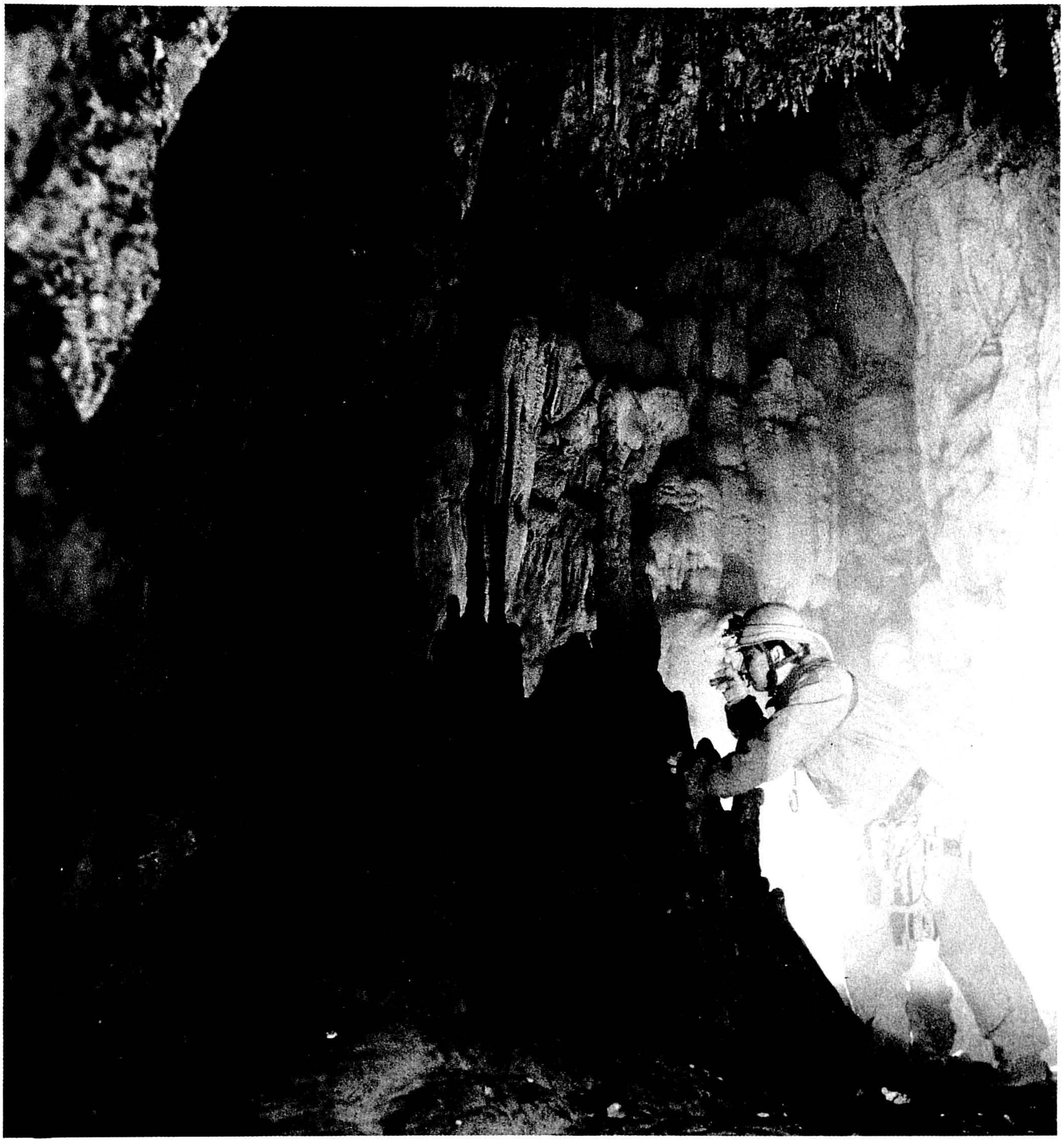
CAVE RESEARCH FOUNDATION

1993 ANNUAL REPORT



Cave Research Foundation

ANNUAL REPORT

1993

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): Chinese caver Zhu An, from the Guizhou Normal University in Guiyang, China, surveys in a cave in the Guizhou province. This trip was part of CRF's continuing cooperative venture with Chinese scientists during 1993. (*Photo by Ian Baren*).

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CAVE CONSERVATION

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

Caves are fragile in many ways. We take considerable care that we do not destroy that which we study because many of the cave features take hundreds of thousands of years to form. Also, many of the processes that formed the cave passages we travel are no longer active in these areas. People who unthinkingly take or break stalactites and other cave formations cause great and irreparable damage. Cave life, such as blind fish, live in precarious ecological balance in their isolated underground environment. Disturbances, such as causing bats to fly during winter hibernation, can be as fatal to bats 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, 2813 Cave Avenue, Huntsville, AL 35810-4431, USA, (phone (205) 852-1300) for excellent advice and guidance for novice and experienced alike.

Highlights of 1993

The Cave Research Foundation was established in 1957 in the Commonwealth of Kentucky as a non-profit scientific organization. The goals of the Foundation, then and now, are to explore and scientifically study the extensive cave systems of the world, encourage the preservation of caves, and educate ourselves and the public through the collection and dissemination of data and information about caves.

Behind those fine principals it is important to remember the excitement felt in our young organization at its founding when the combination of dedicated graduate students, who would spearhead a rebirth in cave science, and talented amateur cavers came together to reestablish respect, in North America, for the various disciplines making up cave science. As cave science grew within the fostering environment provided by CRF, it expanded into many avenues. It was a given that geology would have break-throughs in cave morphogenesis. Its offshoot hydrology blossomed within the Foundation and elsewhere. Young biologists became senior investigators in cave ecology. Standards of speleological cartography were established. World-class work in archaeology was conducted. Inventory and monitoring became a standard method for cave management.

The year 1993 is approaching the millennium and CRF has already progressed two years into the Hamilton Valley Project. True, CRF's strength has always been in its people and it is in our people that we will prosper through the 21st century. Still, the Hamilton Valley Project is an important part of our formula for a continued strong future supporting cave science. Architectural and engineering planning contracts for the buildings have been approved by the Board of Directors. The land preserve, which is a major part of the Hamilton Valley Project, has been established as an administrative structure within the Foundation. In this, there is a strong link with the past with Founding Director Roger McClure acting as the Hamilton Valley Administrator. We predict that in 1994 construction of the infrastructure will have begun with a road leading to the building site, improvement of the county road, digging of a deep well for water. In the spring of 1995 ground breaking will occur.

Elsewhere in our organization, vital projects continue in California, New Mexico, Texas, Arkansas, Missouri, Kentucky and overseas in China. To name one, the Resource Inventory Project at Lava Beds National Monument, in California, represents the model nationwide for capturing this kind of information for managers of federal and state public lands.

Sincerely,

Melburn R. Park, Ph.D.
President

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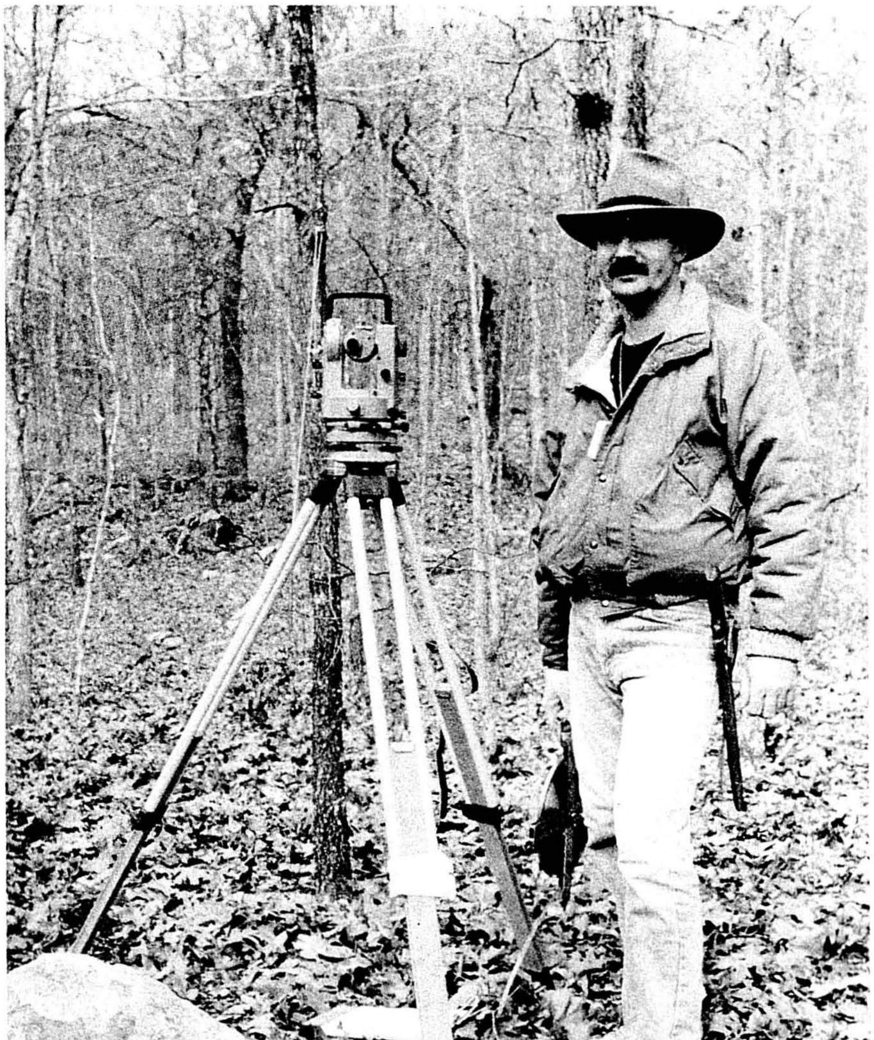

Figure 2: Mike Pearson waits for the range pole to be placed while running a transit survey near Fitton Cave, Arkansas (*Photo by Pete Lindsley*).

CRF's China Project Continues

by Rondal R. Bridgemon

The Cave Research Foundation's cooperative venture with Chinese scientists continued in 1993. For a month during March and April, a thirteen-member team again joined forces with speleologists from the Guizhou Normal University in Guiyang. The primary areas of study during this expedition included a continuation of work started by a CRF team in 1991-1992 near the town of Guado (west of Guiyang) and a new area near Kai Kou south of the capital city. (Cover photo, Figures 3 and 4).

The multi-discipline team consisted of Ian Baren (team leader); Ron Bridgemon (assistant leader); Janet Sowers, Dwight Deal, and Don Coons (geology); John McLean (hydrology); Mick Sutton and Tom Strong (cartography); Mike Newsome and Chuck Pease (engineering). Seven scientists from Guizhou University rounded out the field study group.

A total of 33 caves were visited during the expedition and nearly 18 kilometers of passage were surveyed. Of particular note was the continuation of work in Dou Bin Dong, a magnificent river cave located near Guado. While no physical connection was made to other systems in the area, the trend of newly discovered major trunk passages would make a connection seem imminent. Near Kai Kou a tremendous sink named Wang Son Tai (200 m across and 100 m deep) led into four major trunk passages where over 5 kilometers were mapped in two days.

In addition to the two primary work areas, the team assessed the show-cave potential for several caves and made recommendations for improvement of a cave currently being developed for tours.

A publication detailing the results of the last two CRF expeditions to Guizhou Province is currently being prepared.

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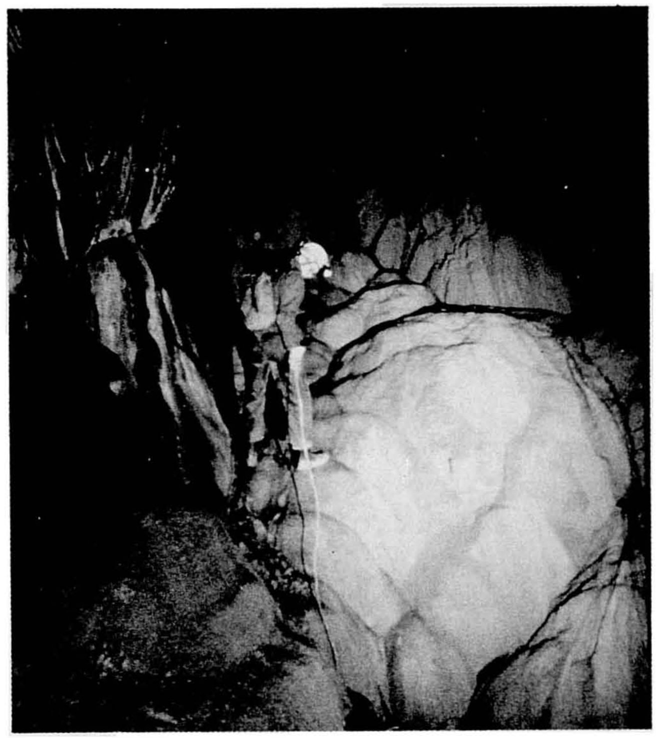

Figure 3: Ron Bridgemon rappels into Blowing Cave during CRF's continuing project in China.

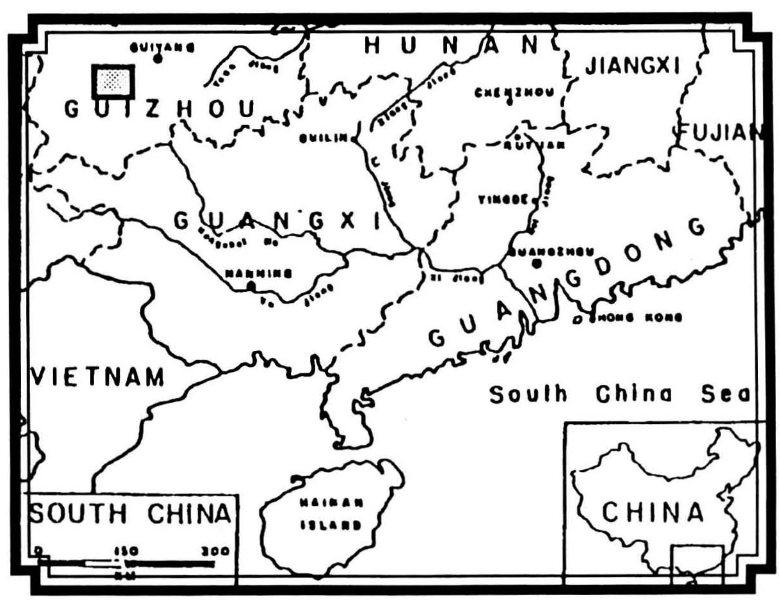

Figure 4: Map showing study area (square) in Guizhou province, China.

Redwood Canyon Cartography 1993

by Peter Bosted

The 1993 caving season saw six cartography expeditions to Redwood Canyon, in Sequoia/ Kings Canyon National Parks, California. As in previous years, the primary focus was on Lilburn Cave. About 260 survey stations were set during 14 survey trips, yielding about 2,400 feet of new passage, plus 500 feet of resurvey. Over half of the new survey came from an extensive area above the Hex Room that was reached by an airy traverse. Interesting deposits in this area included charcoal and malachite. An extension of the AtticAttic region was found which showed promise of heading towards May's Cave, but became too tight. Extensive checking of the quadrangles for the northern part of the cave revealed some errors and some small side passages. Bill Farr re-dove the Upstream Rise, reaching the same point as on his first dive, but this time was able to survey his 252-foot penetration. His survey may help to identify good locations to search for the hypothesized northern extension of Lilburn Cave. In the middle part of the cave, some extensions were made to Pandora's Passage. No trips were made to the south end of the cave due, partially due to unusually wet conditions after five years of drought. At the end of 1994, the length of Lilburn Cave was a little over 14 miles.

Two trips were made into May's Cave, resulting in 570 feet of survey using 61 stations. This cave is more extensive and complex than previously thought, and hard pushing may eventually reveal a connection with Lilburn.

Progress was made in drafting detailed quadrangle maps of Lilburn Cave (see 1992 CRF Annual Report for examples).

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Survey and Inventory of Fleener's Chimney Cave

by Janet M. Sowers

Introduction

Fleener's Chimney Cave is the interior of a volcanic spatter cone, the middle of the three such cones called the Fleener's Chimneys at Lava Beds National Monument. These chimneys were vents for lava of the Devil's Homestead lava flow, which erupted along the Gillam fault during the Holocene. The three chimneys are within 165 feet of each other; two are plugged with cinders and debris and do not lead to cave passages. (Figure 5).

Purpose and Methods

In 1992 the Park Service requested a detailed survey and inventory of this cave. Fleener's Chimney Cave had recently been dug open after decades of closure due to collapse. The data gathered would be used to guide management decisions regarding this cave.

The cave was surveyed with tape and compass by Mike Sims, Bill Devereaux, and Dan Weinberg in November of 1992, and a sketch map of the cave made at a scale of 1 inch = 20 feet. A detailed inventory of the cave's features and contents was made in February of 1993 by Janet Sowers and Bob Martin, using the 1991 General Cave Resources inventory form developed jointly by the Cave Research Foundation and Lava Beds National Monument. Sowers and Martin photographed the cave, collected six mineralogic samples, and added detail to the map on this trip. Bruce Rogers analyzed the mineralogic samples in September 1993.

History of discovery and rediscovery

The first written record of Fleener's Chimneys dates back to 1916. J. D. Howard, a local miller and

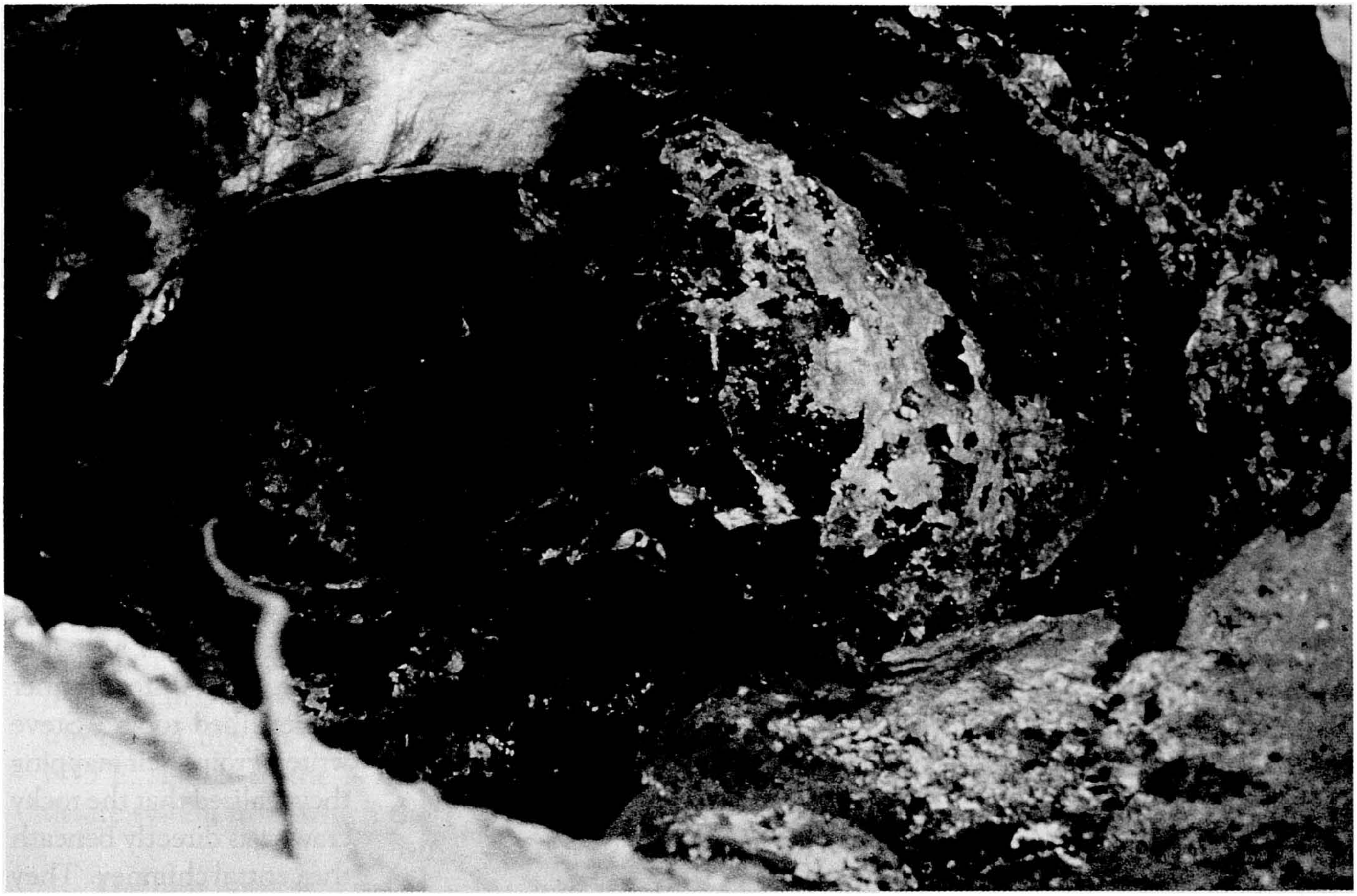

Figure 5: View from the bottom of the vertical entrance shaft. This tube was a conduit for upward moving lava. (Photo by Jante Sowers).

devoted cave explorer, named the chimneys after Sam Fleener, an early settler who homesteaded north of Lava Beds. On Howard's first visit to Lava Beds, he tells of visiting Fleener's Chimneys. On September 10, 1916 he wrote, "I have been to the Lava Beds for the first time, was with Geo. Howell and wife, also daughter. Stopped at the Chimneys, Nine Miles South of Sam Fleeners. George tells me that there are many others, so I have named these Fleener's Chimneys, so as to name the ones I have visited." There is no record that he entered the chimneys at that time.

