1989
ANNUAL REPORT

Cave Research Foundation

Cave Research Foundation
Annual Report
1989

Cave Research Foundation
1019 Maplewood Dr., No. 211
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USA

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

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Cover Photo: A profuse helictite display in the Helictite Room, Caverns of Sonora, Texas. (*Photo by David Jagnow*).

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Cave Conservation

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

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 Also, many of the processes that formed the cave passages we travel are no longer active in these areas.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

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

Cave Research Foundation Directors

Highlights of 1989

The Foundation's cartographic projects at Mammoth Cave and Carlsbad Cavern have been evolving over several decades. As a result, survey data has accumulated in large separate data sets of different format and media. This year saw about 90% of the Mammoth Cave surveys and virtually all of the Carlsbad surveys transcribed to their own single databases. This has made the data more useful and accessible to CRF scientists and the National Park Service.

The CRF Board initiated a long term project to assist in the creation of a world-class research center at Mammoth Cave National Park and a fund-raising drive has commenced.

A joint project between the Lechuguilla Cave Project and CRF was initiated. The project's aim is to obtain a high precision survey line, using state-of-the-art instruments, along the major branches of Lechuguilla Cave. An agreement between CRF and the Pentax Corporation will allow the use of PTXII Total Station Instruments and other equipment on loan from Pentax.

The first full year of the Foundation's cave inventory and environmental monitoring projects at Lava Beds National Monument saw a wealth of data accumulation. Progress reports on some of these projects are included in this report.

Plans for a second CRF China expedition were put into motion. The Board agreed to provide financial assistance in support of a reconnaissance trip prior to the next expedition. The Foundation also created an International Expedition Fund that will be supported by interest from the Bill Mann Fund and individual contributions.

Rondal R. Bridgemon
Cave Research Foundation President

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Science Programs

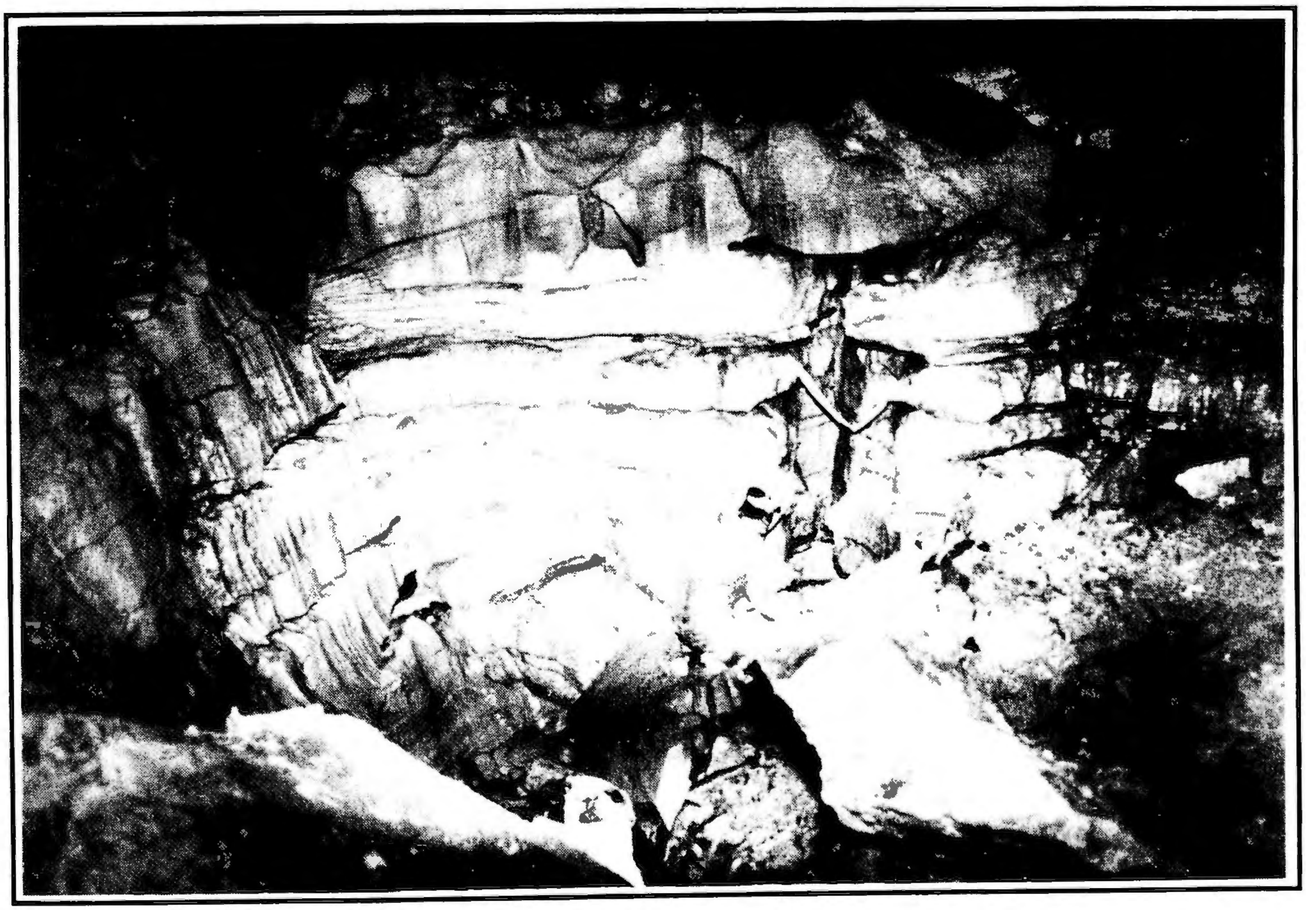

Figure 1: Karl Rusterholtz working on his microbiology studies in the Lucy's Dome area sampling site, July, 1989. (*Photo by Scott House*).

Cartography Program

Reconnaissance Cave Inventory in Lava Beds National Monument

by Mike Sims and Dan Weinberg

The objectives of this project are to 1) develop a reconnaissance inventory card and procedure to provide basic documentation on caves, and 2) to locate and provide reconnaissance information for as many as possible of the 200+ caves in the Monument.

After several drafts, a suitable inventory form on a "pocket-size" card has been developed and has received preliminary approval by the Park Service. Several caves have been located and the reconnaissance information entered on the cards. The project is just getting underway, so the exact cave locations have not yet been marked on the master aerial photos and maps.

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General Resource Inventory at Lava Beds National Monument

by Janet Sowers and Bill Devereaux

The objective of the general resources inventory is to provide systematic information on the resources and attributes of the caves at Lava Beds National Monument. This inventory is more lengthy and detailed than the reconnaissance inventory, and is intended to be done on a subset of caves selected as representative or as having pressing management concerns. A general resource inventory may be conducted as a response to concerns about a cave raised by the reconnaissance inventory. Data from the general resource inventory may, in turn, trigger scientific studies, monitoring, or management planning.

Data from both the reconnaissance inventory and the general resource inventory data will be entered into a computerized data base being developed by Walter Sydoriak of the National Park Service. Ultimately we hope to be able to do computerized searches on any topic and any cave.

