Call guide book, carefully annotated by Alberta Server, a 1923 tourist. The list of names is comprehensive enough that most of the obscure ones (Old Maid's Dome, the Wine Cellar, Little Miss Hercules....) can be placed at least approximately relative to well-known features. Walter Johnson kindly provided a copy of this work. If anyone has a similarly annotated guidebook, we'd very much appreciate a copy. These informal notes tend to preserve names which are recorded nowhere else, and can give some interesting insights into the nature of the historic guided tours. For example, the intensity of the tour trips is astonishing from a modern perspective; in only two days, Ms. Server saw all four routes offered, and also squeezed in the Great Onyx tour. Having finished one route at 11 p.m., she took a half-hour break before setting off again, this time exiting at 3 a.m.

Work continued on improving the quantity and quality of information for existing gazetteer entries, and on cross-referencing. The preliminary printout planned for 1991 fell behind schedule, but will be produced during 1992.

Bibliography

The bibliographic database being assembled in parallel with the gazetteer has begun to take shape as a significant project in its own right. We have begun entering material not directly relevant to the gazetteer, and during 1991 the number of entries increased from 220 to 1000 (still rather small by Mammoth Cave bibliography standards). A collaboration was begun with Ray Mansfield of the British Cave Research Association, who has one of the most comprehensive bibliographic collections of older Mammoth Cave references. Mansfield's material is on file cards, and transferring it to the electronic database promises to be a labor-intensive job. This process is planned to begin in 1992. We hope to eventually include others in a collaboration to publish an up-to-date Mammoth Cave bibliography.

Passage Description

Descriptive efforts continued to concentrate on the Kentucky Avenue area, in parallel with the map sheet nearing completion. Writing readable descriptions of areas such as East Robertson Avenue—an incredible canyon maze—proved challenging, but the effort is starting to shape up into a comprehensive adjunct to the Kentucky Avenue sheet. The emphasis is on connectivity, passage relationships, and route finding, but a lot of other information is added as available.

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Corrosion of Handrails Along Cave Tour Routes

by Rick Olson

Aluminum and stainless steel alloys have largely replaced galvanized or painted steel as the materials of choice for the construction of handrails. Aluminum and stainless look much nicer than the old materials, and have generally been considered more stable. However, hydrous clear to white deposits on aluminum handrails over Bottomless Pit in Mammoth Cave were found to be alumina gels produced by corrosion (Olson, 1991), and similar accumulations have been reported in Blanchard Springs Cave.

The persistent high humidity of the underground environment causes the protective oxide surface layers on aluminum and stainless to become hydrated. This hydration renders the oxide more vulnerable to attack by chloride ion (Shreir, 1976). Most cave passages are not naturally a high chloride environment, but on tour routes perspiration from the hands of visitors accumulates on the top rail, and gradually trickles down supporting posts. Several types of corrosion can result. The top rails develop pits, crevice corrosion takes place within sleeve joints or in sensitized metal near welds, general surface corrosion occurs on vertical posts, and, if the anchoring bolts are of a different alloy, then the salt solution serves as electrolyte in a galvanic cell. In every case, the damage done may not be highly visible, but serious weakening of the handrails can occur.

Corrosion of handrails can be minimized by selection of materials, regular rinsing, and construction design. For example, aluminum alloys with titanium have increased resistance to attack by salt (Merck Index, 1976). Titanium's great strength and corrosion resistance make it useful in marine applications (Weast, 1975), although for handrails it's great cost is probably prohibitive. Low carbon stainless steel alloys with a few percent of molybdenum and a little more chromium than usual are less susceptible to chloride, and are less prone to weld sensitization (Lula, 1986). However, it is important to accept that any of these choices will eventually corrode. Periodically rinsing the handrails would be a helpful step in corrosion control. Chloride salts are highly soluble, so the quantity of water needed would be small. Additionally, if at any point dissimilar metals are used then electrically insulating materials must separate them at all points. Polymer coatings on aluminum railings can delay the onset of corrosion, but, like paint, the protective layer is eventually breached.

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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.

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