Fleener's Chimney Cave was entered and explored in the 1920's. A painted sign in the lower level of the cave reads "E.W. + R.E. Irwin are first in, Sep. 8th, 1922". The sign is painted on a smooth panel of dark basalt in white paint. J. D. Howard made a map of the cave; a copy is stored in the Lava Beds National Monument collection. (Figure 6).

Steve Liebelt, one of the cavers who initiated the recent excavation of Fleener's Chimney Cave, reconstructed the probable history of the cave during the 1920's and 30's in a 1994 letter to the author. Visitors to the cave were probably assisted by steps dug into the sloping cinder wall and a wooden ladder. Sometime during the 1930's the cave was connected to the South Chimney, either by natural collapse of the cinders or by people digging through the soft cinders. The connection enabled visitors to make through-trips, going into one chimney and out the other. Older visitors

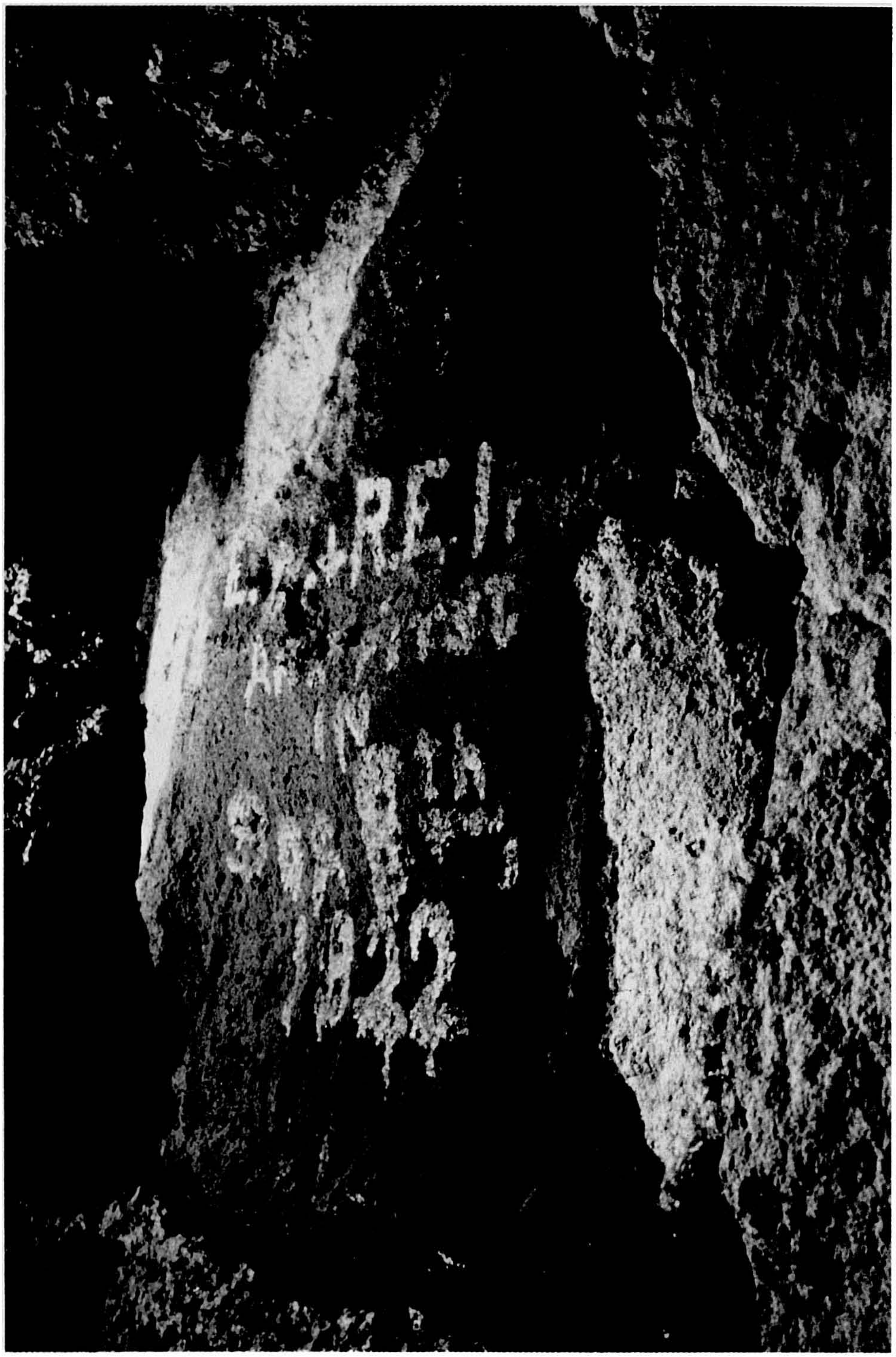

Figure 6: Historic sign in lowest slot-like passage in Fleener's Chimney Cave. (*Photo by Janet Sowers*).

recall such through-trips. Eventually, the entire bottom of the shaft became plugged with cinders and debris and the trips halted. The exact year of closure is not known, but the cave remained closed for decades, its 54-foot-deep shaft eventually reduced to about 20-foot-deep by accumulated debris including cinders collapsed from the walls, and rocks and trash tossed down the shaft by visitors.

In 1989 cavers Eric Anderson and Steve Liebelt heard about the old connection and went looking for it. At the bottom of the south chimney they found a crawlway "into a cinder filled room with a smaller rocky crawl into another cinder filled room", Steve writes. From their mapping they realized that the rocky crawl was directly beneath the central chimney. They shared the news with Lava Beds interpreter Gary Hathaway who pulled out J. D. Howard's old map. They then realized that the rocky crawl was within the vertical shaft of the central chimney and that most of Fleener's Chimney Cave was beneath. They began a digging program in cooperation with the monument, and finally in 1991, after tons of rock, cinders, and debris had been hauled from the shaft, they reopened the cave.

The material hauled out of the cave is a story in itself - a mixture of rock, cinders, and miscellaneous junk dropped down the shaft by visitors. Leibelt writes, "Among the more interesting artifacts include dated beer cans and batteries from the

1930's, live bullets (mostly 22), empty shells of various calibers, fishing tackle, a corn cob pipe, seemingly every style of can or bottle ever made, eye glasses, sun glasses, a camera, coins with dates from the teens to the nineties, a ball-peen hammer, marbles, a deer skull or two, multiple deer jawbones, multiple rodent bones, pieces of the previously mentioned ladder, and of course all manner of garbage..."

Physical characteristics

The cave is best described, from bottom to top, as a vertical slot funneling upward into a single sloping, vertical tube, with a portion of the tube widened by collapse. The lower, slot-like portion of the cave is 1 to 3 feet wide and extends 100 feet in length. The slot is in two levels, totaling 35 feet in height from the bottom of the lowest level to the top of the highest level. The slot trends about N15°E, similar to the N30°E trend of the larger fissure system from which the lava flow erupted.

The tube portion of the cave begins at a depth of 70 feet and slopes upward, becoming vertical at a depth of 54 feet. From here the tube is a vertical shaft to the surface. The tube is lined with a thin coating of smooth lava. This coating of lava is breached near the base of the tube revealing a paleosol at the top of a thick layer of cinders. The breach has allowed loose reddish cinders to cascade down the shaft.

Geology and secondary mineralogy

The geometry of the cave reflects the upward movement of lava through a fissure system. The formation of the chimneys may have been influenced by the presence of a thick layer of cinders overlying the rock fissure (Gillam fault) at the location of the Chimneys. Lava may have welled up through the fissure during the eruption, then pooled at the base of the cinders that lay as a blanket over fissure. Pressure built up at the base of the cinders and ultimately the lava punched through. Lava shot upward, creating a tube-like shaft through the cinders, and building a small spatter cone of lava on the surface.

The most fascinating aspect of Fleener's Chimney Cave geologically is the sense one gets of being inside an erupting fissure. The walls and ceiling in portions of the lower levels are coated with frozen drips of lava. The vertical shaft is lined with volcanic glass. Matching ledges on either side of the lower passages attest to short term ponding of the lava inside the fissure as the lava sank back into the earth.

The cave also contains an unusual amount of mineralization compared to other caves at Lava Beds. Secondary minerals coat portions of the wall and ceiling as coralloids, botryoidal crusts, and clusters of tiny crystals. Fine needles occur in the fine sediment on the floor. Six mineral samples were collected and examined under a microscope by Bruce Rogers. He identified all as gypsum, $CaSO_4 \cdot nH_2O$.

Visitor management

The cave has received little visitation overall, and will likely receive little in the future. Despite its unique geologic features, the cave is small and relatively unappealing compared with other caves in the area, and rappelling the vertical entrance and negotiating the tight passages requires special skills. Entrance is now controlled by a gate both for safety reasons and to protect the cave. Safety is a major concern as the cinder layer exposed in the lower part of the entrance shaft continues to collapse.

Acknowledgments

This study was supported by the Cave Research Foundation and Lava Beds National Monument (reference order #1443-PX8410-92-220). We thank P. Toops, B. Stoffel, E. Anderson, S. Liebelt, K. Strassburg, and C. Roundtree for information and logistical assistance. ∞

Guadalupe Area Cartography

by Pat Helton

Carlsbad Cavern

Carlsbad Cavern survey is unofficially at 30.8 miles which is amazing when compared to the 19.6 mile total we had in September 1991. Dick Venters retired as Area Manager and was replaced by Tom Madison in April. We miss Dick's leadership and look forward to his return to the Guadalupes as just "one of the gang". Tom Madison is bringing CRF up to a new and higher level of professionalism. He is making positive efforts to put the "Research" back into the Cave Research Foundation by recruiting accredited scientists to the program. He has also been instrumental in securing advanced lab facilities in Carlsbad for use by CRF researchers. Operating under the theory that it is easier to train a scientist to be a caver than to train a caver to be a scientist, Tom is making good progress in bringing in researchers in many science disciplines.

In the exploration and survey efforts, a new, detailed set of cave survey standards was put into effect. These standards increase the responsibilities for all members of the survey party. The results to date are very encouraging with sketches and survey data more descriptive and accurate. Loop closure error has been reduced over 50%. Ron Lipinski has developed an exciting 3D rotation map of Carlsbad Cavern that has already proven useful in highlighting new discovery potential. We are now in the process of developing solid 3D modeling of the Cavern and other backcountry caves.

Diana Northup with assistance from Saul Cross continue the biology inventories of the backcountry caves of Carlsbad Cavern National Park. Geological inventories will soon follow.

Spider Cave

Spider Cave is located to the west of Carlsbad Cavern and south of Lechuguilla Cave. Until recently, cavers assumed that Spider was pushed to its survey limits at approximately 8,300 feet. Richard Knapp has been managing further exploration and survey in Spider and is nearing the 20,000 ft. mark with much more to be done, This cave often exhibits tremendous airflow indicating far greater passages exist than presently known. In addition to the exploration and survey in Spider, geological inventories are revealing new mineralogy discoveries which may have an impact on current theories of speleogenesis in the area.

Dry Cave Project

CRF recently reopened the exploration and survey in Dry Cave. Work in Dry Cave in the 1960's and 1970's pushed and surveyed approximately 50,000 feet of passages in this complex maze cave. In the first few trips into Dry approximately 4,000 ft. of new, unsurveyed passage near the entrance area was pushed and mapped. This is a long term project that should find over 100,000 ft. totals when completed. The cave was effectively closed for many years so that significant paleological discoveries could be excavated and studied. The cave remains closed to the general caving public. Since the cave had been dosed for these many years, a baseline biological inventory was conducted by Saul Cross prior to cavers reentering the cave. Val Hildreth and Jim Werker have set photo monitoring points in the cave to study changes in this environment during the push and survey expeditions.

Fort Stanton Cave

Fort Stanton Cave is located in the Roswell, New Mexico district of the Bureau Of Land Management. Under the direction of John Corcoran and Gavin Corcoran, CRF is involved in a precision survey of this historically significant cave. The current survey is nearing the nine mile mark. Randy Cabeen is cooperating with BLM in setting up a security system in the cave to help protect this often vandalized cave.

Lincoln National Forest Project

Under the direction of Dick Venters, CRF is conducting exploration and survey efforts in this new-to-caving area west of Roswell, New Mexico. The area is located with big, unexplored limestone sinks and blowholes. Significant new caves have been discovered and mapped. Much more work remains to be done, and many more years of good virgin caving remain on this project. CRF conducts a week long camp every year on this project.

Carlsbad Cavern Restoration Field Camp

CRF holds a week long restoration camp at the Cavern. Under the direction of Dave and Sue Ecklund, many thousands of volunteer hours have been donated and many thousand tons of rock and rubbish have been removed from some of the more historic areas of Carlsbad Cavern. For the last few years, work has concentrated on the old lunchroom area which was leveled with dirt fill and rock years ago. Restoration has revealed many rimstones, popcorn and other beautiful formations. These volunteers accomplish an amazing amount of work every year.

CRF wishes to thank all of the many volunteers who give their time and effort to these worthwhile projects. You really do make a positive contribution toward the exploration, mapping, research and conservation of these beautiful caves. On behalf of these volunteers, the Guadalupe Escarpment Area of Operations of the Cave Research Foundation wishes to thank Carlsbad Cavern National Park, the Bureau of Land Management, and the National Forest Service for their cooperation and support for our operations.

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Missouri Cave Inventory and Mapping

by Scott House and Doug Baker

As in the past several years, most of the CRF work in Missouri focused on the 1.7 million acre Mark Twain National Forest. Two, new, major projects were initiated on lands owned by the Missouri Department of Conservation and the private Pioneer Forest. Lastly, work continues on one major cave (owned by the Department of Conservation) that lies within the boundaries of the Ozark National Scenic Riverways. In general, although much was accomplished, field work in 1993 was very negatively impacted by the unusual weather typified by tremendous flooding and high water levels in the state from March through November. Access difficulties and safety concerns canceled numerous scheduled trips.

Mark Twain National Forest

A number of caves were mapped, inventoried, and biologically assessed as part of a continuing project to obtain baseline data in an area of the Forest surrounding the Eleven Point River, a national wild and scenic river. The area, in southern Shannon and northern Oregon Counties, lies in the heart of the southern Ozark karst region where several of the nation's larger springs have their recharge areas. Some of the caves lie within the Irish Wilderness, a federally designated wilderness. Two small caves in this area, Sand and Bliss Spring, were surveyed while three trips to Bliss Camp Cave established that it had large trunk passage in it and that it connected to nearby Outflow Cave. The survey of this interesting system is not yet finished. Two crews mapped and inventoried 1700 foot-long Bat Cave and discovered a new section of the cave with the cave's largest roost site. Two more small caves were also surveyed and inventoried.

Elsewhere, the survey of the longest cave in Mark Twain National Forest was completed. Seven trips, totaling over 2000 feet, finished off Douglas County's Still Spring Cave (Figure 7). Long dry crawls and long stream crawls, requiring wet suits, lead to extensive canyons and rooms far upstream. Eventually the leads were finished one by one and another extensive project was finished with 3.7 miles of passage.

Pioneer Forest

One major project that we initiated in 1993 was a cooperative project with Pioneer Forest, a

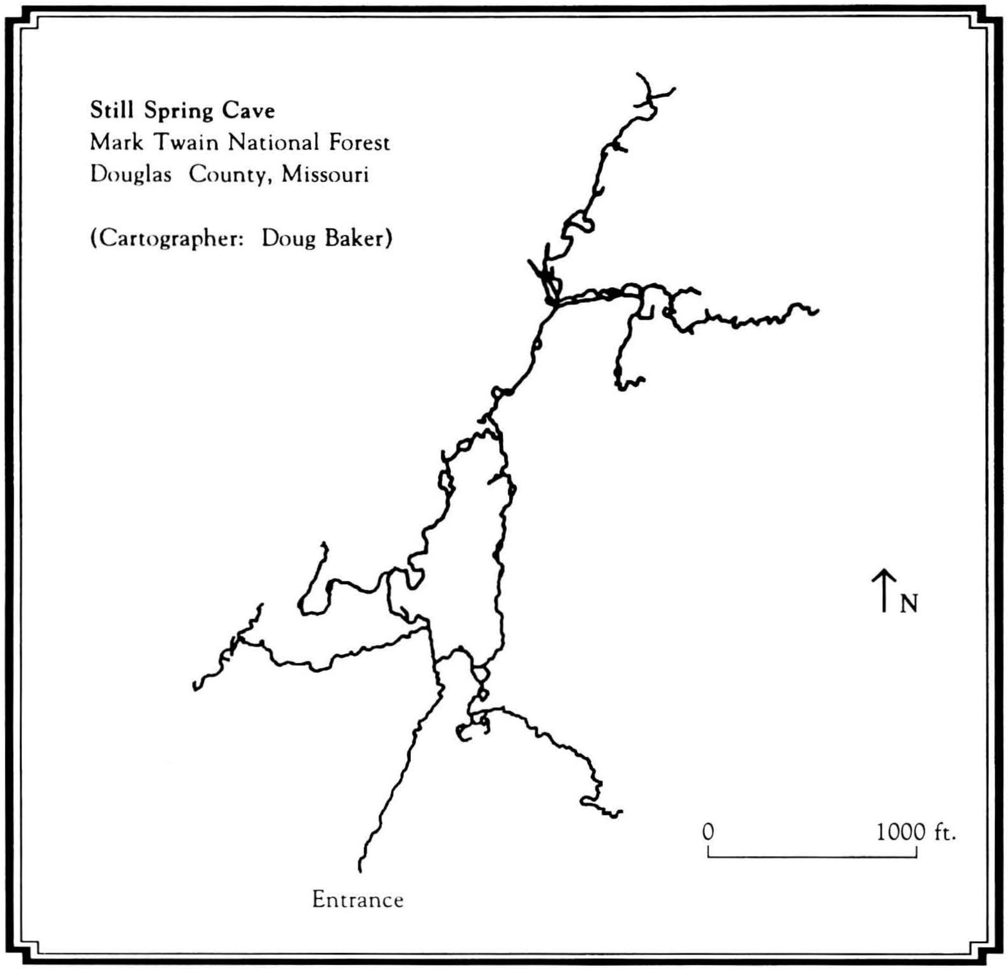

Figure 7: Map of Still Spring Cave, Mark Twain National Forest, Missouri.

private forest of 180,000 acres owned by a well-known conservationist, Leo Drey. Pioneer Forest is a model of a private forest that is managed for renewable resources while protecting lands of exceptional scenic and scientific value(Figure 8). CRF's project builds on work done some years ago on certain portions of the land, particularly Leatherwood Creek, a deep canyon drainage off of the Jacks Fork River. Over thirty caves, most relatively short, are to be found along a three mile stretch of the creek. The goal of the project is to produce cave maps and do a biological and management assessment.