Efforts to date have concentrated on development of the inventory form. This has proved to be a challenge. The form must ask for enough information without being too lengthy, questions must be clearly stated and answers quantitative and objective wherever possible, and data must be in a form that can be easily computerized. Topics covered in the present draft include:

Cave location	Historical data
Entrance configuration	Biology
Atmosphere and hydrology	Geology
Cultural resources	Paleontology
Visitor management	Visitor impact

Also on the form is a space for the inventory team to rate the significance of this cave with respect to seven major attributes. These ratings will serve as flags to scientists and to management that particular features need special attention.

We began developing this form in 1988 by asking experts in appropriate fields what they felt was important to record in a cave inventory. Since that time the form has undergone extensive refinement and revision. We have worked closely with Charisse Sydoriak, the Resources Management Specialist at Lava Beds, to trim unnecessary information and make the form more quantitative and objective. Trial runs in the caves were conducted several times during the process. The present form is about nine pages long and is organized so that pages can be separated and inventory can be done topic by topic if desired. A final version should be ready in April 1990.

The remainder of 1990 will be devoted to preparing the inventory handbook, lining up personnel and training teams, and beginning the inventory in earnest. We hope that our work on the inventory form will pay off both by making the inventory process an interesting and rewarding one for CRF participants, and by providing useful and reliable data for managers and researchers.

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Cave Mapping in Lava Beds National Monument

by Mike Sims and Bruce Rogers

The objective of this project is to map caves that are more than 100 feet in length, or have significant contents or features of concern for cave management. Mapping will concentrate in caves in the Merrill-Skull trench and the Cave Loop-Post Office trench. Also, caves for which a general resource inventory is to be done will be mapped or remapped if necessary to provide a good base map for inventory data. Cave maps will be drafted at 1" = 10 meters, using standard cave mapping symbols.

By the end of 1989, 18 caves had been surveyed for a total of 8,337 feet. Draft maps have been prepared for approximately one third of the caves. The mapping project actually began in 1988 before the formal agreement was signed. We committed to mapping twelve caves and in surveying have already exceeded that number.

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Cartographic Depiction of the Karst of Redwood Canyon

by John C. Tinsley and Peter Bosted

Cartographic efforts to document the karst of Redwood Canyon, Kings Canyon National Park include mapping the three caves of the area (Lilburn Cave, Mays Cave, and Cedar Cave) at a scale of 1:240, producing an atlas of the caves, at a scale of 1:240 or larger, emphasizing details of passages, passage gradients, and cross-sections and survey stations, and compiling a planimetric map portraying the karst features of Redwood Canyon (scale = 1:4800), progressed well during 1989. The cartography of Lilburn Cave is discussed further by Peter Bosted elsewhere in this volume.

The 1:4800-scale map, when completed, will show the topography sinkholes, trails, cave entrances, and sinking tributary streams. Sources of data for the map include poorly-integrated but well-intentioned studies performed prior to Cave Research Foundation's presence in Sequoia and Kings Canyon National Parks augmented by CRF studies, as well as CRF surveys designed to portray trails, streamcourses, and active, developing karst geomorphic features of the Redwood Canyon area. This map will be an integral part of several studies, including the study of rates of soil erosion described elsewhere in this volume; it should also serve resource management's needs as an effective documentation of the principal karst resource of Kings Canyon National Park.

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Carlsbad Cavern Cartography

by Ron Lipinski and Dave Dell

All of the Brunton and Suunto survey data for Carlsbad Cavern is on computer files and incorporated into the SMAPS [1] mapping program. In addition, the theodolite data of Tom Rohrer are also in the files, and are used as the backbone for the rest of the surveys. (The theodolite data was incorporated by taking the reduced data points and unfolding them to obtain pseudo-compass data.) Most of the data were typed in by Dave Dell, Ron Lipinski, and Bob Buecher. The data are arranged in the SMAPS files in directories and subdirectories that are similar to the structure of the cave. The SMAPS preliminary graphics package was very useful in identifying and correcting many blunders in the original data. In all, 127 blunders were identified and corrected. (Most of these were reversal of point names or reading the compass backwards.) Loop closure has not yet been performed on the data because of a present difficulty that SMAPS has in closing loops which contain constrained stations (such as theodolite points) which are not allowed to move.

Figure 2 shows line diagrams for the plan and profile views of Carlsbad Cavern produced by SMAPS from the data set. The profile view shows some interesting features. The distinct levels of Left Hand Tunnel and Lower Cave are apparent. Spirit World hangs above the Big Room, showing how high the Big Room ceiling is and suggesting how thrilling the first ascent must have been. The Mystery Room pit in the far west, and the Lake of the Clouds at the east end of Left Hand Tunnel, are two sources of acidic spring water that formed the cave. Bottomless Pit, just below Spirit World in the profile, is another source, but is not as deep as the other two.

The plan view shows numerous passages and some spray shots used to better define the walls of some rooms. (The detailed theodolite spray shots of the Big Room reported by Elbert Bassham in the 1977 Annual Report are not shown.) The existence of spray shot and repeat surveys raised the question about the true surveyed length of Carlsbad Cavern. An often-quoted length for Carlsbad is 20.8 miles [2,3]. The source of this number could not be determined, but further investigation revealed that past quotes had been based on the total sum of survey data, including redundant shots. Since SMAPS had the ability to flag repeat or spray shots so that they would not be included in a total length, it was decided to systematically go through the data files and obtain an "honest" length for the cave.

The convention used for length is the sum of all tape lengths that are not redundant or spray shots. Thus, for shots up a hill, the tape length is used, not the horizontal projection. The shot that connects a side passage to the main passage survey is also included in the length. When rooms are more than 150 feet wide, a perimeter survey is used for the length. (This doubles the strict length of the room, but big rooms have special privileges.) The depth of a pit is included in the length because that is the taped length of the passage. The length of the cave is thus approximately the minimum-length stick figure that will fit in the cave and penetrate all passages.

Table 1 shows the various sections of the cave grouped as SMAPS directory files and the non-redundant length in each area. The non-redundant surveyed length of Carlsbad Cavern is 19.2 miles (30.9 km).

SMAPS was also used to produce a list of all survey stations and their coordinates. Because loop closure was not performed, some of the stations have several sets of

Table 1. Carlsbad Cavern Lengths as of 12/03/89.
Carlsbad Cavern' non-redundant length: 101431.85 feet = 19.21 miles

Area	***Non-Redundant Length (feet)***	***Area***	***Non-Redundant Length (feet)***
Main Corridor	13002.61	Left Hand Tunnel	23251.06
Entrance	5221.44	Entrance Area	4471.22
Secondary Stream	5510.63	Middle Section	9693.79
Bat Cave	2270.54	East End	9086.05
New Section	24366.97	Big Room	2442.81
New Section Prime	13099.43	Big Room Prime	9312.65
Guadalupe Room	3279.55	Middle Earth	3130.16
Lower Pit Series	3688.35		
Cave Pearl Room	1221.24	Lower Cave	16293.45
Remarkable Crack	3078.40	Transit	2424.59
		Main Trail	3592.61
Western Rooms	12074.95	Back Alleys	3549.08
Scenic Rooms	821.55	Talcum Passage	2180.17
New Mexico Room	6837.44	Naturalist Room	2146.10
Mystery Room	3415.96	Central Boneyard	2400.90