Three trips were taken in 1993 to Leatherwood Creek. Six small caves were surveyed and several potential caves were investigated. In addition, Leatherwood Cave, Leatherwood Arch, and Leatherwood Arch Cave were surveyed (Figure 9). The former is one of the largest caves in the area with over 700 feet of passage. The latter two are really one feature, a natural arch (one of the largest and easily the most beautiful in Missouri) and a cave behind it that also goes through the hill to another entrance.

Missouri Department of Conservation Lands

Another new project was undertaken on lands (80,000 acres) recently acquired by the Department of Conservation through the cooperation of The Nature Conservancy and the Kerr-McGee

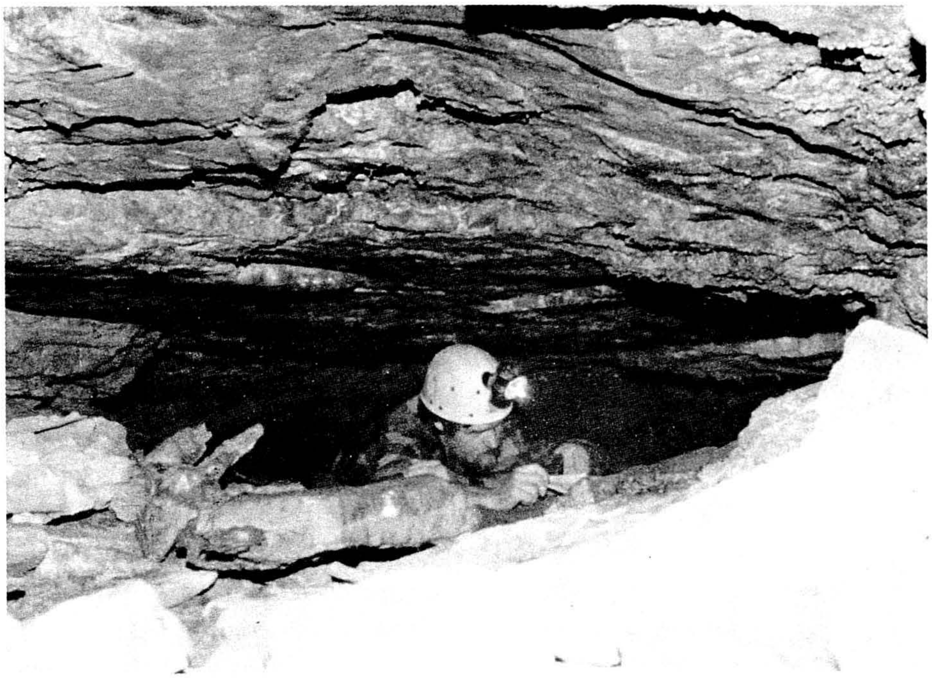

Figure 8: Mick Sutton on a "bug hunt"—part of inventory work in Deep Hole Cave, Pioneer Forest land, Shannon County, Missouri. (*Photo by Scott House*).

Corporation. Again, our goal is to produce cave maps and inventory the caves with particular emphasis on the biota. Three trips were taken to one area, Pipestem Hollow, a fairly long and deep drainage off of the Jacks Fork River. Like Leatherwood Creek, numerous small caves are found here. Three trips were taken to this area in 1993. Fifteen caves were surveyed and inventoried. Some reported caves were found to be too short to qualify as caves. A report on this area is planned for 1994.

Figure 9: The lower entrance of Leatherwood Arch looks out over Leatherwood Creek, Pioneer Forest land, Shannon County, Missouri. (*Photo by Scott House*).

Powder Mill Creek Cave

This large and interesting stream cave is located within the Ozark National Scenic Riverways (National Park Service) on land actually owned and managed by the Missouri Department of Conservation (Figure 10). Access to the cave, a state natural area, is controlled by the Department while facilities support is provided by the ONSR. Despite weather problems, surveys in 1993 totaled some 1200 feet of survey. The cave, in Shannon County, now totals over 5.7 miles in length and has passed well-known Devils Icebox to become the state's sixth longest cave.

Most of the survey work in 1993 once again involved the lengthy side passage section called Hellhole. Two trips were made to finish a complex canyon maze under a large trunk called the Grand Gallery. While some areas were cleaned up, more leads, including large rooms and canyons, were discovered and have yet to be surveyed. Another

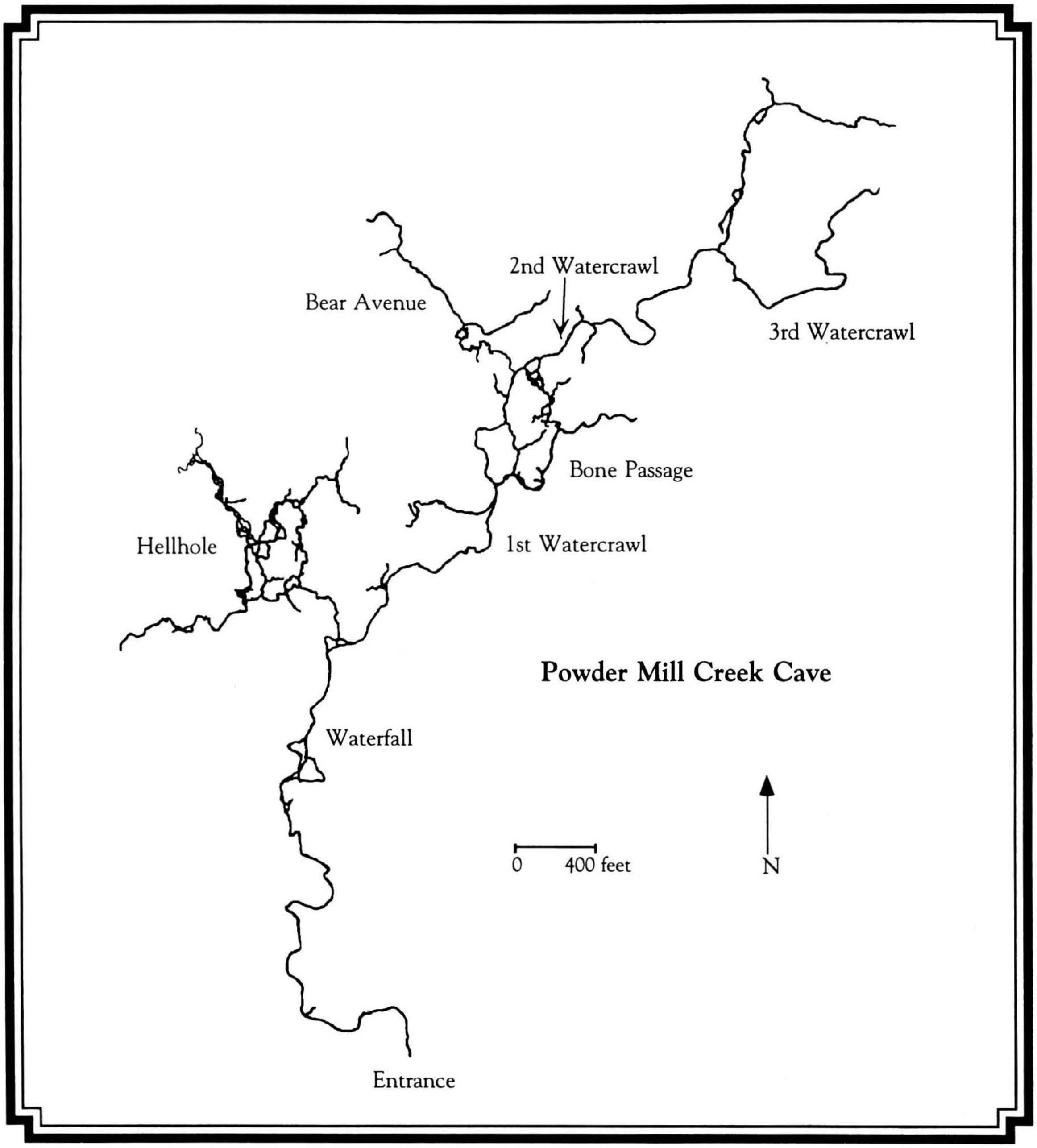

Figure 10: Map of Powder Mill Creek Cave, Missouri.

trip to Hellhole surveyed additional passages in the Snowball Dome area. One additional trip surveyed several hundred feet of passage off of Bear Avenue which is accessed through a tight passage known as the Windy Crawl.

Biological observations are an ongoing part of this project. These observations may form the basis for a more extensive study at some point in the future.

Personnel

Most of the above work was coordinated by Mick Sutton, Doug Baker, or Scott House. Other JV's who have helped with administrative duties or drafting include Sue Hagan, Tim O'Dell, and Steve Irvine. Numerous others participated in the field work.

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Cave Management and Conservation in Missouri

by Scott House

Some notable events occurred in 1993. Greer Spring, Missouri's second largest, was acquired by the Forest Service from the LAD Foundation, a private conservation foundation. (The LAD Foundation had purchased it from private interests which had protected the site for many years.) The issue of drilling for lead on Forest lands in the Ozark karst watershed became a moot issue when the interested party said that they were not interested in drilling at this time due to the poor quality of the ore. CRF's findings on the hydrology and biology of the caves of that area were presented at a meeting in January.

A new issue came up late in the year. A Forest Service proposal to build 300 miles of off-road vehicle trails on the Forest was submitted. As with other land-use plans we will study the proposal and comment on it.

The Department of Conservation issued a cave management plan in September of 1993. It is a synthesis of previous directions and is interesting because it provides a very good management direction without numerous specifics and impediments. Parts of the plan were developed with consultation from CRF members.

There was some renewed work on agency cave databases in 1993. Over 800 agency caves are currently in a database that we use to keep track of agency caves. Such information has proved to be invaluable.

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

by Scott House

The big cave kept getting longer but the most intriguing discoveries in 1993 were in the smaller caves in the park. New initiatives in parts of the system were complemented by a general clearing of the cartographic backlog elsewhere.

FIELD WORK

Morrison and Proctor Cave (Hawkins River Area)

Once again, field work in the river areas concentrated on completing certain areas and fixing others. Like last year, several trips were taken to Lee Avenue to finish off leads along it. Several other trips concentrated on the Coons Trail and X-15 Pit areas on the route to Kaemper Avenue; this area is still not completely surveyed out. Sections of the trunk river passage downstream from the Doyel Valley entrance were resurveyed for greater detail. Other areas of the upstream section of the river were also resurveyed for greater detail. Lastly, some leads off of the T survey (Bridge Avenue) were surveyed. A new mapping effort for Proctor Cave was begun with 3400 feet resurveyed; all of this was in the historic Proctor areas.

Mammoth Cave Ridge

As in the past few years, Mammoth Cave Ridge received the majority of the system efforts. Over three miles of new and resurvey was done in the Historic end where two new maps are now underway. This included the main tourist trails, Cyclops Avenue, Livelys Way, areas off of Pensacola Avenue, leads off of the tourist routes, and Audubon

Avenue. Some resurvey was done in areas near Alberts Domes and off of Welcome Avenue. In the central part of the cave new and resurvey was done in the Rhoda's Arcade area, the Bishops Dome area, and passages off of Marion Avenue. Nearly a half-mile of new passage was discovered and surveyed off of Eleusinian Way, a maze of passages located east of Emily's Avenue. Work continued on Mystic River with 2000 feet of new and resurvey. Further southeast, trips on the Cathedral Domes map area surveyed another 3000 feet of new passage in an attempt, largely successful, to finish off all of the leads in that area. Resurvey in Mammoth Cave totaled over four miles this year while leads yielded 1.6 miles of new passage.

Flint Ridge

Most of the work this year concentrated on Salts Cave; a new map of upper Salts is under way and new surveys had to be done. Over two miles, mostly of giant trunk passage, were resurveyed; this careful resurvey also turned up over 1300 feet of new passages. Trips to Unknown Cave worked on the Unknown entrance and Ball Trail areas with a total of 3000 feet of new and resurvey.

Length of the System

The Mammoth Cave System is now over 341 miles long. New mileage came mostly from Mammoth Cave Ridge. Note: some parts of the system actually show a decrease from a year ago. The cave is not shrinking but our manipulation of the database is improving and duplications were removed.

Cave	Miles	Kilometers
Colossal Cave	29.32	47.19
Crystal Cave	14.03	22.59
Salts Cave	19.91	32.04
Unknown Cave	44.00	70.81
Flint Ridge Total	**107.26**	**172.63**
Mammoth Cave	134.01	215.66
Proctor/ Morrison	37.22	59.9
Roppel Cave	62.75	100.98
System Total	**341.24**	**549.17**

Other Caves in the Park

Once again, a great deal of work was done on the less extensive caves in the park as we try to both bring some old projects to completion and pursue new initiatives. On the north side of the Green River, 1000 feet was surveyed in mile-long Buffalo Creek Cave and much more remains to be done. 500 feet of resurvey was done in Running Branch Cave which is essentially complete at 4700 feet. The big news came at well-known Wilson Cave where over 4000 feet of new passages were discovered and surveyed in an intense effort. The new passages range from tight crawls to high canyons and deep pits and put the length of the cave at 6000 feet. Two smaller caves, Squirrel Hollow Springhouse Cave and Wilson Sugar Pit, were also surveyed.

On the south side of the park four survey trips to Smith Valley Cave yielded more than 1300 feet of new passages to make that cave approximately 8000 feet long. Seven survey trips into demanding White Lightning Cave increased the length of that promising cave by over 2300 feet to a total of 3400 feet (Figure 11). One trip to Long Cave finished that cave's survey effort by surveying 1000 feet giving it a length of 5900 feet. Four trips to Dennison Cave apparently finished that project and a couple of very small, unnamed, caves were also surveyed.

DATA REDUCTION

Much of the survey data accumulated by this project is entered and reduced via the commercial SMAPS program (version 4.3) and then translated

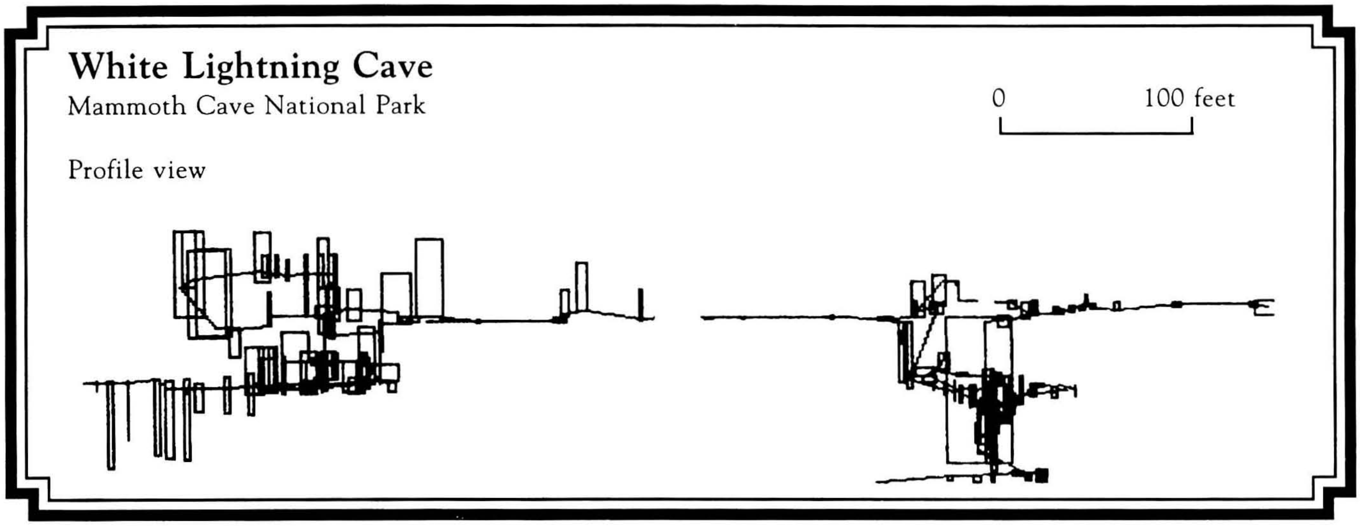

Figure 11: White Lightning Cave, Mammoth Cave National Park, Kentucky.

into CRF's Cave Map Language (CML) for archiving CML, written for MS-DOS or Macintosh computers in C, has advanced features that allow it to perform more error-tracking procedures. An interface for CML, called "Vectors" and written for the Macintosh, is a very usable product for achieve manipulation and data retrieval. Our goal is to achieve seamless transfer of data back and forth from CML to SMAPS.

The database of CRF survey books now has 3100 entries and continues to be a very useful product; through manipulation of this database the length of the cave is determined. CRF, the National Park Service and the Central Kentucky Karst Coalition continue to merge survey book databases; the goal is to integrate all these available survey networks into one. (Figures 12 and 13).

CARTOGRAPHY

Work continues on finishing some of our 1:600 base maps. The pencil draft of the Cathedral Domes sheet is now virtually done and will be inked in the next year. The Bishops Dome and Frozen Niagara sheets are both nearly finished. The Cleaveland Avenue, Snowball Dining Room, Blue Springs Branch, and Marion Avenue sheets are all dependent on the underlying Mystic River section being finished before they are completed. The Main Cave sheet is mostly done but surveys of Roaring River need to be redone before it is completed. The following list names various sheets in pencil on mylar format and the cartographer in charge:

Sheet	Cartographer
Cleaveland Avenue	Doug Baker
Historic	Doug Baker
Echo River	Doug Baker
Colossal Cave	Jim Borden
Bishops Domes	Kevin Downs
Cocklebur	Kevin Downs
Pohl Avenue	Paul Hauck
Cathedral Domes	Scott House
Frozen Niagara	Scott House
Main Cave	Scott House
Proctor Cave	Pat Kambesis
Marion Avenue	Bob Osburn
Snowball Dining Room	Bob Osburn
Hawkins River (4)	Bob Osburn
Alberts Domes	Bill Putnam
Salts Trunk	Mick Sutton
Blue Springs Branch	Mick Sutton

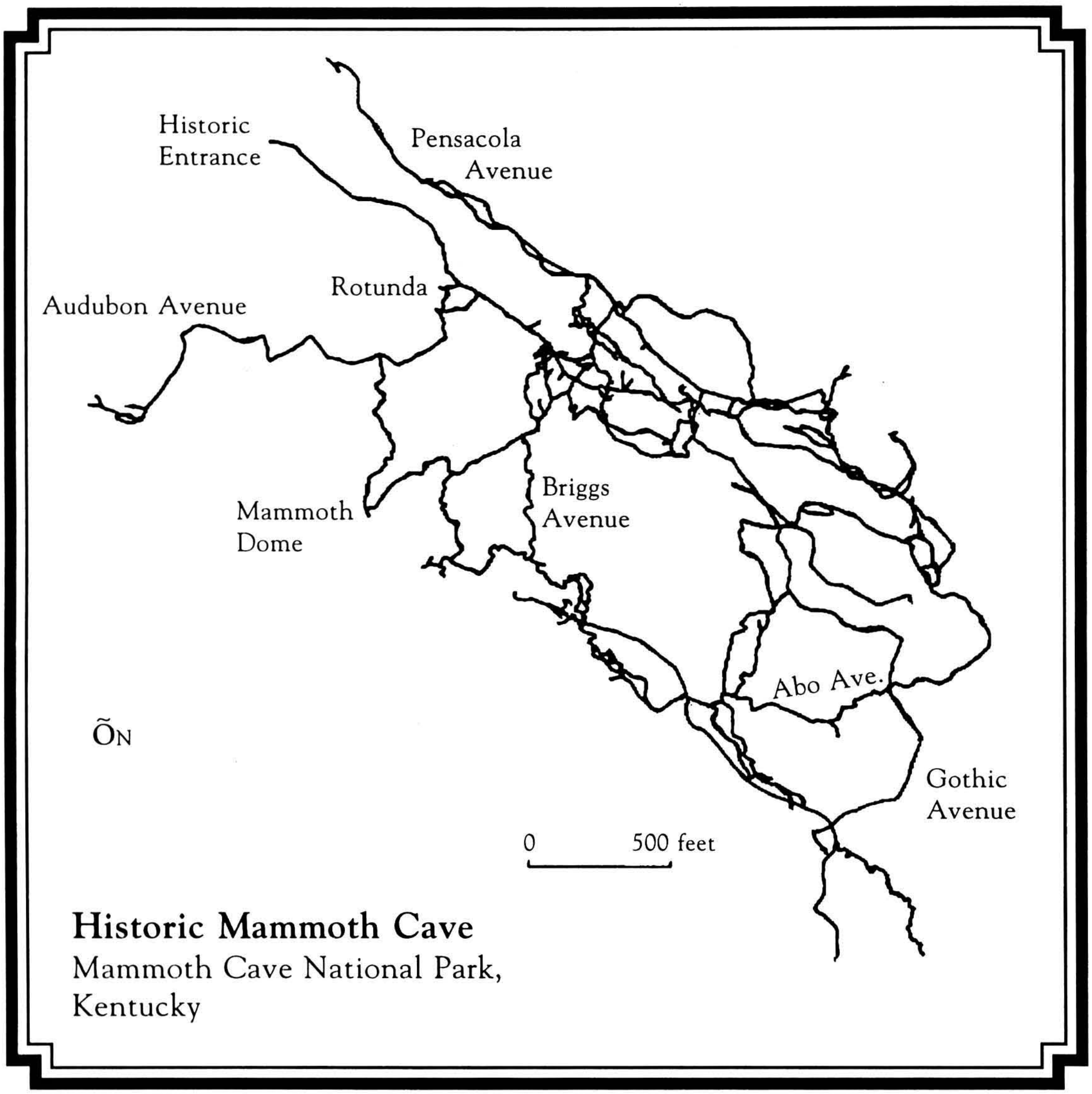

Figure 12: Computer-drawn map of a section of Historic Mammoth Cave, Kentucky.

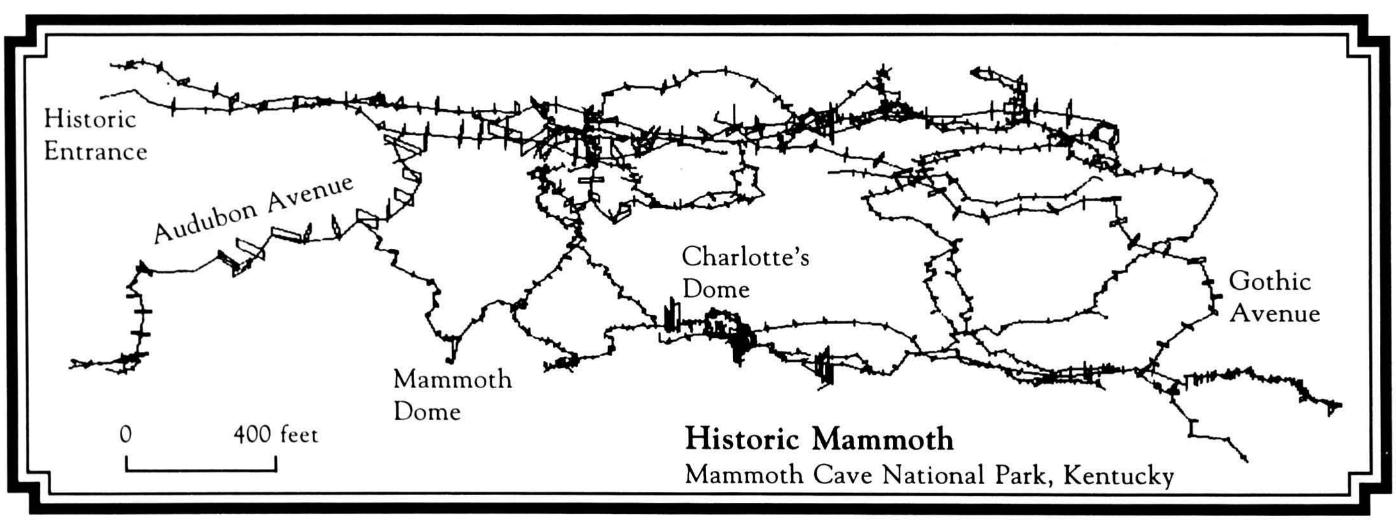

Figure 13: Computer-drawn map showing cross sections of the Historic Mammoth Cave section shown in Figure 12.

Most of the smaller caves that have been surveyed have also been drafted. There are still a number of older cave surveys that will have to be field checked before drafting can be done. Other caves for which surveys are complete and are being drafted include:

Rigdon Pit .... Phil Bodanza
Dickey Pit .... Phil Bodanza
Long Cave .... Tim Schafstall
Dennison Cave .... Walter Johnson
Running Branch Cave .... Scott House

The following are still being surveyed:

Crow/Hackett Caves .... Scott House
Buffalo Creek Cave .... Stan Sides
Smith Valley Cave .... Tim Schafstall
Wilson Cave .... Jim Greer
White Lightning Cave .... Rick Olson

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Fitton Cave Survey Project, Arkansas

by Pete Lindsley

The Fitton Cave Survey Project in Arkansas had six successful expeditions during 1993 with expeditions led jointly by Mike Pearson, Danny Vann and Pete Lindsley. Average participation, which was slightly less than 1992 due to increased work schedules in our core group, was a dozen people. However even the smallest expedition of six JVs at the October trip was successful with two survey parties. The core group of about a dozen people were joined by around 20 new JVs during the year. Five of the expeditions were one-day trips and one was a two-day trip.

During 1993, emphasis was placed on the lower level portion of cave from the Round Room downstream to the Out Room. This section of the cave is quite complex with up to four levels below the major East Passage trunk. Surveys in these more complex areas are using pairs of teams that can survey simultaneously along adjacent levels and tie surveys together for closure control. Plans are being made to generate multi-level cross sections in some of the more complex areas of the cave to enhance the present East Passage quads. Additional areas surveyed during 1993 included portions of Grand Central, the downstream section of the cave where the cave stream disappears before it reappears at the rear of Fitton Spring Cave. The rear of Fitton Spring was examined closely for possible leads, but without success. Another nearby small spring was entered for the first time, but it could not be determined if this was a related karst feature.

Danny Vann took over the Area Manager job from Jack Regal starting in the spring of 1993. Danny is acting as our local contact and is helping the expedition leaders in making expedition plans, arranging for survey equipment and filling out the paperwork.

The map shown in Figure 14 illustrates some of the survey in progress in the cave. A surface stream enters the cave just uphill from the Bat Cave entrance and reappears in the cave as a small waterfall. This stream has downcut the floor of the Bat Cave passage and is seen to meander under the older, upper levels of the passage. This stream continues south past the Round Room to the T-Room where the Bat Cave passage connects with the East Passage. At this point the stream turns to the east and continues its meandering about 50 feet under the larger trunk of the East Passage. The stream is joined by other, smaller, sources of water at the T-Room and midway towards the Out Room. Additional amounts of water join the main stream from the New Maze and the stream disappears after reaching the Grand Central area just

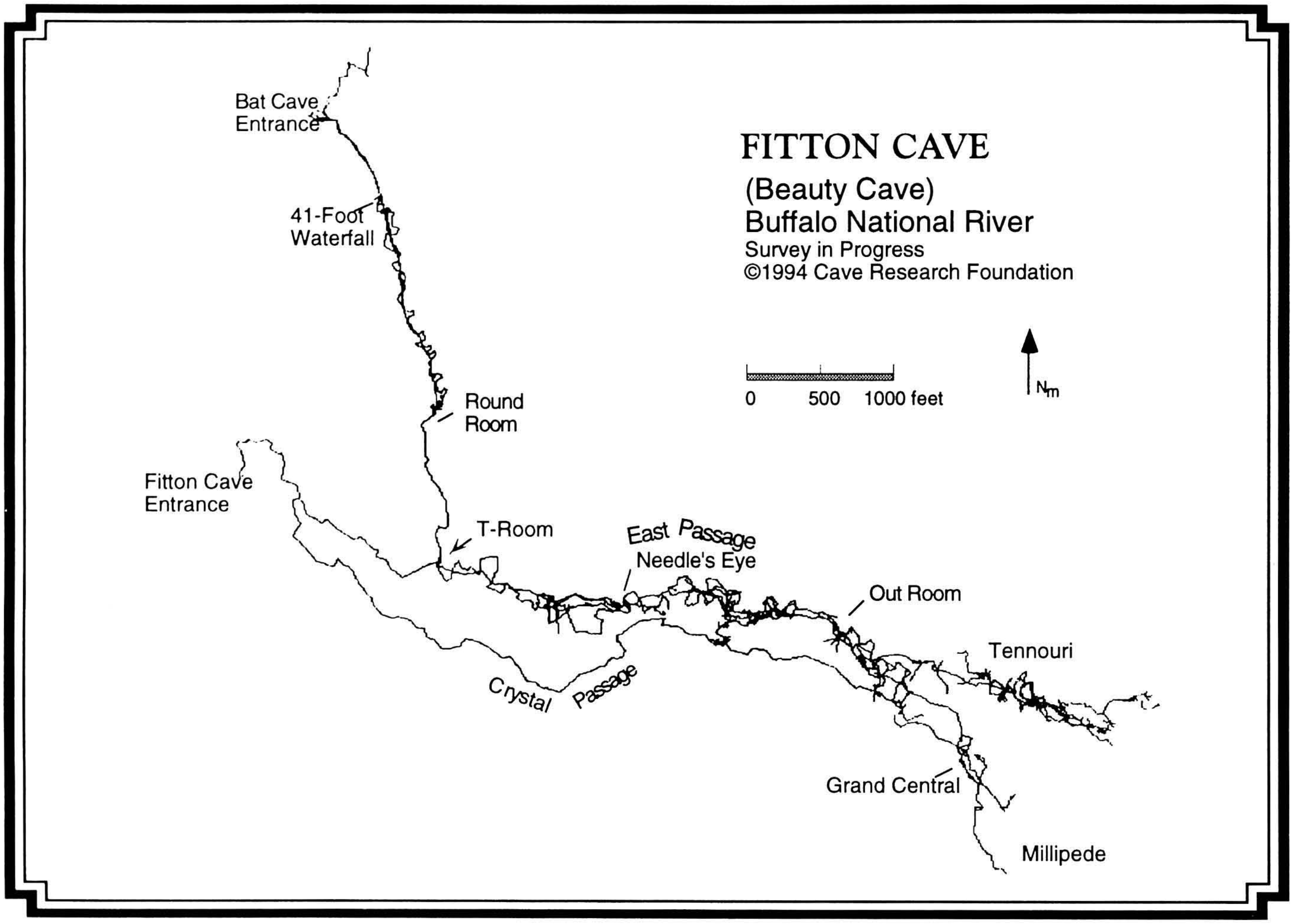


Figure 14: Map of Fitton Cave, Arkansas showing survey in progress.

before the Millipede passage. (The New Maze lies above Grand Central between the Tennouri Passage and Jurgen's Leap to the south.) The stream reappears in Fitton Spring Cave approximately 2,000 feet upstream from the shelter-like entrance just above Cecil Creek which acts as the base level for many of the caves in this area.

One interesting observation during 1993 has been a strange layer of carbonized material below a certain level in the Lower East Passage just upstream from the Out Room. The material appears to be small burned chips of wood, possibly washed in following a forest fire. The elevation levels associated with this material are approximately 20-30 feet above the present water base level, indicating a significant 1-time flood sometime in the past. We have observed a small amount of wood material, sediments, and also bat bones associated with this layer, probably adequate for some sort of dating technique. Our guess is that there was a major flood following a forest fire that deposited the material in the lower level of the cave. The mystery awaits further study.

The three-day summer expedition, usually held in early August, is a good opportunity for scientists and "long distance" CRF cavers to make long range plans to visit the cave. In addition to the previously mentioned carbon chips, there are several other potential projects including mineralogy, geology, hydrology and biology that will be of interest to qualified scientists and researchers.

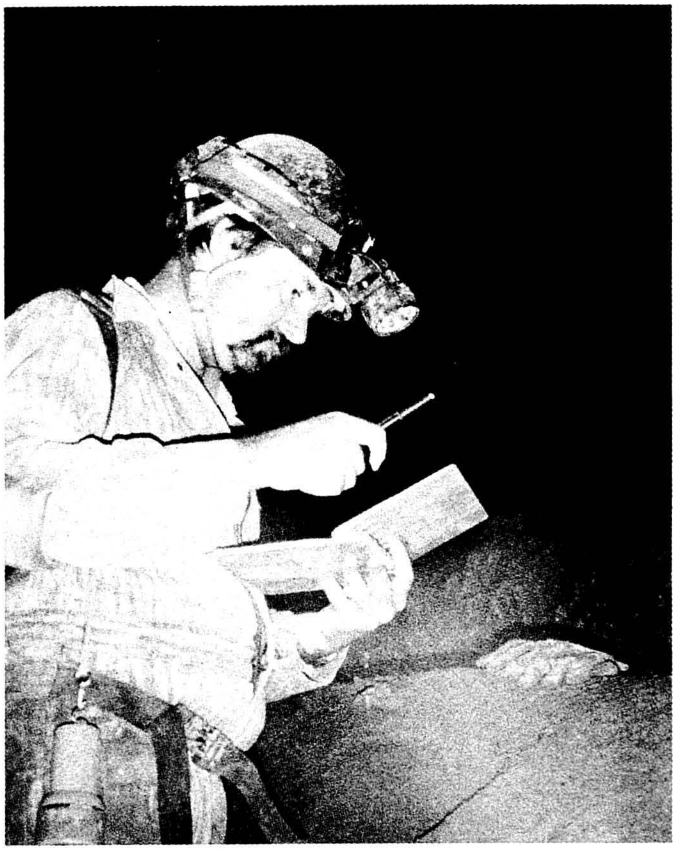
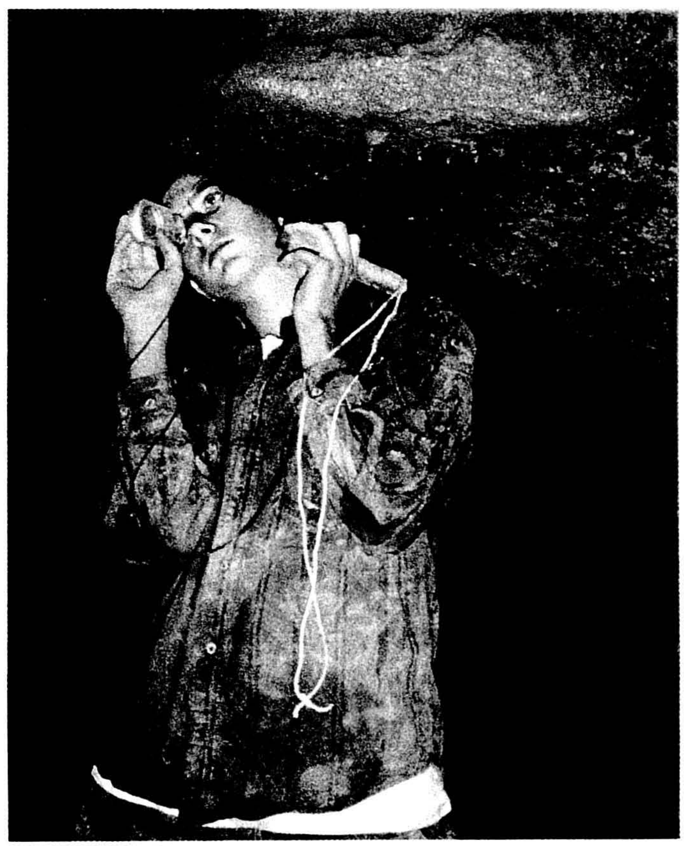


Figure 15: Mike Pearson (above) records survey data while Steve Lindsley (right) takes a reading with a Suunto compass in Fitton Cave, Arkansas. (*Photos by B. Stickney*).



THE SCIENCES

Figure 16: Deana Groves sits near a large spring within Mammoth Cave National Park, Kentucky. (*Photo by Chris Groves*).

GEOSCIENCES

Sedimentology and Surface Mapping of Redwood Canyon Karst, California

by John C. Tinsley

This research measures rates of sediment yield and rates and processes of sediment transport among the karst features of Redwood Canyon in order to (1) improve our understanding of the karst as a physical system and (2) to gain insight into the region's natural history using a sedimentological perspective.

Sediment monitoring points have been established at 15 points, including different elevations within the cave and above ground among the nearby sinkholes and stream terraces. The sediment-monitoring studies enable researchers to judge the scope and impact of runoff events on the cave, and to advise cave diving exploration projects and hydrologists concerning the cave system's response to runoff-producing storm events.

The 1992-1993 season was a significant runoff year, and with large volumes of sand expelled from Big Spring. Stream-terrace deposits formed in 1991-92 in Redwood Creek downstream from Big Spring were eroded during peak runoff and a new set of terraces formed as spring runoff abated. The automated sediment sampler failed to trigger; its operation has been distressingly unreliable and we anticipate removing it this field season. The large sinkhole in Pebble Pile Creek continued to fill with sediment derived chiefly from the slumping bank forming the north wall of the sinkhole; contributions of sediment also were received from Pebble Pile Creek channel itself. The top of the slump is as close as 25 feet from the Big Spring trail. The sediment in the bottom of the sinkhole is 10 feet below the former channel of Pebble Pile Creek. Although little or no detritus was fed into the cave from the sinkhole in Pebble Pile Creek, the sediment load transported through the cave continued to be voluminous. We had hoped that a big runoff year coupled with minimal sediment input into the cave would "clear the blockage" observed by Bill Farr's SCUBA explorations at 71-foot depths in the single-conduit feeding Big Spring. Despite the large volume of sediment throughput, the Big Spring orifice remained occluded, owing to sediment being transported to the siphon system from other parts of the karst basin. The static sediment sampler located in the Z-Room was dismantled and re-deployed in the Lake Room and in the Hex Room areas, as we have learned about all we can from 7 years monitoring at the Z-Room locality. Sediment waves having an amplitude of 8 to 9 meters have been observed in the Z-Room associated with spring runoff events; water depths routinely overtop the sediment sampler. The piezometer located at the Z-Room showed 65 feet of water, drowning the sampler beneath roughly 35 feet of water.

During the 1994 field season, present plans include:

1. Complete the first surface karst map showing the entire Redwood Canyon Karst area. A small area of 3 sinkholes was found to have been omitted from the compilation. Thus, one additional survey will be required to complete the survey of all known sinkholes in Redwood Canyon. Four surface streams need to be surveyed.