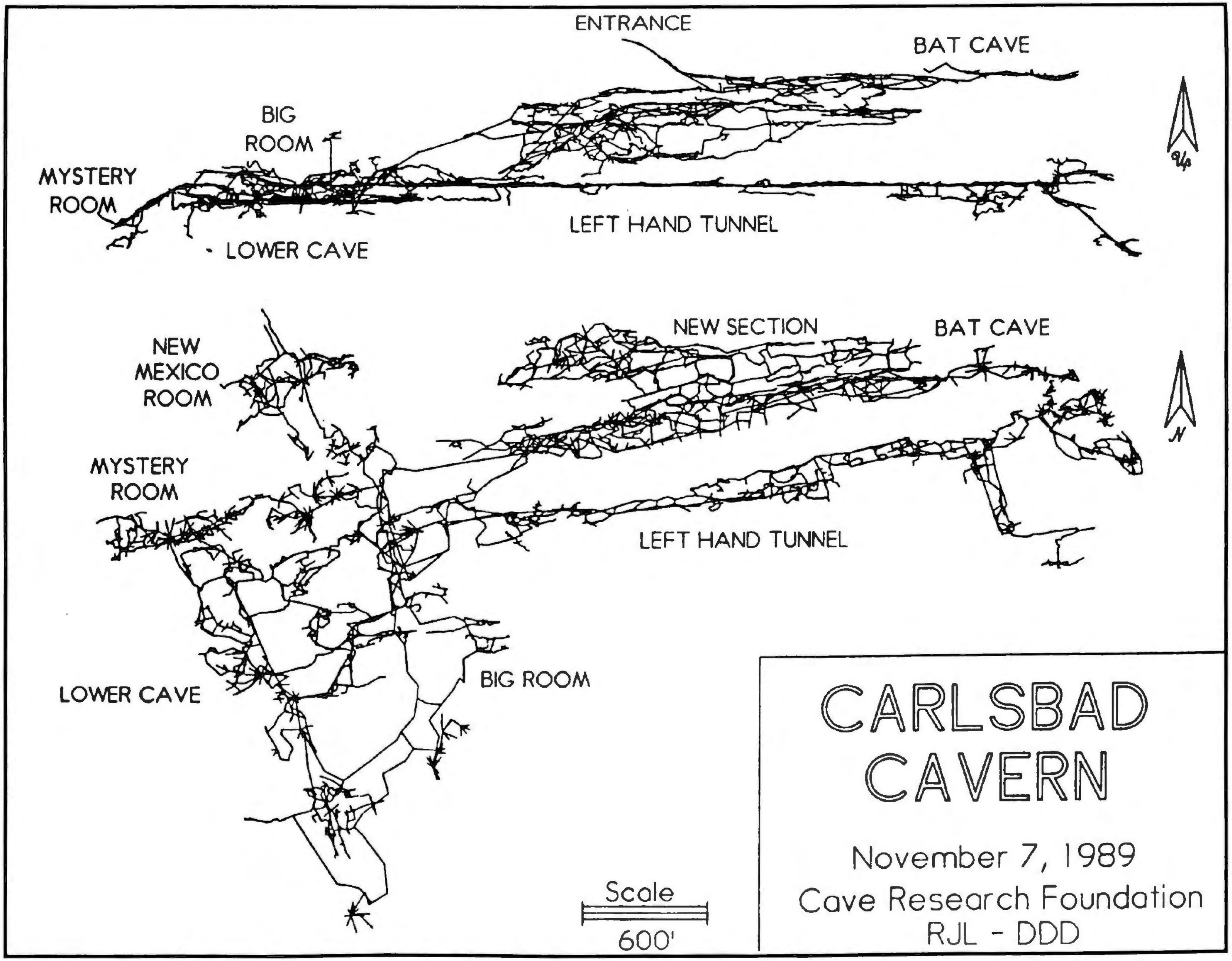

Figure 2: Profile and plan views of Carlsbad Cavern line diagram.

coordinates. The resulting list consists of 5580 shots (including repeat shots) and occupies about 100 pages. Fortunately, the list is also on a computer file (323 kbytes).

Next year, the data will be adjusted for loop closure, assuming SMAPS is improved so as to handle constrained stations in a loop. Then the reduced and adjusted points can be plotted and an inked version of the quadrangle maps (at 1:600) can be made. To clearly see every point labeled on a line plot would require a scale of about 1:240. SMAPS and a laser printer could be used to make a book of such plots; it would only be about 300 pages long.

References

D. P. Dotson, *The SMAPS Cave Survey Management System*, SpeleoTechnologies, Inc, P.O. Box 293, Frostburg, MD, 21532

P. Courbon, C. Chabert, P. Bosted, and K. Lindsley, *Atlas of The Great Caves of the World*, Cave Books, St. Louis, p. 106, 1989.

NSS News, p. 229, September 1989.

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Fitton Cave Survey Project

by Pete Lindsley and Gary Schaecher

The primary goal of the Project is the systematic precision survey of Fitton Cave, Arkansas. Located in the Buffalo National River, access to the cave is controlled by a permit system managed by the United States National Park Service. An initial milestone of the Project was the survey of the major trunk passages in the cave. A secondary milestone was the preliminary release of the draft map quadrangles. These two milestones were completed during 1989 as well as planning for continuation of the survey work in the cave. Cartography continued under the guidance of Gary Schaecher, the Chief Project Cartographer.The majority of the survey of the major trunk passages was completed in late 1987. The first five preliminary quadrangle sheets covering the major trunk passages from the Fitton entrance to a point just past the Out Room along the Crystal Passage route were completed in 1987.

During 1988 the Foundation emphasized cartographic efforts to bring the maps up to date with all the field surveys in the major trunk passages of Fitton Cave. Inking of the first five quadrangles was completed and copies of the maps were delivered to Buffalo National River in May, 1988. The next seven quadrangles included one in the Tennouri Room area, three along the Bat Cave - to - T-Room route, two in the Millipede Passage area and one East Passage quadrangle. During the summer of 1988, Robert Taylor's East Passage data was incorporated into the quadrangle system. In the fall of 1988, after Dave Hoffman slightly adjusted the scale on his previous sketch data to fit the new project quadrangle scale, work began on the three Bat Cave quads.

In April, 1989, a meeting was held with Buffalo National River Resource Management Specialists Russell Lesko and John Apel to discuss the Project's progress and future plans. A set of up-to-date ("PRELIMINARY") Fitton quadrangles was delivered to the Park and discussed in detail. Plans for continuation of the field work on the Project were completed, with much additional passage to be surveyed in all portions of the cave. These "minor" passages are on different levels of the cave, both above and below the trunk passage presently featured on the draft quadrangles.

A total of 401 PHUG ("people hours under ground") was recorded on three 1989 expeditions with 8 survey parties. The June 10 expedition, which had people from Texas, Arkansas and Oklahoma in attendance, fielded one survey party of 5 cavers. Work was started on the south end of the New Maze area with a survey tied to Jurgan's Leap passage. The August 12 expedition fielded four survey teams with 15 people. With only two experienced surveyors and two with limited surveying skills, this expedition was primarily a training expedition. Two teams worked in the New Maze area, one worked the area just below the Out Rock, and one worked the breakdown leading down to the Lost Passage. On the October 14 expedition three teams were fielded with a total of 14 people. Two teams worked in the New Maze area and a third worked in the Lost Passage breakdown area. Both areas were connected with previous surveys.

Following the August expedition which emphasized a review of Project survey techniques, the survey book used in the cave was improved. The map symbols used to describe the cave in the sketch were clarified by combining symbols published by the NSS, CRF and AMCS. "Hints for a Better Survey" were added to clarify station naming, backsight and wall dimensioning techniques. The data sheet was also improved to clarify recording of the backsight data and a grid was added to aid the sketcher.

Near term survey objectives will center on the New Maze, Tennouri Helictite, and Lost Passage areas. Wall detail and passage cross sections on existing and future maps will be emphasized. Future work is expected to start in the Lower East Passage and Fitton Spring areas. With a good baseline quadrangle map set in hand, CRF is now in a position to support some additional scientific work on this "little Mammoth" cave in the Ozarks. There are several potential projects including mineralogy, geology, hydrology and biology that will be of interest to qualified scientists and researchers.

Interested primary investigators should contact Pete Lindsley, Project Manager, or Gary Schaecher, CRF Arkansas Area Manager, for additional information.

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HyperCave - A Hypertext Concept For Display of Cave Data

by Pete Lindsley

The Fitton Cave data base is being featured in HyperCave, a hypertext example of a new concept in display of scientific data. The computer program is presently implemented with the Hypercard language on a Macintosh computer. The user-friendly interface offers a casual observer an overview of the Cave Research Foundation and it's operations. Simply by clicking the mouse pointer on icons representing items in the data base, the user can scan through the data much like flipping through an encyclopedia. The initial "beta version" of HyperCave, released in 1988, emphasized the user interface concept and contains general CRF data including the Fitton Cave Project. Future work will add the Fitton Cave map quadrangles to the data base and will allow improved demonstration of the concept of providing both an overview of the resource and details of interest to the specialist.

Reference:

Lindsley, R. Pete, October 1, 1988, "HyperCave", (A Hypercard stack for the Macintosh computer).

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Missouri Cave Survey and Inventory

by Scott House

Ozark National Scenic Riverways

The ONSR is an elongated park along the Jacks Fork and Current Rivers of the southeastern Missouri Ozarks. Ten years of efforts have increased the number of known caves in the park from eighty to nearly three hundred. Of these about 170 have been surveyed. With most of the larger known caves surveyed in the park efforts have centered on three objectives: 1) to survey the remaining smaller and/or more remote caves, 2) to survey caves just outside the park whose waters drain into the park or are otherwise hydrologically significant, and 3) to look for new caves in geologically promising areas. Most of the caves are found along certain lithologic boundaries and efforts are normally concentrated at these horizons in the nominally flat-lying rocks of the area. Most efforts during 1989 were related to the first objective and virtually all of this work was centered on the Jacks Fork drainage. Trips were taken to survey Panther Cave and Dam Cave in Texas County, Lost Jenny Cave in Shannon County, and several shelters and small caves along the lower Jacks Fork. Additional trips were taken to locate new caves or confirm old locations. One large, wet cave located just outside of the boundarieswas the site of several survey trips; the cave and surrounding area has been suggested to the state as a natural area.

Missouri Department of Conservation Lands

Cave-bearing lands owned by the Department of Conservation are either Natural Areas or state forests. One weekend trip was taken to Great Scott Cave, Washington County, which is a bat hibernaculum and maternity colony and thus closed virtually year-round. Considerable new footage was added to the cave which is now nearly 2.5 miles long. Two caves in Shannon County, Big Bear and Little Bear were mapped in one day by two crews. Several trips were taken to the largest cave on department land, Powder Mill Creek Cave. The trips focused on two areas: 1) the continuation of the main stream, called the Third Watercrawl, was extended and a new side passage was partially mapped; 2) a series of low passages referred to as Hellhole eventually opens into an area of complex crawlways, climbs, and trunks that has been the subject of several survey trips with much left to be done. Trips into Powder Mill are getting quite lengthy - upwards of 14 hours - and the wear and tear on surveyors is considerable.

Mark Twain National Forest

This unit of the Forest Service covers a vast area over much of southern Missouri. Several projects are ongoing at this time. Most work has concentrated on the Lead Mine Study Area of Oregon, Shannon, Carter, and Ripley counties. A proposal has been ventured that might permit lead mining in Missouri's largest karstic area. The intent of the cave studies is to provide more information on the resource to the agencies involved in the decision-making process. Several trips were taken to Kelly Hollow Cave, Oregon County, which is now the Forest's second longest cave. Most of the footage is in a newly discovered area of this well-known cave. In the same area Brawley Hollow Cave, Coward's Hollow Cave, and 7 Pile of Rock Cave were also surveyed. In response to a MTNF request a large group of CRF JV's drove to Barry County in far southwest Missouri to investigate two caves that were in the middle of an (unlikely) oil and gas drilling permit area. Much local publicity had been generated by this proposed permit and a newspaper reporter and television crew accompanied the MTNF and CRF personnel into the caves which were alleged to be very deep and extensive. The larger cave was determined to be only a couple of hundred feet long and eighty feet deep while the smaller was only a very marginal cave at all. Nonetheless, the attendant publicity made for good education and public relations. Two other caves were also investigated; one was mapped but the other proved to be a copperhead den and was evacuated with great alacrity.

Elsewhere, several trips were taken to extend the length of Douglas County's Still Spring Cave, the Forest's longest cave. Lastly, one trip was taken to nearly complete Cave Hollow Cave in Iron County.

Conservation and Education

The Foundation continued to provide support for the Ozark National Scenic Riverways programs. The Foundation provided assistance and input to two management plans that were formally approved in 1989: the River Use Plan and the Cave Management Plan. In addition, JV's led educational tours of Round Spring Cavern for two groups: one for an Ohio geology club and the other for ONSR seasonal interpreters who were either going to be leading cave tours or were in need of some speleological background information.

The Foundation promoted Forest Service actions leading to the gating of two sensitive caves: Cave Hollow Cave, a bat maternity colony, and Still Spring Cave, a paleontological site. The Foundation also has provided information and guidance to the Forest concerning two drilling permit areas in the Ozarks.

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

by Scott House

Cartographic efforts at Mammoth Cave National Park were affected by a number of new efforts in 1989. In conjunction with NPS efforts to effect a cave geographic information system CRF made long strides in coalescing and standardizing its survey data mass and software is being written to effectively deal with the wide variety of data types and formats. Traditional cartography made great gains as well and 1989 can be marked down as an important year for CRF efforts.

A revised cartographic research plan for the project was written and signed by CRF and Mammoth Cave National Park. The project now has status as a Resource/ Research Project rather than the old natural history permit. Standards are more closely identified and goals will be set for periods of up to several years.

FIELD WORK

Mammoth Cave Ridge

Field work continued to concentrate on resurveys of major passages, reinspection of others, and careful examination and survey of untouched leads. Newly discovered passages in the ridge accounted for over two miles of survey and resurvey accounted for a little over four miles of survey. Much was accomplished in the complex of passages trending toward Albert's Domes, particularly resurveys of Welcome and Ganter Avenues and new surveys of small side passages and cutarounds off of them. Additionally, Jessup Avenue, Flint Alley and several of their side passages were resurveyed. The survey of the Solitary Cave area was nearly completed in an intensive effort to understand that unique area. Work was also continued in the area of Black Chambers, Ranshaw Avenue and Monties Pass.