2. Continue monitoring sediment stations within Lilburn Cave to observe effects of runoff and storm events on sediment movement.

3. Remove the automated sediment sampler from Big Spring if it cannot be repaired in the field to restore reliable function.

4. Continue compiling a cave map showing the sedimentary deposits of Lilburn Cave.

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Analysis of the Flow Behavior of Big Spring, Kings Canyon National Park, California

by Linda Urzendowski, John Hess, and Mike Spiess

Big Spring, the resurgence of the karst aquifer flow within the Lilburn Cave system (Kings Canyon National Park, California), displays the uncommon phenomena of ebb and flow discharge during periods of high runoff. Time-series, hydrograph and spectral analyses of the stage and discharge data, and a bench-scale model were combined to elucidate the internal hydrology of this cave-spring system.

Stage data for this study were recorded digitally at Big Spring almost continuously since the fall of 1988 and within the Z-Room since November, 1991. The Z-Room is located within Lilburn Cave approximately 700 m north of Big Spring and about 10 m higher (Moore and Sullivan, 1978). Time-series observations of the Z-Room and Big Spring stage levels revealed two distinct types of flow patterns during the high runoff season (usually February through early June). The first is an ebb and flow, 180° out-of-phase response where a drop in stage in the Z-Room results in an instantaneous rise at Big Spring. This suggests that the system is completely filled with water and the rise at the spring is a pressure response when the Z-Room achieves a sufficient amount of hydrostatic head to activate the system. The second type of flow recognized at Big Spring is a high, sustained flow implying an in-phase response between the Z-Room and Big Spring stages. This occurs when flows at the spring are at least two to three times that of the normal base flow. The triggering mechanism between these two modes of flow behavior is poorly understood, but results suggest that the transition may be chaotic.

A large, abrupt drop (>1 m) in the Z-Room stage occasionally results in a rebound in the Z-Room stage of approximately 0.5 m. The pressure pulse of this rebound is not recorded in the spring datalogger. This suggests that either the pressure transducer that measures changes in stage at the spring is not sensitive enough to capture the fluctuations, or that the system absorbs or buffers the oscillations. This rebound phenomena has been described by van der Kamp (1976) during observations of slug tests in highly transmissive aquifers, and is explained by the inertia of the water level change.

Hydrograph analysis is a method of interpreting discharge-time data to elucidate properties of an aquifer or river in response to some input (usually precipitation). Analyses of the Big Spring hydrographs, using a modification of the method described by Mijatovic (1968) and Bonacci (1993), were performed on the spring hydrograph recession limbs. The analyses indicate that the portion of Lilburn Cave between the Z-Room and Big Spring acts primarily as a conduit flow aquifer, with approximately two-thirds of its flow discharging from large diameter conduits, one-fourth from smaller conduits and open fissures, and the remainder from small fissures and fractures.

Spectral analysis of a time-series consists of partitioning the data into the unique frequencies at which the system operates. This method can provide valuable insight into the physical processes operating within the system, and are used in the prediction of future behavior. The power spectra determines any dominant frequencies that the system might be operating at, which indicates periodicity in the data set. The power spectra performed on multiple data sets strongly indicate a nonlinear system, with evidence of linear, or quasi-linear, behavior found on a smaller scale (Jankovic, personal communication, 1992). Linear behavior indicates that the system is homogeneous and steady. In a linear karst system, for example, there is no variation in conduit size, saturation, or hydraulic conductivity. Nonlinear behavior is usually the result of a non-homogeneous, non-steady system with variations and inconsistencies found in the above mentioned parameters. Both types of flow in this system behave stochastically (or randomly) at the input, which is thought to be a result of flow path blockage from a variable sediment load present within the system. The transfer function represents the ratio between the output to input power spectra (in this case, spring to cave) on an amplitude versus frequency graph. It indicates the degree of attenuation that may be occurring within the system, and may indicate additional inputs or outputs to the system. The kernel function represents the response of the system to an instantaneous unit input (Driess, 1989), in this case, a flushing event. Transfer and kernel function analyses confirm the presence of nonlinear and quasi-linear flow regimes, and further indicate that no additional significant inputs of outputs to the system exist.

Based on the results of a bench-scale model designed and built to simulate the ebb and flow cycles, the analytical results, and the actual behavior observed within the Z-Room and Big Spring, a generalized representation of the internal geometry of the cave-spring system was developed and is shown in Figure 17. A single conduit containing a sediment plug is the best-fit model for this system. The hydrograph analyses confirm that the portion of the karst aquifer between the Z-Room and Big Spring is primarily a conduit flow system, and the spectral analyses did not show evidence of other significant inputs or outputs. Results of the bench-scale model indicate that the most probable scenario is a single large conduit that conveys the majority of the flow to the spring, with a sediment plug in its lowest sump behaving stochastically to cause the ebb and flow cycles during periods of high runoff.

A sediment plug is thought to be the stochastic element causing the cyclic flow behavior since large quantities of sediment are observed in Lilburn Cave. During low flow periods (summer and winter months), water passes through the sediment plug as porous media flow and discharges uniformly at Big Spring. The stage in the Z-Room begins to rise when recharge into Lilburn Cave exceeds the capacity of discharge through the plug. When the Z-Room stage achieves sufficient hydrostatic head to breach the plug, the sediment is displaced into a larger cross-sectional area present above the sump, suspending most of the sediment because of a lower velocity. As the water level in the Z-Room drops and flows out through the spring, the hydraulic gradient is lowered causing the largest particles to drop back into the sump reblocking the flow path. This results in a rise in stage in the Z-Room and an ebbing at Big Spring until sufficient hydraulic head is reached to again breach the plug. The rebounding effect observed in the Z-Room after a large, abrupt drop in stage supports the sediment plug theory, since performing a slug test on an aquifer can be compared to the quick breaching of a sediment plug.

Each sediment plug that forms probably varies in size and consistency because some of the smaller-grained sediments get flushed out of the system while new sediment is constantly being added. Predominantly fine-grained sediments are deposited at Big Spring because the lower velocity in the

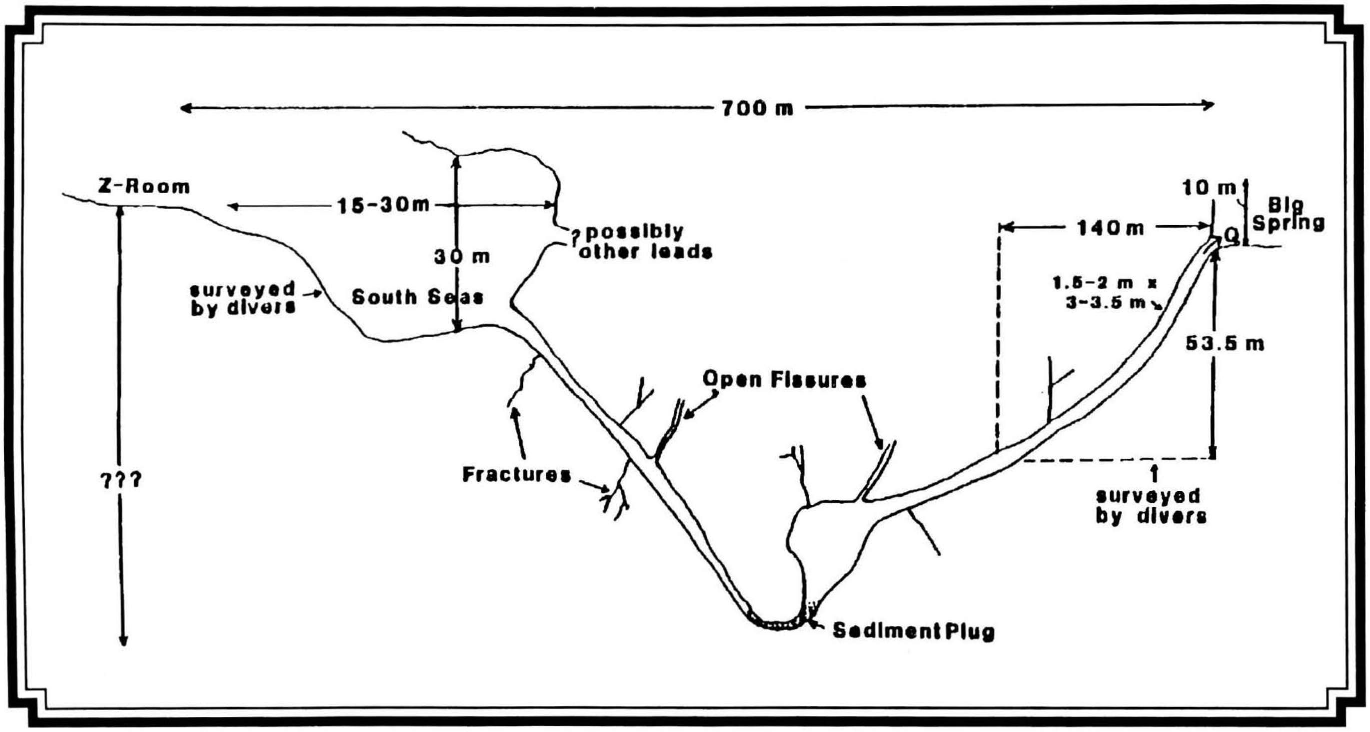

Figure 17: Proposed model of the Lilburn Cave–Big Spring system. South Seas and a portion of the conduit at Big Spring have been surveyed by divers. The system is assumed to be primarily a single conduit system containing a sediment plug in the lowest sump that stochastically blocks the flow path creating ebb and flow cycles. A larger cross-sectional area is present above the sump that retains much of the sediment because of a lower velocity during a flush. Some fractures and open fissures are probably present throughout the system, as indicated by the hydrograph and spectral analyses.

larger cross-sectional area is insufficient to convey the heavier, coarser particles out of the system. When the sediment falls back into the sump creating an ebb cycle, the degree of blockage probably also varies. For instance, it may completely block the entire cross-sectional area of the sump during one ebb cycle and only partially block it during the next. Also, new sediment is probably entering the conduit system from the movement of water within the Z-Room and South Seas. These are examples of how the stochastic action of a sediment plug could result in inconsistent ebb and flow discharge cycles at Big Spring.

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Network Flow Modeling of Developing Karst Aaquifers: Turbulent Flow

by Alan D. Howard and Christopher G. Groves

A major question concerning pattern development of karst flow systems concerns the selective enlargement, or lack thereof, among a large number of potential flowpaths along fractures or bedding planes within a body of limestone making up an incipient karst aquifer. Geologic and hydrochemical controls on the development of these patterns have been studied by a number of investigators using both field observations and quantitative analysis. The purpose of this work is to continue quantitative analysis of the conditions that lead to selective (single-passage or branchwork) *versus* non-selective (maze) flowpath development during the earliest stages of karst flowpath evolution; it extends our earlier model for solution within fracture systems under laminar flow (Groves and Howard, 1992) to the turbulent flow that occurs during the later stages of passage enlargement. Such an analysis is complicated by the dependency of the rate of limestone dissolution upon both chemical and hydrodynamic conditions within the fluid forming the systems, both of which are constantly changing as system evolution proceeds. As a consequence, simulation modeling is the most practical approach to investigating early stages of limestone aquifer development.

Under laminar flow conditions a set of linear equations relating discharges and head losses within a flow network can be readily solved. However, in turbulent flow alternative techniques must be used to solve the flow field. This has been simplified by considering only two turbulent regimes, hydraulically smooth and fully rough. As any of laminar, smooth- and rough- turbulent flow may occur within different passages in a cave network simultaneously, the relationship between heads and discharges is non-linear. We have developed an iterative approach to solve the system of flow equations for unknown heads at passage intersections, and from this discharges within the passages.

At each time step and at each location within the network of passages three potential rate-limiting kinetic mechanisms are evaluated. These are surface reactions at the limestone-water interface (reaction-limited rate), diffusion of calcium ions from the bulk solution to the limestone surface (diffusion-limited rate), and CO_2 hydration in the bulk solution (hydration-limited rate). The reaction-limited rate is further divided into first-order kinetics (dissolution rate proportional to the distance from saturation with respect to calcite, i.e., the saturation deficit) when the solution is not close to saturation and a high-order rate (dissolution rate proportional to the fourth power of the saturation deficit) when the solution exceeds about 70% of saturation. The actual dissolution rate becomes the minimum among these rate-limiting processes. Only the diffusion-limited rate differs explicitly between the laminar flow conditions and the turbulent flow considered here. Gnielinski (1976) presents a mass diffusion correlation valid for turbulent flows with Reynolds Numbers up to 10^6 which is used in this model.

In contrast to the highly selective passage enlargement that occurs early in cave network development under laminar flow, the transition to turbulent flow often results in more general passage enlargement leading to various degrees of maze network development. The greatest maze development occurs with a combination of large initial passage diameters and high hydraulic gradient, with the passage diameter providing the greatest control. High hydraulic gradients (*ca.* 0.05) are required to have even modest maze development when initial effective passage diameter is in the range of 0.001m, but very low hydraulic gradients (*ca.* 0.0003) result in strong maze development when initial passage diameters are about 0.01 m.

Development of alternative pathways under

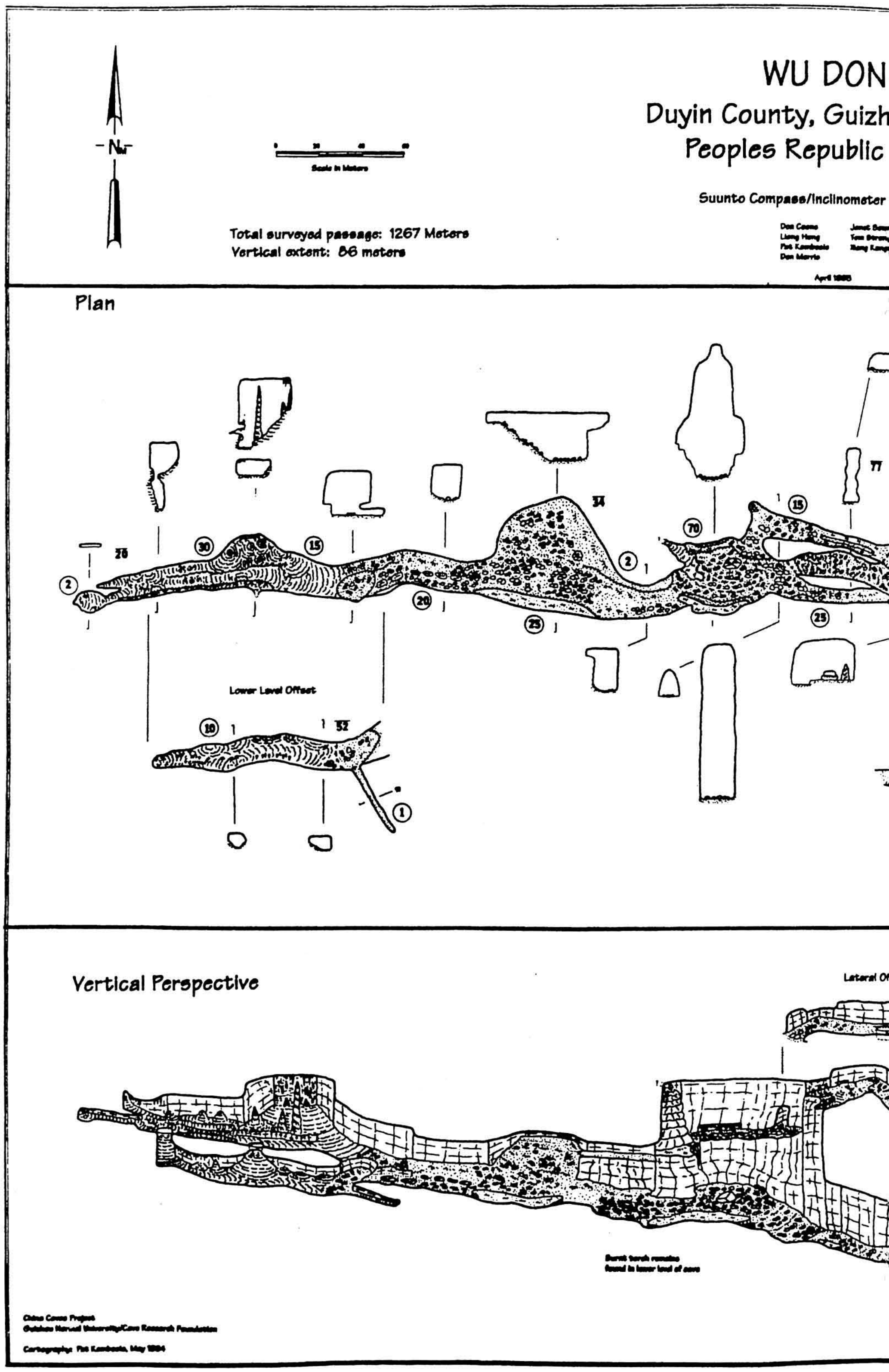
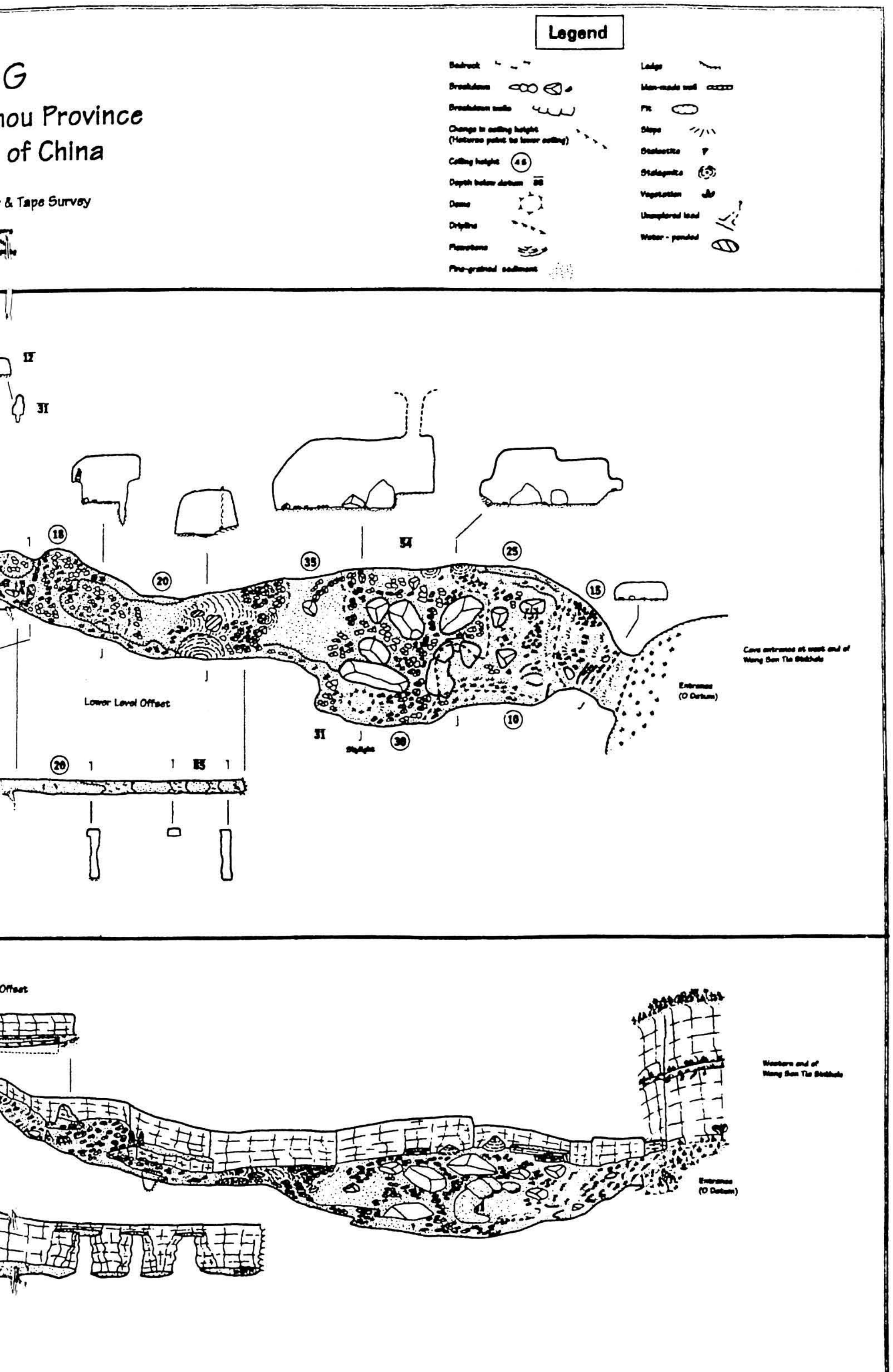


Figure 18: Map of Wu Dong Cave, Guizhou Province, China, showing both plan and vertical perspective views. This map, drawn by cartographer Pat Cambesis, won a medal award in the cartographic section of the 1994 Naitonal Speleological Convention.