To continue the improvement of the survey net, resurveys of El Ghor and Belfry Avenue were continued and new surveys were done of Valley Way Side Cut and Shelley Avenue. A possible connection between Blue Spring Branch and Sarah Margarets Dome was pushed but was not successful.

In the southeast end of the ridge a major connection was found between high level passages originating at the top of Cathedral Domes and an upper level of Kentucky Avenue near Mount McKinley (Figure 3). Other work along Kentucky Avenue continued the slow cleanup of areas with smallish leads. These leads almost constantly provide new survey and add to the overall picture of the cave. Cleanup work was also done in low crawls off the Bransford Avenue West area.

Hawkins River Area

Despite a number of cancelled trips to due rainy weather coinciding with many expeditions a fair amount was done in the river passages. Over a mile of new survey was put in; most of this was up the L survey trending toward ridges southeast of the park. Approximately 1.5 miles of the river was resurveyed to provide a more accurate survey net for the area and to improve on the sketch qualities.

Flint Ridge

Most of the work centered on Colossal Cave and passages connecting it to other parts of the ridge. Weller Avenue was resurveyed from its origin in the lower level of Salts out to its connection with Lehrberger Avenue. Resurveys were also done on Austin Avenue and in Indian Avenue. The goal with these major passages is to create a tight survey net that can be closed simultaneously. The old commercial trunk of Colossal, Grand Avenue, was also partially resurveyed.

In Unknown Cave work continued on sorting out a mess of passages and levels in the Textbook Shaft, Foundation Hall, and McClure Trail areas. New survey continues to accumulate in these areas.

Theodolite surveys were run across Flint Ridge beginning at a station on the Flint Ridge Road going to the Colossal entrance, Woodson Entrance, Bedquilt Entrance, Salts Cave entrance, and then to another point on the Flint Ridge Road at the Sells Road intersection. These will be continued in 1989.

Small Caves

Some work has continued in other caves in the park; traditionally albeit somewhat erroneously referred to as "small" caves. 3500 feet of a new survey of Long Cave was completed. Several hundred feet were surveyed in Running Branch on the north side of the Green River. Lawton Cave and Hunts Sink Cave were surveyed. One trip to Lee Cave turned up a small amount of survey in the Thorsell Shafts area. Hackett Cave #1 and Crow Cave #2 were surveyed in the general area of the Frozen Niagara entrance.

DATA REDUCTION

Much progress was made on a universal cave-data interpreter called Cave Map Language, written by Mel Park. Use of this program will allow us to utilize all surveys recorded on magnetic media by CRF over the years. The outstanding feature of the program is its ability to parse the data, correctly interpret the nature of this data, and then act on the data in different ways. When fully functional, this will allow us to use entered data not just for data reduction but also to create schematics, lists of tie points, log sheets, records of personnel, compass eccen

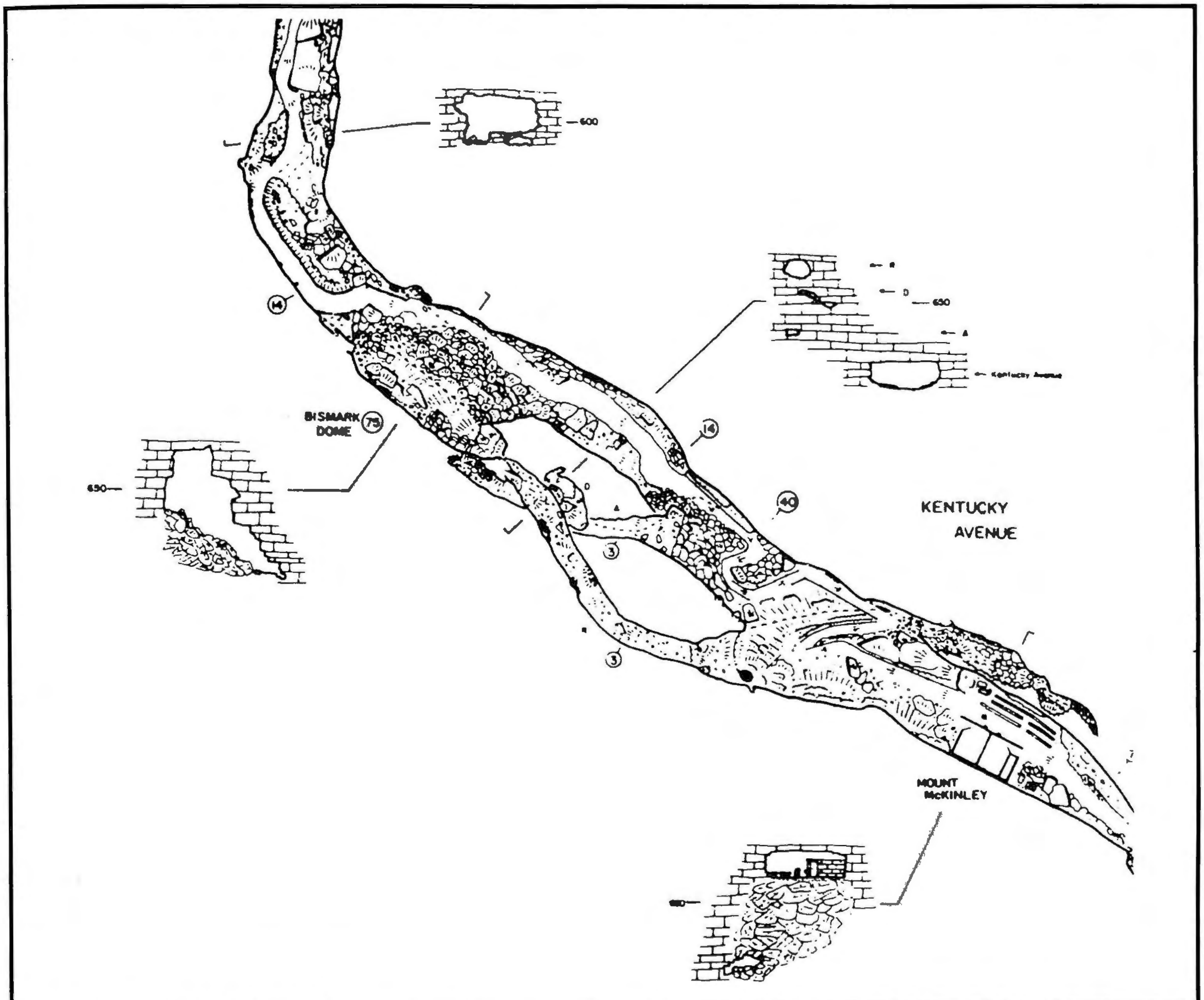

Figure 3: Cartographic detail in the Mount McKinley area of Kentucky Avenue, Mammoth Cave, Kentucky.

tricities, etc. The program deals with ASCII files and the data is therefore interchangeable with most commercial database and CAD programs. To fully implement the program CRF's data has been gathered and converted to Macintosh and MS-DOS formats. Copies of this machine data have also been provided to NPS for use in their planned cave geographic information system.

CRF has also made use of the commercial SMAPS reduction program and some new data has been entered into it. We are still evaluating its suitability for our use. Lastly, considerable improvements were made to the venerable Cave Recorder program enabling continued use of older 8-bit machines currently available to us.