G
ou Province
of China
& Tape Survey
Legend
Bedrock
Breakdown
Change in ceiling height
Ceiling height
Depth below datum
Dome
Dripline
Flowstone
Fine-grained sediment
Ledge
Man-made wall
Pit
Slope
Stalactite
Stalagmite
Vegetation
Unexplored lead
Water - ponded
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conditions of turbulent flow depends on the ability of relatively undersaturated solutions to penetrate deeply into the fracture network and the more even flow distribution among alternate flowpaths in turbulent or mixed laminar and turbulent flow. Our results support two of the hypotheses suggested by Palmer (1975, 1991) for the development of network maze patterns:

1) Presence of a network of large initial pathways. Large fractures (*ca.* 0.004 m or larger) might be formed by application or release of stresses by such processes as unloading, tectonic activity, or gravity sliding. In an analysis of 260 maze caves, Palmer (1975) found that most were associated with topographic settings favorable to unloading, including escarpments, residual hills, and regions subject to Pleistocene glaciation. Some maze caves were also found within the axes of anticlinal flexures.

2) Large hydraulic gradients and large maximum discharges. Field evidence also suggests that maze cave formation occurs in response to episodic flooding of passages by recharge from discrete recharge points during intense rainfall or snowmelt. This can take place, for example, where the limestone receives drainage from a large catchment of non-carbonate rocks. Passage constrictions as a result of collapse, sediment blockage, or insoluble beds can also contribute to steep gradients.

Over and above these situations, the simulations indicate that any hydrogeologic setting promoting long duration, turbulent phreatic flow of initially unsaturated water through limestone fractures, such as in a regional artesian flow setting, is likely to result in some maze development. On the other hand, single-channel or branchwork patterns will be favored for conditions of cave development entirely via laminar flow (unlikely within large cave systems), initially tight fractures, and low hydraulic gradients. In addition, cave development via solution by underground, free-surface streams (vadose conditions) will likely also result in branchwork patterns. Such cave systems are likely to have started by shallow phreatic flow originating from a number of discrete sinkhole inputs, but have become vadose as passages enlarged and the piezometric surface is depressed. Several factors disfavor maze development by free-surface cave streams: 1) the development of free-surface streams depresses the water table, so that flow from tributary feeders occurs at high gradients and the sharing of groundwater among adjacent fractures that is largely responsible for maze passage development is discouraged; 2) as main passages cut downward by abrasion or dissolution, more slowly eroding tributary conduits develop steep gradients or enter as high-level springs, further concentrating flow into a dendritic pattern; and 3) introduction of sediment along the major subterranean streams may encourage sedimentation and flow blockage within adjacent solutionally-enlarged fractures.

Acknowledgments

We would like to thank Deana Groves, Janet Herman, Carol Wicks, George Hornberger, Robert Ribando, and Robin Diederich with assistance in various aspects of this research. Financial support for the project was provided by the Cave Research Foundation, The University of Virginia, and the National Speleological Society.

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Influence of the K/T Chicxulub Impact Crater and the Holbox Fracture Zone on the karst geomorphology and hydrogeology of the northern Yucatan Peninsula, Mexico

by Slawomir Tulaczyk

The northern Yucatan Peninsula is a flat part of a carbonate platform composed of a few hundred meter thick sequence of almost pure Tertiary and Quaternary limestones. The carbonate rocks of the region underwent karstification since the Late Tertiary time. Despite presumably similar conditions, the karst formed in the northwestern Yucatan is characterized by high abundance of deep sinkholes (cenotes), whereas the northeastern Yucatan has fewer cenotes but abundant solution corridors.

Recent research has defined two large, regional structural features in northern Yucatan: the Chicxulub Impact Crater (ChIC) in the NW and the Holbox Fracture Zone (HFZ) in the NE (Pope et al., 1991; Southworth, 1984). The Impact is reflected in the morphology of the region by the Ring of Cenotes (RC), a circular ring of sinkholes located above the rim of the Crater (Perry et al., 1992). The HFZ facilitated development of solution corridors and corridor poljes (Tulaczyk et al. 1993a, 1993b).

This study provides new data on structure of the northern Yucatan aquifer and puts forward an hypothesis on the character and origin of the apparent differences in karstification of its NE and NW parts.

Vertical electrical soundings (VES) were made in 32 locations in NE and NW Yucatan (Figure 19). Twenty four of the locations were surveyed during the 1993 field season. We applied Schlumberger arrangement with the maximum AB/2 spacing up to 420 m. Results are used to study distribution of fresh and saltwater as well as changes in bulk porosity.

Resistivities of rock layers, modeled with the RESIXP software package, help to estimate rock porosity with application of the Archie's law (Archie, 1947). For calculations of the Resistivity Derived Porosity (RDP), the conductivity of fresh or saltwater is assumed.

Geoelectrical curves resulting from the surveys in NE Yucatan are less noisy than the ones from the NW Yucatan surveys. We think that this fact can be explained by higher abundance of shallow inhomogeneities, i.e. caverns, in NW Yucatan as opposed to NE Yucatan. Presumably, at least the upper part of the NE Yucatan aquifer may be approximated by a porous media.

The highest fitting errors occur for the soundings made in the NW relatively close to the coast. In these soundings, noise increases upon penetration of the relatively shallow freshwater-saltwater interface. This may result from "leakage" of the current into the highly conductive saltwater layer.

The sounding curves from NE Yucatan are characterized by considerably lower amplitude of maxima and minima in recorded resistivities. The latter suggests that the different layers within the NE Yucatan aquifer have only slight contrasts in resistivity whereas in NW Yucatan these contrasts are stronger.

Curves obtained from the surveys in the NW region are of the KQ or KQA type. These types of curves are consistent with the traditional model of the northern Yucatan aquifer in which a few dozen of meters thick freshwater lens is underlain by a regional saltwater intrusion (Back and Hanshaw, 1970). Surveys made in the NE part of the study area yielded mainly the KH and KHK curves.

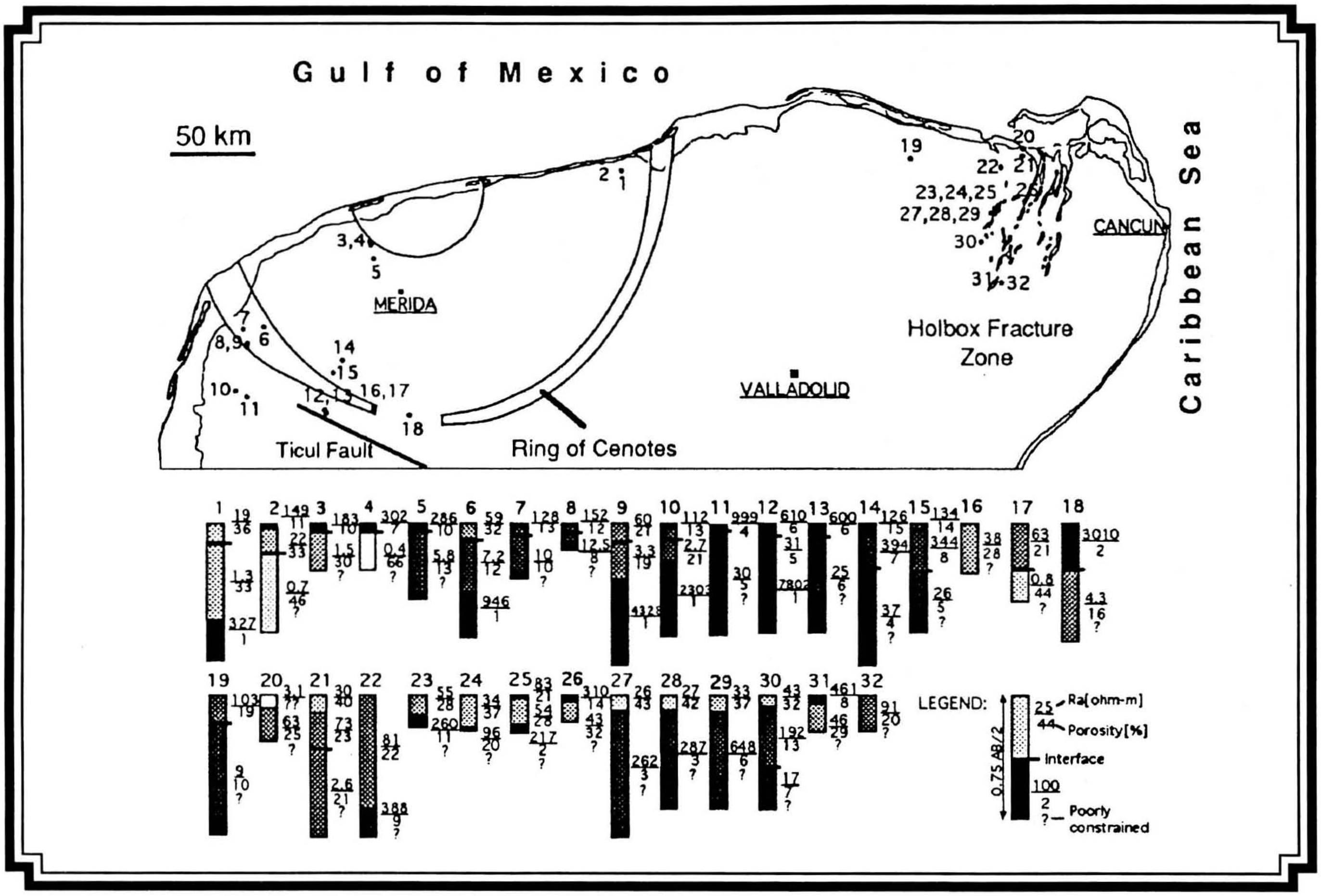

Figure 19: Location of VES surveys in northern Yucatan and obtained layered-earth models.

Models based on these curves show a freshwater lens that is 140 to >200 m thick (Figure 20) and subdivided into an upper layer with high RDP and a lower layer with small RDP.

Preliminary modeling shows that high RDP is typical for the portions of aquifer underlying the CR and the corridor poljes associated with the HFZ, suggesting that higher porosity of underlying strata determined in both cases the location of the morphological features.

More inhomogeneous, cavernous character of the NW Yucatan aquifer inferred from our results agrees with the apparent higher abundance of sinkholes in this region. The carbonate aquifer in NE Yucatan approaches a porous media with a high porosity layer in its upper part. This layer may be associated with concentration of corrosional processes in the water table zone. An unusually large thickness of the freshwater lens in NE Yucatan may result from lower permeability of the porous limestones of this region as compared to the cavernous limestones that seem to dominate NW Yucatan. The differences between hydrogeology and geomorphology of the NW and NE Yucatan are potentially caused by the different character of structural features present in theses regions. However, some other factors (e.g. lithological differences) that remain unknown due to poor knowledge of Yucatan geology can play their role too.

The higher abundance of caverns in NW Yucatan is consistent with fracturing of the Ter-

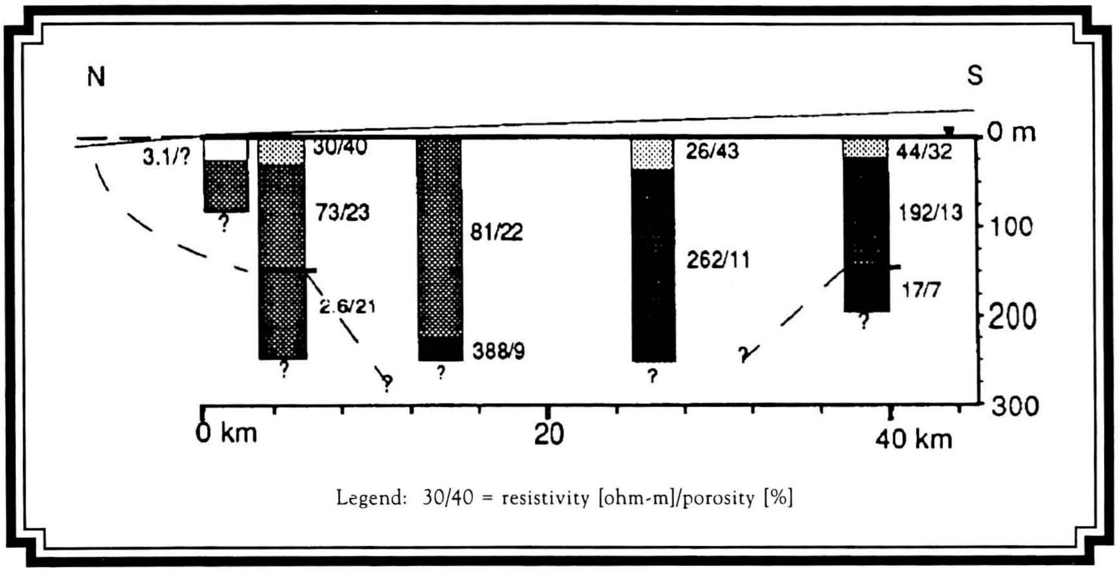

Figure 20: N–S cross-section through the northeastern Yucatan aquifer.

tiary carbonate rocks that was related by Pope et al. (1991) to thermal contraction due to cooling of the K/T Chicxulub impact area. The occurrence of high porosity zones beneath the RC and the poljes of the HFZ provides support for the hypothesis that buried, previously karstified structures can replicate themselves into younger carbonate layers in later stages of subaerial exposure (Tulaczyk, 1993b).

Acknowledgments

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ECOLOGY

Distribution of *Antroselates spiralis* in Indiana

by Julian J. Lewis and Ann Marie Lewis

Formerly the only population of the aquatic troglobitic snail *Antroselates spiralis* known in Indiana was the one listed by Hubricht (1963) in Sibert's Well Cave, Crawford County. In 1992-93 over 40 caves and springs in Harrison, Crawford and Washington counties were searched for *Antroselates*. Due to the suspicion that *Antroselates* would occur in caves where the Northern Cavefish *Amblyopsis spelaea* was also known, the *Amblyopsis* sites listed by Keith (1988) were specially targeted for inspection.

Antroselates spiralis was found in six additional Indiana localities:

(1) Sharpe (Wyandotte) Spring Cave—This cave is located on the west side of Sharpe Creek Valley and receives the water from Wildcat and BB Hole caves. Only a few feet of cave passage is enterable by conventional means. Maegerlein (1980) reported diving explorations into the cave with 850 feet of passage being traversed. He found *Amblyopsis* swimming among the submerged breakdown in the spring conduit. A single juvenile *Antroselates* was found on one of the many pieces of breakdown present in the entrance of the cave, along with *Caecidotea stygia*. No snails were found in Wildcat Cave and BB Hole is closed by collapse of the entrance.

(2) Bussabarger's (Rhode's) Cave—The entrance to this cave is located behind a barn and has a long history of being used as a dump (Jackson, 1954). A very brief description and the location of the cave are given by Powell (1961). Although a map was unavailable, the cave appeared to be less than 300 feet in length. A large passage, floored with breakdown obscured by garbage, sloped steeply down to a large mud-bottomed pool of undetermined depth. *Amblyopsis* was reported in the cave by Keith (1988). One *Orconectes inermis* was present during our trip. The habitat was poor for finding *Antroselates* as no rock was visible in the pool. Water dripping from formations created a small tributary inlet in which a single snail was found under a piece of breakdown about 10 inches in length. *Caecidotea stygia* was also present on the rock.

(3) Firetail Spring—This spring is in the narrow piece of land between Indiana Highway 62 and the Blue River (Figure 21). Divers have reportedly penetrated and explored the spring conduit (David Black, personal communication). Keith (1988) reported *Amblyopsis* from this site. Although dozens of large rocks were present in the spring's orifice and stream, only one snail was found on the visit of 29 December 1992. The spring had been disturbed, with nearly every rock in the stream turned upside down with the moss-covered tops of the rocks lying on the bottom. While inspecting nearby Sinking Foot Cave Spring, the owner told us that he frequently searched both springs for "bugs" to use for fishing bait. Other animals present included *Caecidotea stygia*, *Lirceus* sp., *Gammarus minus*, *Phagocata gracilis*, the snail *Goniobasis* sp., and aquatic insect larvae.

(4) Harrison Cave Spring—This 19-foot-wide spring emerges beneath the large entrance to

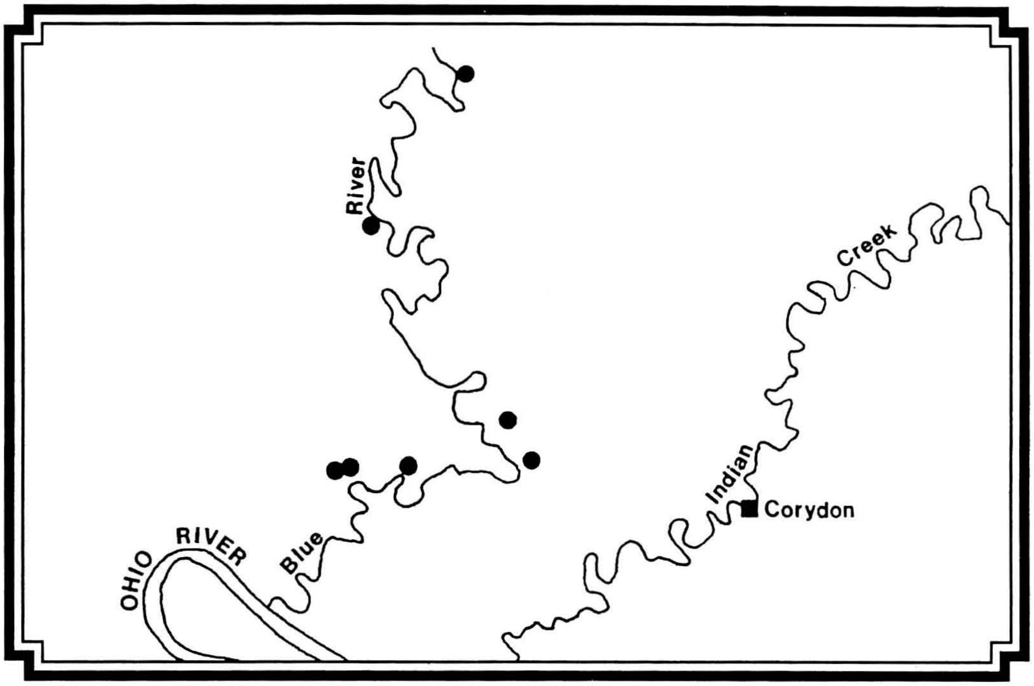

Figure 21: The distribution of Antroselates spiralis (dots) along the Blue River in Indiana (from Lewis, 1993).