Work continues on revising the length of the cave by analyzing the survey books one by one and separating new survey from resurvey. This is a slow and difficult process with over thirty years of data accumulated. The result is an incomplete and very conservative length of the cave which at year's end stood at 314 miles or 505 kilometers. Again, this is a very incomplete figure and the true current length is probably at least 10 miles greater than that.

CARTOGRAPHY

Progress is continuing on putting the cave on sheets of gridded mylar at a scale of 1:600. The Kentucky Avenue sheet is nearly done and inking has begun on it. These are the sheets that are currently in progress (pencil on mylar) accompanied by the name of the cartographer:

Crystal Cave (2 sheets) .... Art Palmer
Unknown Cave, Pohl Avenue .... Paul Hauck
Mammoth Cave
- Frozen Niagara .... Scott House
- Kentucky Avenue .... Michael Sutton
- Cathedral Domes .... Scott House
- Cleaveland Avenue .... Doug Baker
- Blue Springs Branch .... Michael Sutton
- Main Cave .... Scott House
- Marion Avenue .... Robert Osburn

The following sheets are in a preliminary (pencil on paper) stage:

Colossal Cave (3 sheets) .... James Borden
Hawkins River System (4 sheets) .... Robert Osburn
Unknown Cave
- Brucker Breakdown .... Scott House
- Mather Avenue .... Scott House
- Gravel Avenue .... Michael Sutton
- Northwest Passage .... Michael Sutton

In advance planning and field work phases are:

Mammoth Cave
- Historic .... Doug Baker
- Echo River .... Doug Baker
- Bishop's Domes ....
- Cocklebur Avenue ....

Several maps of smaller caves within the park were in final stages of completion including:

White Trail Cave	Little Beauty Cave
Rubble Cave	Jim Cave
Lawton Cave	

At the request of the NPS a map showing historic trails and place names in Mammoth Ridge was produced by Michael Sutton. This will be expanded into a small-scale trail map as time allows.

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Geoscience Program

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

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

Introduction

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

Example Records

Forty-two days of the Big Spring stage hydrograph (March 23 - May 4, 1989) are shown in Figure 4. The ebb and flow behavior can be observed from the beginning of the record (March 23, 1989) through day 93 (April 3, 1989). From that time on, the stage slowly drops with a small diurnal cycles superimposed on the long term decline.

Figures 5 and 6 present more detailed examples of the types of records being obtained from the recording system on Big Spring including temperature and electrical conductivity. In Figure 5, five days of record are presented. During this period of ebb and flow behavior, the stage generally varied from a low of 0.6 feet to a high averaging approximately 1.4 feet including an interesting example of the stage going to near zero on March 25, 1989. Approximately 20 ebb and flow cycles per day occurred during this period. Water temperature varied between 5.6 and 6.0°C and electrical conductivity varied from 83 to 96 µmhos/cm over the five days except for the sharp increases on March 25, 1989.

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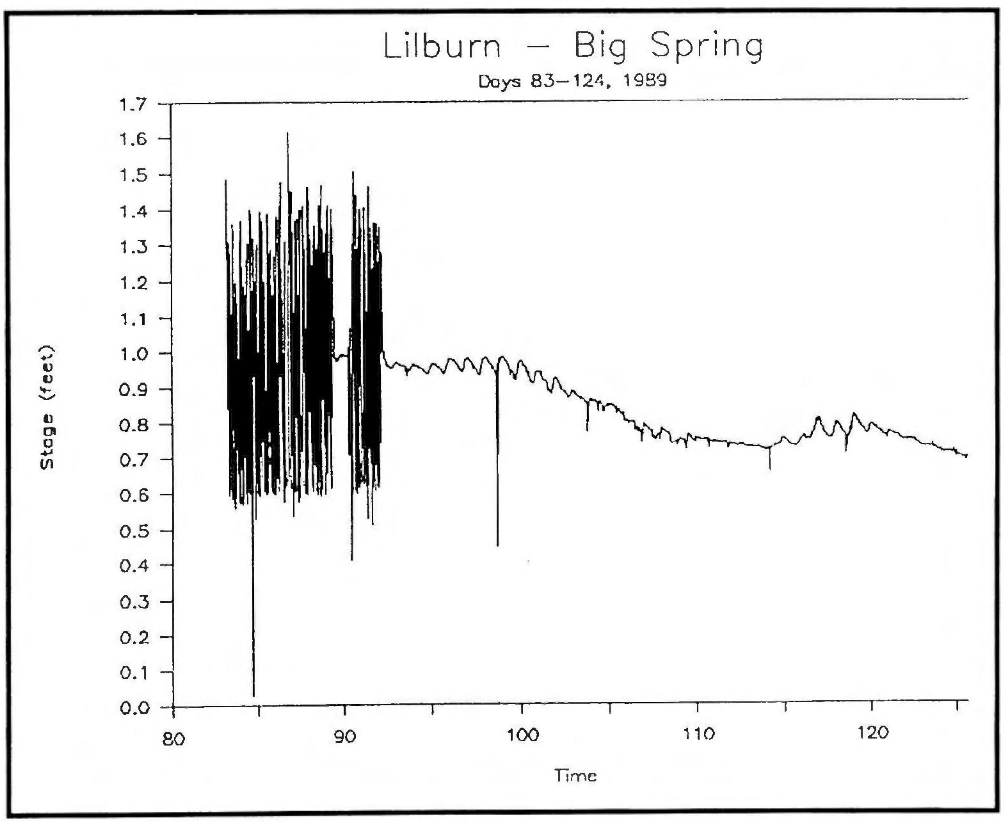

Figure 4: Big Spring Stage – March 23-May 4, 1989.

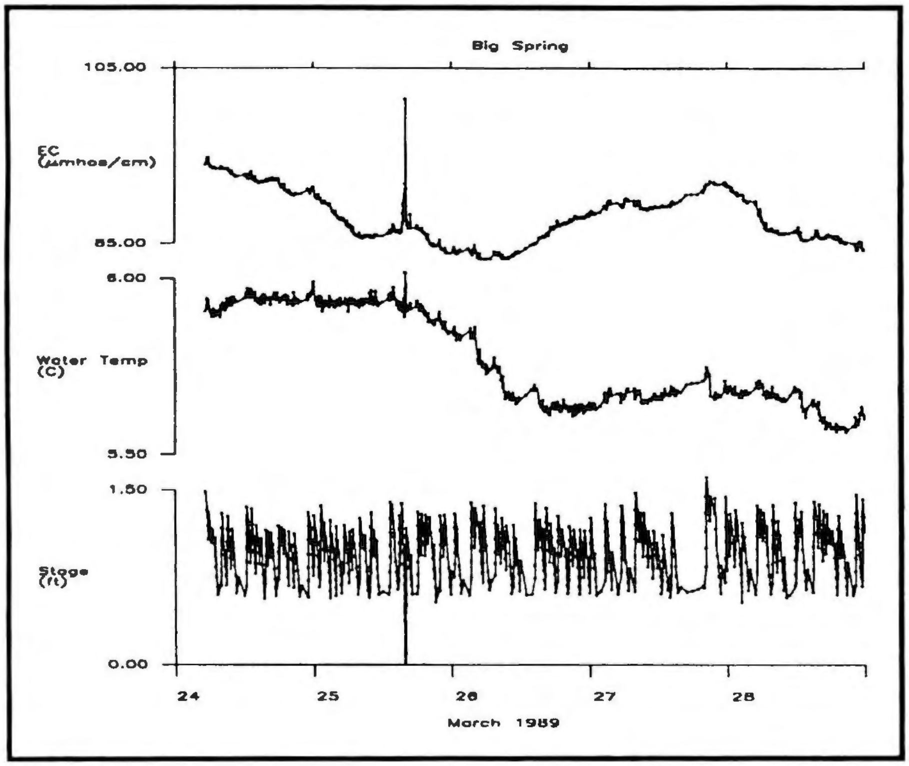

Figure 5: Electrical conductivity, temperature and stage hydrographs for Big Spring on March 24-28, 1989.

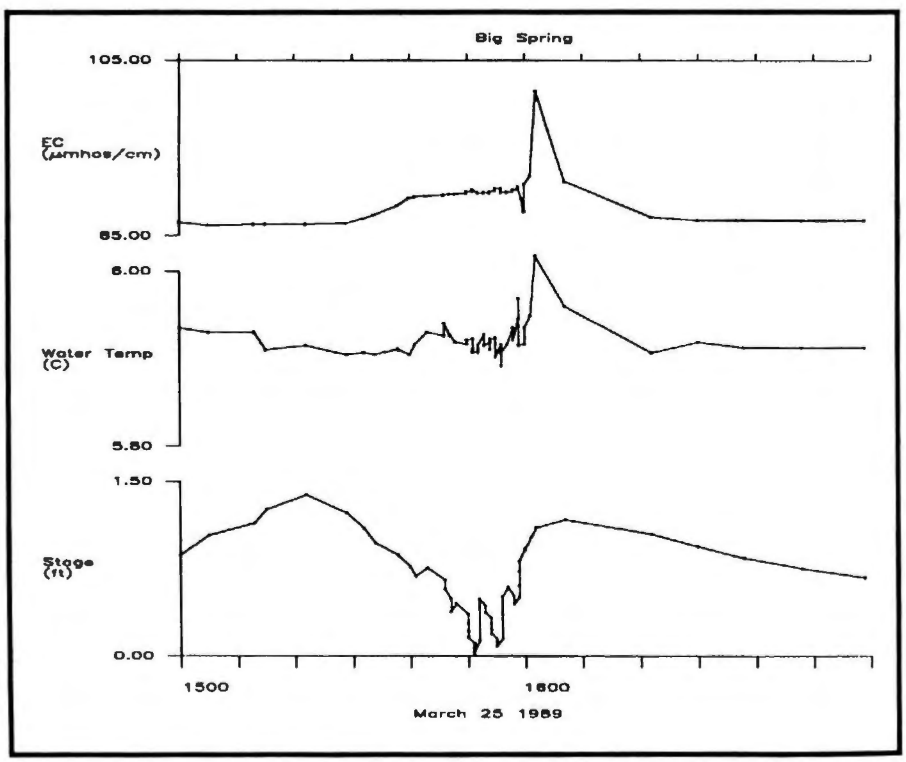

Figure 6: Detailed electrical conductivity, temperature and stage hydrographs for Big Spring on March 25, 1989.

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

by John C. Tinsley

Introduction

Sinkholes and Sinkhole Sediments

Colluvial and alluvial processes which transport earth materials from slopes to sinkholes and caves are important in the evolution of karst basins; however, opportunities to estimate rates of soil erosion and slope degradation in karsts of the western United States under conditions of natural vegetation are seldom realized. Into the nearly pristine drainage basin of Redwood Canyon, a 700-year old silicic volcanic ash was erupted from the eastern Sierra Nevada and subsequently blanketed the mantled karst; this tephra deposit forms a discrete horizon in selected sinkholes and provides a stratigraphic basis for calibrated, volumetric estimates of post-tephra sediment eroded to the sinkholes (Tinsley, 1983). The study includes about 38 of the 60 sinkholes mapped in the karst; the results presented reflect a simple yet effective means of obtaining estimates of this karst-related process.

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

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

Methods

In each sinkhole, an array of 15 to 30 holes are excavated using a hand-powered soil auger and the respective thicknesses of tephra and post-tephra sediment are measured in each hole. The respective volumes of tephra and post-tephra sediment are estimated using standard isopach mapping techniques. The quotient of the tephra volume (or post-tephra sediment volume) divided by the area of the basin draining into the sinkhole yields an estimate of the vertical thickness of tephra or post-tephra sediment eroded into the sinkhole from the drainage basin. Of course, a key assumption is that the sinkhole has behaved itself by having trapped sediment and has not leaked appreciable tephra or post-tephra sediment into the subjacent cave system. Sinkholes floored with sediment composed chiefly of sand-sized and finer particles function as a natural filter, permitting water to percolate through to the cave, but effectively trapping the sediment. Sinkholes which contain open or active swallets, evidence of active collapse, or which contain boulders and cobbles simply are not useful for this study. Swallets and active collapse indicate by-passing of sediment directly to the cave and concomitant loss of signal; cobbles and boulders are intrinsically poor filter media and also are impenetrable to the soil auger. As the number of sinkholes suitable for this study is small, compared to the number of sinkholes in the karst, the number of geomorphic variables which can be evaluated from the process standpoint will be smaller than I had hoped for at the outset of this study. Initially, I had expected to compare many sinkhole and drainage basins as possible, the estimated erosion rates among a population of small basins can be studied as functions of basin size, slope, aspect, vegetation or other parameter of interest. However, only 10 or 12 sinkholes are likely to be truly useful; most sinkholes are "leaky", probably owing to the intrinsic perversity of Nature. The estimated erosion rates would be applicable to the mixed coniferous forest ecosystem under conditions of present climate which prevailed during the past 700 years. Only by comparing results from the well-plugged sinkholes can we obtain stable estimates of sediment yield for further analysis.

Results

Thirty-eight sinkholes have been examined and ten sinkholes have been augered as of 12/31/89. Small basins and sinkholes characterized by basin hillslope declivities of less than 8% to 10% tend to retain at least part of the mantle of volcanic ash, which then becomes mixed with the soil owing to biological and physical processes of root penetration and burrowing animals. In this instance, the stratigraphic record is diffuse or intermittent, and uncertainties in the results increase. Slopes steeper than about 10% generally shed their ash mantle readily into the sinkholes and are more efficient contributors of sediment, especially coarse sediment, than their more gently-sloping neighbors. These sinkholes give the best results and are easiest to work with in the field, as the rate of sedimentation typically exceeds the rate of bioturbation within the sink. The tephra blanket apparently ranged in thickness from 1 to 5 cm thick in the Redwood Canyon area. Erosion rates of the soil mantle measured in this way range from 0.5 -1.5 cm/yr during the past 700 radiocarbon years.

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Variation in Carbon and Oxygen Geochemistry and Petrography of the Mississippian Redwall Formation, North-Central Arizona: Implications for Extricating the Diagenetic History of Paleokarst Carbonates and Evidence for the Earliest Microcodium Microfossils

by Ray Kenny

The Mississippian Redwall Formation, north-central Arizona, contains a full spectrum of preserved paleokarst features developed under a regionally extensive, pre-Pennsylvanian exposure surface (DeVoto, 1980; Sando, 1988). Carbonate precipitative phases from the Redwall have been isotopically analyzed for C and O isotope signatures which may be useful in unraveling the complex diagenetic history of paleokarsted carbonate formations.