Harrison Cave. No stream passage is presently enterable in Harrison Cave, which ends in breakdown shortly after the entrance. Local residents report that at one time a stream passage was enterable. At Harrison Cave Spring the water emerges through a jumble of breakdown with a thick covering of moss present on most of the rocks. *Antroselates* was found to be fairly common on the undersides of the rocks. A single specimen of an undetermined subterranean snail (*Fontigens?*) was also discovered. Other species present in the spring were *Caecidotea stygia*, *Lirceus* sp., *Goniobasis* sp., *Phagocata gracilis*, and a variety of aquatic insect larvae (e.g., caddisflies, craneflies, etc.). This is the only *Antroselates* locality from which *Amblyopsis* has not been reported. If the cave system feeding Harrison Cave Spring becomes enterable the discovery of *Amblyopsis* is to be expected.

(5) Black Medusa Cave—A single specimen of *Antroselates* was found by David Black in June, 1993 during a trip to map the cave. We visited the cave 27 June 1993, censused and found numerous *Antroselates*. The water from the cave emerges as a series of springs on the bank of Blue River, but the snails were not found in the springs. Inside the cave other species found were *Caecidotea stygia*, *Crangonyx* sp., and *Orconectes inermis*. *Amblyopsis spelaea* was reported from the cave (David Black, personal communication), but was not present in the area examined.

(6) Hidden Spring Cave—The cave entrance was under water from the adjacent Blue River during a visit 6 June 1993. On 27 June 1993 the snail was found to be fairly common in the cave. Also present were *Caecidotea stygia* and *Crangonyx* sp. David Black (personal communication) reported *Amblyopsis* from a pool near the end of the cave. A map and description of Hidden Spring Cave, which requires a wet suit for exploration, was presented by Cook and Black (1992).

In Indiana, *Antroselates spiralis* appears to be restricted to caves and springs of the lower Blue River drainage in Harrison and Crawford counties. The snail was not found in Fredericksburg Cave, an *Amblyopsis* locality where numerous stream pools were littered with pieces of breakdown suitable for *Antroselates*. The absence of the snail there suggests the northern boundary for the range of

Antroselates. Similarly, to the northwest the snails were not found in Old Town Spring Cave, Marengo.

Several sites were searched for *Antroselates* in the adjacent Indian Creek drainage, including King's Cave and Binkley's Cave (*Amblyopsis* localities). Indian Creek and Blue River are hydrologically connected via the sink of Indian Creek and resurgence at Harrison Spring. Despite this possible dispersal route, the snails were not found in any of the caves or springs searched in the Indian Creek drainage.

Acknowledgments

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The Ferns of Selected Lava Tube Entrances in Lava Beds National Monument – The 1993 Surveys

by Christopher M. Richard, Alan R. Smith, and C. Don MacNeill

Field Work

The 1992 fern survey at Lava Beds National Monument, California (Richard et al. 1993, Smith et al. 1993) raised many more questions than it answered. Analysis of the first year's data made clear the need for follow-up study, both of the fern distributions themselves and the history of environmental impact and conservation efforts in the caves at Lava Beds. Our entire findings are available at the Monument (Richard et al. 1994)

The first year's study raised the interest of the Monument staff in fern occurrences. Their field work led to the discovery of two new caves with significant fern populations, and the rediscovery of Jack William Cave. Ongoing CRF cave survey work discovered additional sites.

We performed fern surveys, with the assistance of Monument and CRF personnel, in May and September 1993. A study of Monument archives yielded a picture of historical intervention with the fern populations, particularly those at Fern Cave. Additional specimens from Lava Beds were located at the Herbarium at Humboldt State University, and Rancho Santa Ana Botanic Garden. Interviews of prior botanical researchers and Monument workers were performed.

Summary of Findings

Lava tube cave-entrance and collapse-structure microhabitats in Lava Beds National Monument harbor a fern flora within the Modoc Plateau remarkable for both species diversity and the number of populations. Our observations suggest that these relatively stable, protected environments with attenuated light levels and greater moisture availability resemble conditions typical of coastal forests and thereby provide island refuges for species not found in the surrounding, hostile, semi-desert, sagebrush-scrub landscape.

Of the numerous sites surveyed for the presence of ferns during 1992 and 1993, ferns were found at twenty cave entrances and nine other sites. We relocated all fifteen fern occurrences known from prior collections, except *Polystichum munitum* from Fern Cave, where, presumably, it is extirpated, and three collections by Applegate (1938) with non-specific or contested collection data.

We saw no ferns in fully open, exposed, level areas; all were, at least, on the sides of outcrops or walls of collapse features, typically with northern to eastern exposures. Ferns were most frequently observed in the entrance area of the caves, also on the walls of the larger, deeper breakdown trenches.

Analysis of the natural history of the fern species and cave entrances suggests a categorization of the ferns into two groups characterized by their microdistributions–the groups correlating with environmental variables. The first group is found in environments with year-round moisture in the soil and atmosphere, and low light. The second group endures greater moisture fluctuations and, typically, higher light. It is however easier to recognize and refer to them by their microhabitat preferences. Thus in the context of Lava Beds the former can be referred to as breakdown species and the latter as lip species. The breakdown species are large, green all summer, observed only in caves under skylights in soil on breakdown or occasionally on walls in particularly moist caves, and are generally considered mesic or "woodland ferns." The lip species are small, seasonally dormant, found typically on the lips or a short distance into the entrances of the caves, typically rooted in crevices, and are generally considered xeric or "rock fern" species.

The lip species are typical ferns of northeastern California, although they are rare in the sagebrush scrub that typifies most of Lava Beds. The breakdown species are ferns of the coastal regions, and their presence in the sagebrush scrub is the major finding of this study.

Analysis of the Caves

Three caves studied are of sufficient biological or historical interest to warrant mention here.

Fern Cave

Fern Cave is the best known site for ferns in Lava Beds. The cave has a single entrance–a skylight centered over a fern-covered breakdown pile. Abundant moisture keeps the atmosphere near saturation. On the top of the breakdown pile, soil has developed from eolian sediments and organic debris from mosses and ferns. The flanks of the breakdown are buried in an Indian midden deposit.

These moist, fertile, well-lit but protected, temperate conditions currently support a lush cover of *Dryopteris expansa*. The tallest plants are directly under the skylight; plants become gradually smaller toward the fringes of the population and are mere sporelings a few centimeters tall at the periphery, where light is very reduced.

Botanical and historical study allows a partial reconstruction of the history of impact on the fern species growing in this cave. We were unable to positively determine which fern species had been originally present in Fern Cave. Large ferns were absent for a hiatus of nearly a decade, beginning around 1930, resulting from visitor impact. *Pentagramma triangularis* has been consistently reported since 1936, during the large-fern hiatus. There was a recovery period, beginning with a closure of the cave around 1939, during which

Dryopteris expansa grew in the cave. Subsequently there was the unexplained appearance of *Polystichum munitum* after 1948, and its extirpation between 1978 and 1981.

Jack William Cave

In 1992 the LABE museum collection included two specimens of *Dryopteris arguta*, both collected in 1940 by an unnamed collector, labeled: "Ent to Jack William Cave, Power Line Road." The Monument staff possessed no other reference to Jack William Cave, and did not know the cave's location. The power line and road are no longer in service and the road is seldom traveled. In 1993, two seasonal employees located a small cave, very close to the road, with an obvious clump of *D. arguta*. They named it Split Level Cave, but based on the presence of ferns it is now assumed that this cave is the "lost" Jack William Cave.

Little Fern Cave

Ranger Barney Stoffel named this cave in recent years, but the cave shows signs of prior entrance. It is a small vertical pit with an entrance ca. 1 yd^2, and ca. 12 ft deep, slightly wider at the base. There is a cone of sandy soil below the entrance.

About five fertile clumps of *Polystichum munitum* grow on the east wall of the pit near the bottom. Hundreds of smaller, infertile plants grow in the sandy accumulation on the breakdown. The atmosphere is quite moist, and moss growth is lush. *Cystopteris fragilis* grows on the lip.

Management Recommendations

We propose that several fern populations receive ongoing or new attention to their preservation. The *Cheilanthes gracillima* that growing at Blue Grotto is one of only two very small clumps known from Lava Beds. It should be monitored to assure that no threat develops in the future. The breakdown species *Dryopteris arguta*, *D. expansa*, and *Polystichum munitum* require protection from visitor impact if they are to persist. In some instances, continued isolation may suffice, however, monitoring is in order. The *Adiantum capillus-veneris* in Fossil Cave should be monitored since it on the only known clump in Lava Beds.

FURTHER STUDIES

Three directions of study present themselves. First are the visitor impact studies discussed above. Second, study of sediment cores from Fern, Fossil, and Jack William caves using palynological methods to identify and date fern spores, coupled with genetic investigations of the living populations could be a powerful tool in answering the biogeographic questions. Finally a study correlating the seasonal location of the shaft of sunlight in Fossil Cave with relative abundance of *Dryopteris* and *Polystichum* would provide a unique insight into the ecology of these species.

Acknowledgements

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Baseline Biological Inventory of Caves in Southern Missouri

by Mick Sutton

The Missouri cave inventory began as a project to map and inventory caves surrounding a mineral lease area in the Mark Twain National Forest (MTNF) between the Eleven Point and Current Rivers in Oregon and Shannon Counties. In 1993, following completion of this first study, the project moved on to a second phase covering other caves within the MTNF Eleven Point District. In addition, two other inventory projects were started: on a recently purchased block of Missouri Department of Conservation (MDC) land, and on the Pioneer Forest, the largest privately owned forest in Missouri. Both of these areas are also in Shannon County. Field work on all of these projects was disrupted by consistently bad weather throughout the year, but a significant start was made.

All of this land has the same general *characteristics* as the original area—the terrain is a subsoil fluviokarst consisting of spring-fed rivers separated by uplands mantled with deep residuum and dissected by steep-sided valleys, with a surface relief of about 120 m. The surface is underlain by gently dipping dolomites, sandstones, and cherts of Lower Ordovician age. The upland valleys carry surface flow only for short periods following rain; most water is transported through the residuum to discrete subsurface channels.

Work on the expanded MTNF project concentrated on a group of caves along the Eleven Point National Scenic River. Two caves, both featuring low stream crawls more or less at river level, were connected via a much larger interior series of passages which remain incompletely explored. Access is easiest by several hundred yards of deep wading down the river—definitely a summertime, dry weather job. A neighboring cave was found to include a population of Salem cave crayfish, an Ozark endemic and a species of State concern. Beaver activity continues to be a significant factor in the biological make-up of many of the caves on and near the river.

A very different cave was Surprise Sinkhole, an upland open sink—a type of cave rare within the study area. An undescribed springtail had been collected from here previously, but they were absent on this trip, possibly owing to the wintertime visit since the sink is a cold trap. The longest cave mapped and inventoried (about 500 m) was well-known Bat Cave in Oregon County. The gray bat population here has been in decline owing to heavy visitation, but the surveyors discovered a remote roost (unoccupied, as this was a winter trip) well-protected by a less than charming crawl in liquid guano. The US Forest Service plans to gate the cave, which should promote heavier use by the bats of some of the less remote roosts. Some of the guano piles had typical mite/pseudoscorpion type communities, but others contained unusually large numbers of large carabid beetles (*Platynus tenuicollis*) and a troglophilic rove beetle (*Atheta* sp.). In addition, there was some follow-up survey work in a cave within the original study area.

No extensive caves are known from the MDC property. Work here concentrated on a single valley, Pipestem Hollow, with a dense concentration of a dozen or so small caves. This is a beautiful steep sided tributary of the Jacks Fork River. One stream cave was discovered, which turned out to be the longest of the lot at about 170 m. Several other small caves were added to the catalogue, and the known caves were located, mapped and inventoried. Since many of the caves lack a dark zone, we paid more attention to twilight zone fauna than was the case in the earlier MTNF inventory. One interesting find is that the ubiquitous mosquitoes that inhabit every twilight zone seem to represent only a single rather small species, *Culex erraticus*. We have also been paying more attention to twilight zone woodrat activity, since the eastern woodrat *(Neotomnafloridana)* has recently been added to the state "watch list" of species of possible concern. Woodrat nests are now monitored for signs of recent activity such as fresh scat or fragments of green cedar twigs.

Pioneer

The Pioneer Forest project also concentrated on a single Jacks Fork tributary, the renowned and rather remote Leatherwood Creek. This is even more impressive than Pipestem Hollow, consisting of a deeply incised, meandering stream channel with exposed dolomite bluffs, one of the largest natural arches in Missouri, and a high concentration of caves, including at least one fairly extensive one. About a dozen caves here have been mapped and inventoried, including Leatherwood Arch which leads into a small associated cave. Many of the caves carry streams with typical dark zone aquatic communities, dominated by troglobitic isopods.

*** All of these projects will continue through at least 1994.

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Movile Cave, Romania—A Subterranean Chemoautotrophically-based Ecosystem

by Serban M. Sarbu

Generally life on earth depends, directly or indirectly, on the energy of the sun for carbon fixation in the process of photosynthesis. However, in the late 1970's oceanographers and marine biologists discovered rich communities of deep-sea organisms thriving around thermo-mineral vents on the bottom of the Pacific Ocean near the Galapagos Islands, at several thousand meters depth. Numerous studies showed that chemolithoautotrophic sulfur-oxidizing microorganisms use energy from the oxidation of hydrogen sulfide dissolved in the thermomineral waters to fix carbon.

The discovery of another chemoautotrophically based ecosystem, located underground rather than on the floor of the ocean, has provided a more accessible example of this type of system for study and comparison. In 1986, geologist Cristian Lascu discovered a 240 m long network of cave passages, partially flooded by thermomineral sulfurous waters, at the bottom of a 25 m deep well dug in the limestone plateau of southeastern Dobrogea, Romania. Movile Cave, the only known human access to this system, contains a rich cave adapted invertebrate fauna that depends on the food produced in situ by chemoautotrophic sulfide-oxidizing microbes. This represents the first known subterranean ecosystem primarily, if not entirely, based on chemoautotrophic carbon fixation.

Physico-chemical Charateristics of the Movile Cave Environment

Movile Cave is located on a karst plateau, at a depth of 20 meters under the surface. It does not have a natural entrance and the only access to it is the artificial shaft dug in 1986. It consists of a network of passages dug in Sarmatian limestones (12.5 million years old). The upper level of the cave is dry whereas the lower level is partially flooded by thermal sulfurous waters. Several air-bells are present in the lower level of the cave. The atmosphere of the air-bells is very poor in oxygen (7-10%), very rich in carbon dioxide (2-3.5%), and contains small amounts of methane (1-2%). The water temperature is 21°C, the total dissolved mineral content is approximately 1000 mg/l and the amount of dissolved hydrogen sulfide varies between 4 and 13 mg/l (Sarbu and Popa, 1992). The cave walls of the lower level have been extensively corroded by chemical processes similar to those described for caves in New Mexico (e.g. Carlsbad Cavern, Lechuguilla cave) (Hill, 1990). Hydrogen sulfide from the sulfurous cave waters reacts with oxygen from the air to form sulfuric acid which in turn reacts with the limestone walls of the cave. The byproduct of this reaction is gypsum (calcium sulfate) which is deposited on the cave walls (Egemeier, 1981).

What data support the hypothesis that Movile Cave is well isolated from the surface? Flowstone formations such as stalactites or stalagmites are completely absent in Movile Cave. Their absence suggests a lack of surface water infiltration. The reduced oxygen concentrations and the increased amounts of carbon dioxide in the cave, especially in the air-bells, indicate a reduced gas exchange between the cave and the surface, an additional consequence of the impermeability of the rock layers above the cave. Additional support for the isolation of the Movile Cave ecosystem from the surface is offered by the absence of other natural and artificial indicators such as diatoms, fecal streptococci, and insecticides in the cave water and sediments. Carbon stable isotope data we have obtained recently also indicate that there is no input of organic matter of photosynthetic origin into the subterranean ecosystem.

The Fauna

Forty-nine species of terrestrial and aquatic invertebrates have been discovered in the cave so far, of which 31 are previously undescribed (Sarbu and Popa, 1992). Twenty-one endemic species of terrestrial invertebrates collected only in the lower level of the cave in the vicinity of the sulfurous waters are included in this group. The vast majority are arthropods belonging to four classes: arachnids; crustaceans; myriapods; and insects. The majority of these species are well adapted to the peculiar environment in which they live: they lack eyes and pigment, and their appendages (legs and antennae) are elongated. Nineteen aquatic species have been collected in the lower submerged level of the cave. They belong to six phyla: Platyhelminthes (flatworms), Nematoda (round worms), Rotifera (microscopic animals related to round worms), Annelida (segmented worms), Mollusca (snails), and Arthropoda (ostracod, copepod, isopod, and amphipod crustaceans, and insects).

Ecosystem Function in Movile Cave

A detailed examination of the region appears to preclude the possibility of significant input of organic matter from the surface (there are no lakes, rivers or swamps in the region to provide organic matter that could infiltrate the system). Despite the lack of a significant food input from the surface however, the terrestrial and aquatic cave communities are very rich, both in number of taxa present and in the population sizes of these species.

What is the source of the food base for this system? The answer appears to lie in the microbiota inhabiting the lower level of Movile Cave. Microbial mats occur floating on the surface of the water and covering the limestone cave walls in the remote air-bells where the cave's atmosphere is depleted in oxygen and enriched in carbon dioxide. Examination of these mats reveals a network of fungal hyphae with an average diameter of 3 μm composed of several species of fungi. The hyphae form a matrix which is colonized by bacteria. The bacteria are essential for the functioning of the ecosystem: they are chemoautotrophic organisms belonging to the genera *Beggiatoa*, *Thiobacillus*, and *Thiomicrospira*. These microorganisms use the energy derived from the oxidation of hydrogen sulfide to fix carbon dioxide and to produce organic molecules (Sarbu and Popa, 1992).

The chemoautotrophic microbiota living in the mat and in the water, represents the first level (i.e. primary producers) in the trophic chain of the Movile Cave ecosystem. In the aquatic community, the primary consumers include the large populations of ciliates, nematodes, annelid worms, rotifers, and copepod crustaceans living under the floating mats where they graze on the mat bacteria and fungi. The gastropods, isopods and amphipods are detritivorous and feed on the floating mats as well. Three predators are present in the aquatic community: the flat worm *Dendrocoelum* sp., the blind leech *Haemopis* n.sp., and the troglobitic water scorpion *Nepa* n.sp. The terrestrial community primary consumers: collembola, terrestrial isopods, and millipedes crawl on wall mats and on floating mats and feed on the rich microbiota. Numerous predators occur in the terrestrial community (spiders, pseudo-scorpions, centipedes, beetles) and feed upon the rich populations of primary consumers. (Figure 22).

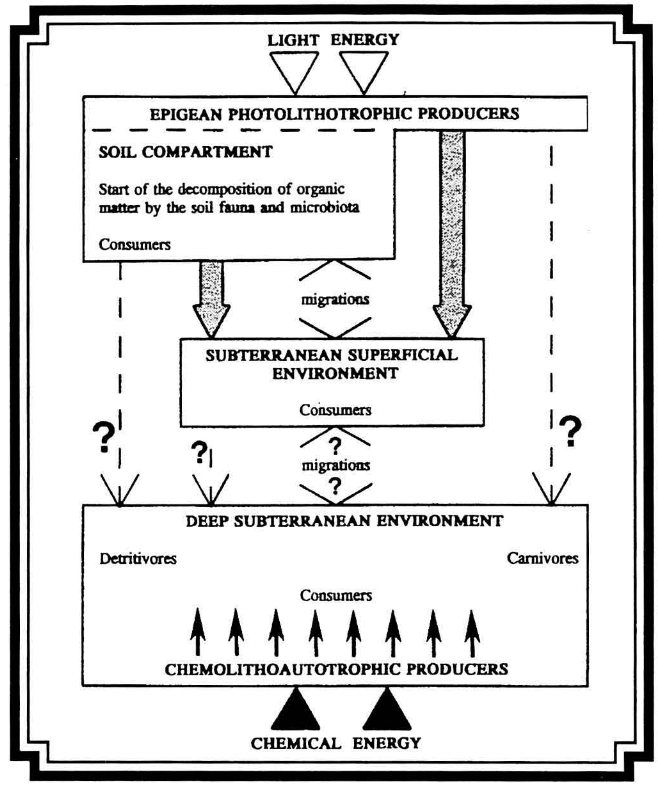

Figure 22: Schema of biomass and energy flow between the surface and the subterranean ecosystem – new model proposed for the Movile Cave ecosystem.

* * *

Research on the Movile Cave ecosystem is far from completion. Unfortunately, the cave passages are very narrow and the ecosystem is extremely fragile. Even minor modifications of one of the physico-chemical parameters of the cave environment (e.g., temperature, humidity, composition of the atmosphere) could adversely affect the ecosystem and lead to the extinction of some of the species inhabiting the cave. Thus we wish to minimize our impact in order to preserve as much as possible of this unique ecosystem. We have recently completed the construction of a field-research laboratory at the surface that will permit us to reproduce the physico-chemical parameters of the cave environment and perform experimental work that cannot be accomplished in Movile Cave itself. Thus we will be able to investigate quantitatively the process of chemoautotrophic carbon fixation, to study microbial ecology and eco-physiology, and study the ecology and behavior of the Movile Cave fauna without destroying it.

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ARCHAEOLOGY

Cave Research Foundation Archaeological Project, 1993

by Patty Jo Watson and Mary C. Kennedy

As described in the 1992 Annual Report (pp.46–47), CRF Archeological Project personnel have begun a new investigation of ancient diet and nutrition as evidenced in the Salts Cave/Mammoth Cave human paleofecal remains. All 12 specimens collected in 1992 (in collaboration with Mammoth Cave National Park Division of Science and Resource Management: Jeff Bradybaugh, Chief; Bob Ward, Cultural Resource Specialist) were photographed in situ and in the lab, and then dated by the University of Arizona NSF–AMS Facility (Table 1). Paleoethnobotanist Kristen Gremillion of Ohio State University has partitioned each one and processed one–half of it to enable macrobotanical as well as microbotanical, parasitological, and biochemical analyses. Kristen is carrying out the macrobotanical identifications and interpretation, pollen analysis is being done by Kristin Sobolik (University of Maine), parasitological study by Charles Faulkner (University of Tennessee), and biochemistry by Patricia Whitten (Emory University). So far it appears that pollen is abundant and identifiable in most samples, and that the requisite biochemistry is also present to enable the specimens to be sexed.

CRF Archeological Project personnel have also been centrally involved in the joint NPS–Earthwatch cultural resources inventory in Mammoth Cave. Fieldwork was conducted from July 11–31 and from October 17–November 5, 1993 (see summary by Mary Kennedy in November 1993 **CRF *Newsletter***).

In 1964, a group of JVs participated in the replication of a prehistoric caving trip using giant ragweed, also known as horseweed, for torches (Watson 1966, Ehman 1966). Some of the surplus weeds from this experiment were left inside the cave where they have remained ever since. The most obvious of these is the large bundle at the base of the slide into Mummy Valley. In December 1993, a CRF/AP work party collected a sample of this material for radiocarbon dating. We plan to use this organic material of known age as a control sample to check the accuracy and precision of radiocarbon dates from the system. If there is a large discrepancy between the radiocarbon age and the known age, we would then explore what factors caused this discrepancy and whether the same factors might be affecting the prehistoric determinations. What we are more likely to learn is that the determination is within 2 standard deviations of the known age of the sample, i.e., that it is accurate within the limitations of the radiocarbon technique, which is a statistical approximation. Either way, this additional indicator of the confidence we can place in the prehistoric dates is worth pursuing.

That same December workparty (George Crothers, Naoko Yokoyama, Dave Kluth, Davé Warren–Taylor [NPS], Mary Kennedy, and Patty Jo Watson) documented, stabilized, and began backfilling the open trenches in Salts Cave Vestibule. Archaeological excavation of trenches J and K took place in the mid 1970s. The research plan included backfilling once excavation was completed, but the profiles were an excellent record of

Table 1. New Paleofecal Dates from Mammoth Cave and Salts Cave*

	Provenience	Radiocarbon Years B.P.	Lab #
MCF-1	UpperMammoth, Wright's Rotunda[1]	2335 ≠ 75	AA-10079
	UpperMammoth, Wright's Rotunda[2]	2485 ≠ 70	AA-10080
MCF-2	Mammoth, Black Chambers	2575 ≠ 65	AA-10081
MCF-3	Lower Mammoth, Jessup C3	2365 ≠ 70	AA-10082
MCF-4	Lower Mammoth, Ganter G63	2485 ≠ 70	AA-10083
MCF-5	Lower Mammoth, Ganter A71	2605 ≠ 70	AA-10084
MCF-6	Lower Mammoth, L. Ganter, B18	2700 ≠ 80	AA-10085
SCF-1	Middle Salts, Q5	2570 ≠ 70	AA-10086
SCF-2	Upper Salts, P26	2410 ≠ 70	AA-10087
SCF-3	Upper Salts, P26	2605 ≠ 80	AA-10088
SCF-4	Upper Salts, P45[1]	2590 ≠ 70	AA-10089
	Upper Salts, P45[2]	2580 ≠ 70	AA-10090
SCF-5	Upper Salts, Neville K5	2500 ≠ 80	AA-10091
SCF-6	Middle Salts, H8 below P67	2700 ≠ 60	AA-11738

* NSF-Arizona AMS Facility. Dates are corrected for isotopic fractionation and uncalibrated.
[1] sample with mold
[2] same sample with mold removed

the complexity of natural and cultural depositional events that occur in a hydrologically active setting such as the Vestibule. Upon completion of excavation it seemed worthwhile to leave the trenches open for heuristic purposes, and the Park Service granted permission for this. During the 1980s, however, several episodes of very heavy rain carried water into the excavations, and obscured the profile faces. The remaining deposits were threatened with undercutting by subsequent flooding, so it seemed the time had come to backfill.

We documented the location of the openings with sketch maps and photos. Then landscape fabric was used to line the trenches, demarcating intact deposit from backfill, stabilizing and protecting the profiles during filling,and allowing better drainage than plastic or newspaper, which are sometimes used for these purposes. After many years of seeing the Vestibule with open trenches it was a little disorienting to see it returned to its pre–excavation landscape, but we are relieved that the trench area is now protected from future, heavy, surface run–offs.

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CRF FELLOWSHIP AND GRANT SUPPORT FOR 1993

Each year, the Cave Research Foundation sponsors a graduate Fellowship competition. Applicants must be conducting graduate research leading to a degree in a karst-related field at an accredited institution of higher learning. Announcements are mailed in the Fall; proposals are due by January 31, and awards are made in April or early May. Members of the CRF Science Committee are among those who serve the Foundation by reviewing the proposals; outside reviews may be sought in order to gain additional perspective or to help to resolve disagreements among reviewers. Science Committee members who sponsor applicants by serving as academic advisors or who write letters of recommendation in behalf of a candidate are not among the reviewers of the proposals submitted for the Fellowship.

The Fellowship program is supported by proceeds earned by an endowment fund. This year, three Grants of $2000 were awarded, totaling $6,000.00 distributed among three applicants out of the six proposals that were submitted to the Foundation. The competition was unusually keen, and a majority of the reviewers were disappointed that the Foundation's pockets were not deeper enabling us to fund more of the meritorious research proposed.

1. For his proposed research entitled *The Phylogeny of Missouri Populations of Ozark Cavefish (Amblyopsis rosae) and Southern Cavefish (Typhlicthys subterraneus)*, Mr. Dean Bergstrom, Fisheries and Wildlife Program, 112 Stephens Hall, School of Natural Resources, University of Missouri, Columbia, Missouri, 65211, is awarded a 1993 CRF Karst Research Grant in the amount of $2000.00.

Mr. Bergstrom's research in part seeks to delineate the phylogenetic relations between populations of Missouri's Ozark and Southern Cavefish throughout their ranges using techniques of mitochondrial DNA sequencing and a non-destructive sampling protocol. Whether intraspecific genetic differences arise within Ozark and Southern Cavefish, and the degree to which they do so, is critical to their management as either independent, endemic entities; or, as a common pool with populations being interchangeable. For example, the presence of substantial differences in the mitochondrial DNA sequences between populations found in adjacent caves would provide evidence of extended genetic isolation. Comparing western and eastern populations of the Southern Cavefish, which are regarded as having been isolated by the Mississippi River, would reveal the degree to which populations have diverged since their isolation.

2. For his proposed research entitled *Structural and Functional Response of a Cave Aquatic Community to Organic Enrichment*, Mr. Kevin Simon, Department of Biology, Virginia Polytechnic Institute, Blacksburg, VA 24061-0406, is awarded a 1993 CRF Karst Research Grant in the amount of $2,000.00.

Mr. Simon's research addresses the effects of organic enrichment via ground water pollution on a cave aquatic community with emphasis on the feeding ecology and trophic position of the troglobitic isopod *Caecidotea recurvata*. He will examine the role of biofilms in energy flow within the cave aquatic community.

3. For his proposed research entitled *Influence of the K/T Chicxulub Impact Crater and the Holbox Fracture Zone on the Karst Geomorphology and Hydrogeology of the Northern Yucatan Peninsula, Mexico*, Mr. Slawomir Tulaczyk, Department of Geology, Northern Illinois University, DeKalb, Illinois, 60115, is awarded a 1993 CRF Karst Research Grant in the amount of $2000.00.

Mr. Tulaczyk's research will involve the collection and interpretation of geoelectrical data, chiefly electrical resistivity profiling and sounding to map the distribution of salt water intrusion and to model changes in bulk porosity within the various layers comprising the carbonate aquifer of northern Yucatan Peninsula. His preliminary data challenges the canonical view of the regional karst system and should lead to improved understanding of regional karst systems in tropical karst platforms, the degree of compartmentalization characterizing carbonate rock reservoirs, and will provide additional insight into the influence of an impact structure on the development of secondary porosity in rocks that are *younger* than the impact.

The Science Committee and the Board of Directors of the Cave Research Foundation congratulate the recipients of the 1993 awards and wish each of them a speedy and successful quest with their outstanding karst-related research.

Summaries of some of this research appears elsewhere in the CRF Annual Report.

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EDUCATION

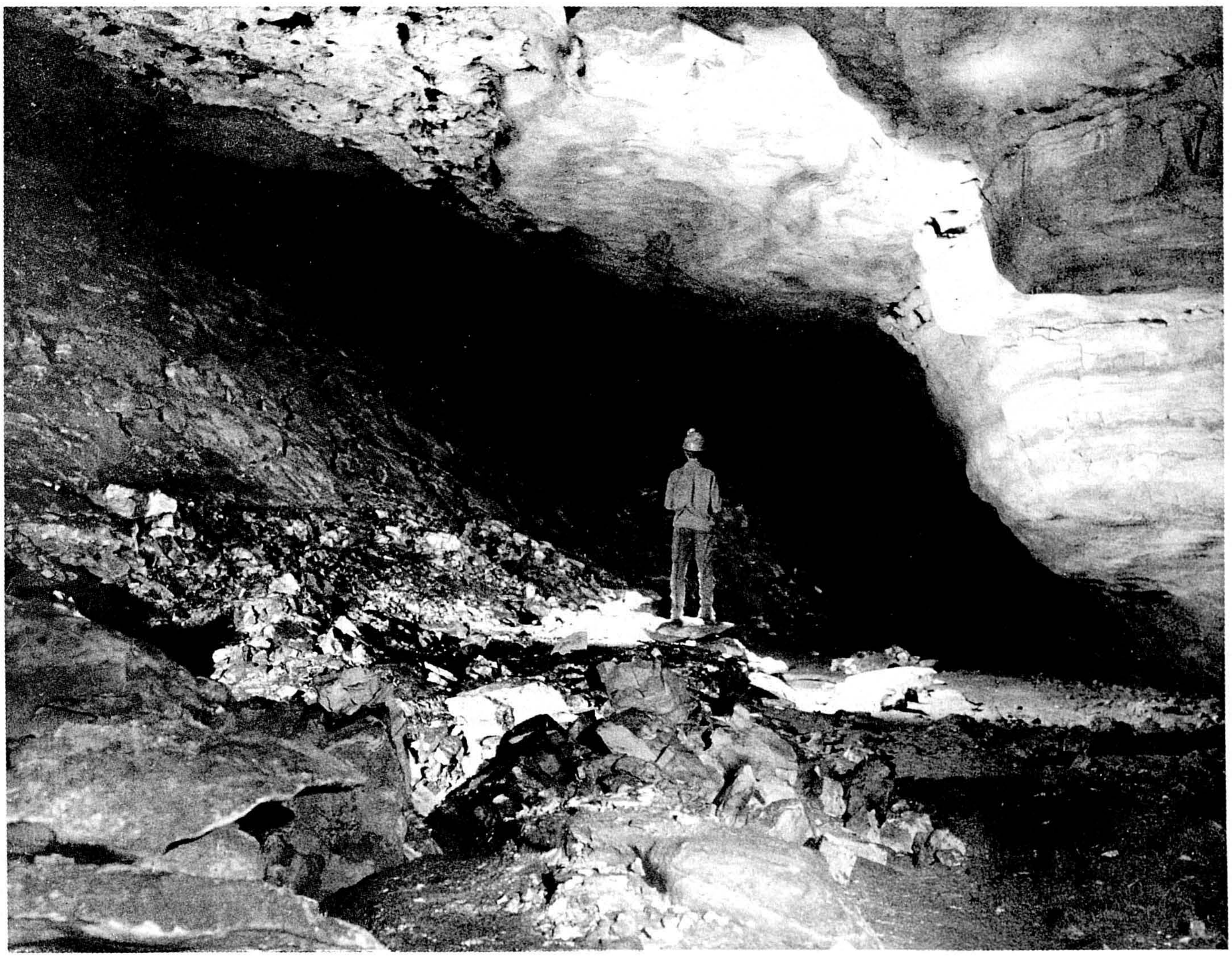

Figure 22: Steve Lindsley lights up the passageway in Fitton Cave, Arkansas during a survey/photographic expedition. (*Photo by Pete Lindsley*).

Effects of Septic Systems on Trophic Dynamics of a Cave Aquatic Community

by Kevin S. Simon and Arthur L. Buikema Jr.

Groundwater organisms are increasingly threatened by groundwater contamination, including underground storage tanks, surface water intrusion, and septic systems. Upwards of 50% of all septic systems in the U.S. currently may be malfunctioning and are potentially one of the greatest threats to groundwater and its resident fauna. The potential impact of groundwater pollutants in karst areas is increased by lack of thick soil layers for proper filtration of sewage outfall and rapid transport of contaminants in karst bedrock.

Septic outfall may contain household chemicals that are directly toxic to groundwater communities. Excess input of organic material and nutrients also may result from improperly functioning septic systems. Input of excess organic material (sawdust) to a cave in Lee County, Virginia led to the extirpation of populations of two species of troglobitic isopods and a troglobitic amphipod (Culver et al., 1992). Septic outfall may similarly affect groundwater fauna. Compounding this problem is the lack of information on trophic dynamics of cave aquatic communities (see Culver, 1985) and detailed species distribution lists.

We are investigating the effects of septic system outfall on some basic components of cave aquatic community trophic dynamics. Holsinger (1966) found unusually large populations of *Caecidotea recurvata*, a troglobitic isopod, in Banners Corner Cave, Russell Co., Virginia. Holsinger suspected the cause was input of organic material from overlying septic systems. Recent physicochemical and biological data show the septic systems continue to influence the cave aquatic community.

Study sites in Banners Corner Cave are shallow (<0.25 m) seep-fed pools ranging in size from 0.5 to 6 m^2. Water quality parameters including pH, dissolved oxygen, conductivity, alkalinity, hardness, Cl^-, NO_3^-, and SO_4^- are being measured monthly and have been used in estimating the level of impact at each site. Impacted sites typically have high levels of Cl^-, NO_3^-, SO_4^- and increased conductivity (Table 2). Dissolved oxygen is usually much lower in heavily impacted sites, sometimes falling below 1 mg/l. Sites 2 and 7 are used as reference sites and the remaining five sites range from moderate to heavy impact. Site 1 has relatively high levels of nutrients and conductivity, however, it does not receive heavy organic and bacterial loads that the other impacted sites receive. Isopod and amphipod populations have also been considered in assessing impact. Biological factors are discussed below.

Effects of the septic systems on potential food sources for the isopods and amphipods are being examined. Sediment organic content, and bacterial and fungal biomass in sediments are being measured at all sites. Field enclosures are being used to measure individual growth rates in sites at each level of impact. Laboratory feeding studies are being conducted to determine which food types provide the greatest nutritional resource for *C. recurvata*.

Measurements of densities and size-class distributions of isopods are being conducted quarterly at each site using mark-recapture methods. Photographs taken during the mark-recapture trials are digitized to establish size-class distributions of isopods at each site. In Spring 1993, highest isopod densities occurred in moderately impacted sites (Table 3). Site 7, a reference site, contained a relatively low density of isopods and none were present in heavily impacted sites, sites 3 and 6. Site 2, a reference pool, is much smaller than the other sites and receives very little organic input. The lack of food sources is probably the cause of the absence of organisms in this site. Troglobitic amphipods (*Stygobromus mackinii*) were found only at sites 1 and 7 (Table 3). Both sites receive little excess organic input and maintain high levels of dissolved oxygen.

Mean sizes of isopods is lower in impacted sites compared to reference sites (Table 2). In Spring 1993 mean size in site 7 was significantly greater than mean sizes in other impacted sites based on one-way analysis of variance. Site 1 was significantly greater than one of the impacted sites (Site 5). Growth may be inhibited in impacted sites that have suppressed oxygen levels. Data from summer, fall and winter mark-recaptures will be examined to see if the trend continues.

Moderate enrichment by the septic systems may lead to increased densities of C. *recurvata.* However, high levels of impact cannot be tolerated by C. *recurvata* or S. *mackinii.* S. *mackinii* appears to be more sensitive to disturbance by the septic outfall, probably in response to periods of extremely low levels of oxygen. Excess input of organic material in addition to nutrients seems to play a major role in reducing dissolved oxygen and increasing detrimental effects on the aquatic community. The role of toxicants from households also is being examined.

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Table 2. Mean levels of selected water quality parameters (for 10 months).

Site #	2	7	1	4	5	3	6
Dissolved Oxygen (mg/l)	10.1	10.2	9.8	7.9	5.3	5.2	6.8
Conductivity (umhos)	248	323	526	326	376	425	481
Cl^- (mg/l)	1.2	1.7	23.5	11.8	15.9	6.6	10.2
NO_3^- (mg/l)	7.9	9.8	10.0	31.6	38.8	14.7	15.7
SO_4^-	12.2	14.0	25.7	19.8	23.2	15.0	15.6

Table 3. Isopod Densities.

Site	Isopod Density (#/m^2)	Mean Size of Isopods (mm)	Amphipod Density (#/m^2)
1	27.5	7.68	1.5
4	43.5	6.52	0.0
5	18.2	6.35	0.0
7	3.0	8.45	5.6

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CAVE BOOKS

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

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

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Richard A. Watson .... Used and Small Lot Remainders

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

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

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

Publications represents a major and growing effort in the Foundation. We continue to solicit manuscripts and add new items to our inventory. Revenue from this effort provides primary support for many Foundation programs, including the Annual Report. Books published by Cave Books (Intl. Standard Book Number ISBN prefix 0-93978-)are now listed in Books in Print, and Cave Books is listed in the standard directories as a publishing house with interests in nonfiction and fiction having to do with caves, karst and speleology.

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