The preserved thickness of the karsted Redwall ranges from zero (where the soluble limestone has been completely eliminated by chemical dissolution) to greater than 25 m. An unnamed, aerially extensive, red residual paleosol horizon and rubble breccia mark the subaerial exposure surface unconformity. This horizon is similar in lithology, age, and origin to the Molas Formation of Colorado and is herein considered correlative (see Fetzner, 1960).

Petrographic studies and back-scattered, scanning electron microscopy (S.E.M.) of the pre-Pennsylvanian paleosol reveal preserved organic features which resemble Microcodium (Figure 7A). Microcodium is a problematic organism associated with calichification pro

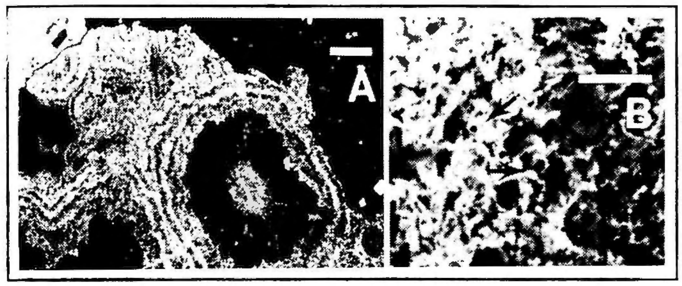

Figure 7: (A) Microcodium in pre-Pennsylvanian paleosol. The microfossils are no longer calcite, but have been replaced and preserved by silica and iron. Scale bar is 100 µm. (Photo #B758). (B) S.E.M. photomicrograph of Microcodium microtubules (arrows). These microtubules are thought to represent intracellular fungal hyphae. Scale bar is 10 µm. (Photo #B761).

cesses and paleokarst cavities (Klappa and Esteban, 1983). Originally considered to be Codiacean algae, Microcodium are currently interpreted as a symbiotic association between fungi and cortical cells of roots (Klappa, 1978). Specimens of Microcodium were obtained from a paleosol exposure along Hunter Creek (SE1/4, S 33, T11N, R13E, Woods Canyon Quadrangle, Arizona). The Microcodium are an integral part of the paleosol and in situ growth is indicated by specimen truncations within the host paleosol. Apparent dimensions range from 300 to 650 mm in diameter. The specimens are spherical, vary from single to twin aggregates, and form petal-like prisms or palisades which radiate from small nuclei. The occurrence of microtubules (Figure 7B) suggest an organic origin. The specimens from the pre-Pennsylvanian paleosol of north-central Arizona, documented herein, represent the earliest known occurrence of Microcodium - predating Upper Jurassic specimens by more than 150 m.y.

Precipitative carbonate from the Redwall was isotopically analyzed in bulk and as separates for $^{13}C/^{12}C$ and $^{18}C/^{16}O$ ratios. The isotopic data are reported in the usual δ notation. $\delta^{18}O$ values for the paleosol and Redwall range from -1.9% to -12.0%; $\delta^{13}C$ values range from 1.7% to -7.8%.

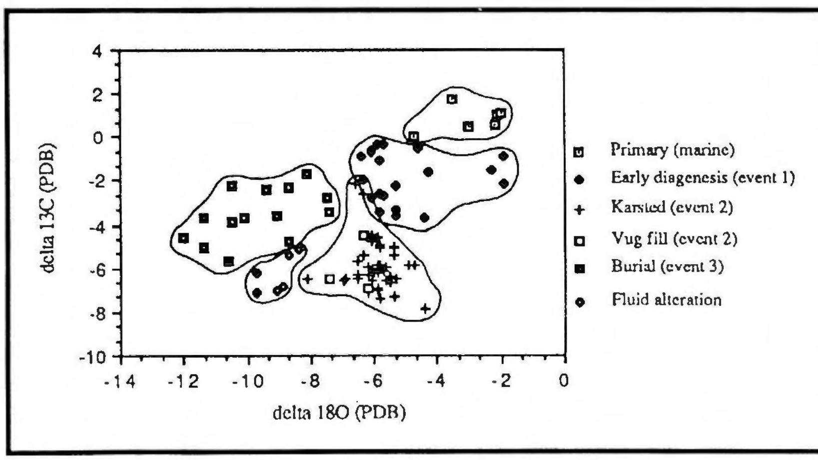

Figure 8: Redwall carbonate. Graph of C and O isotopic values.

Figure 8 shows C and O isotope variations produced during early to late carbonate diagenesis. Three potentially useful geochemical patterns emerge when the data is viewed from a continental-type karst framework: (1) early carbonate stabilization (event 1) is primarily distinguished from remnant marine carbonate by marginally depleted ^{13}C and ^{18}O values (see Allan and Matthews, 1982). As the shelf carbonate stabilizes during early diagenesis, the C and O atoms equilibrate with ambient water (a mixture of marine and meteoric water); (2) continental karst features (vug fills and altered cave travertines) are grossly characterized by invariant ^{18}O and variable ^{13}C (Figure 8; diagenetic event 2). This geochemical pattern results from precipitation of carbonate in the presence of depleted meteoric water and dissolved soil-gas CO_2. The range of $\delta^{13}C$ values stem from variations in the amount of dissolved CO_2 and the extent of water-rock ratio interaction (see Lohmann, 1988); and, (3) deep burial diagenesis characterized by a geochemical field of depleted ^{18}O values.

Invariant $\delta^{18}O$ values related to karsting (event 2) serve as a baseline and allows the paleometeoric water value to be deciphered. The average, empirical $\delta^{18}O$ value (event 2, Figure 8) is -5.6% (PDB; 25.1% SMOW). Using an estimated near surface temperature of 298°K and the carbonate fractionation equation (eqn. 1),

$$1000 \ln [(\delta^{18}O_c(smow) + 1000)/(\delta^{18}O_w(smow) + 1000)] = 2.78 (10^6 \times T^{-2}) -3.40 \quad \text{[eqn. 1]},$$

the $\delta^{18}O$ of the ancient meteoric water can be derived. $\delta^{18}O$ of ancient meteoric water is approximately -33% (PDB) or -3% (SMOW). This value is consistent with a modern, warm tropical climate. Following upland karsting an episode of deep burial diagenesis (event 3) occurred and carbonate reprecipitated in equilibrium with depleted fluids. Macroscopically similar karst and burial vug fills are dissimilar geochemically indicating at least two generations of calcite vug fill precipitation. Deep burial formation waters have often undergone complex and controversial paths of evolution and may have a wide range of O-isotopic values. The release of bound water in clay minerals may account for the origin of these waters. Lawrence and Taylor (1971) suggested that structurally bound water in clay minerals reflects only the composition of the local meteoric water and not the source rocks. Based on this premise, the $\delta^{18}O$ of the clay minerals in equilibrium with a meteoric water value of -3% (SMOW), using equation 2,

$$1.018 = [1 + (\delta^{18}O_{clay} / 1000]/[1 + (\delta^{18}O_{w} smow/ 1000)]$$
$$(a_{ox} \text{ gibbsite} = 1.018) \quad \text{[eqn. 2]},$$

is about 15% (SMOW) or -15% (PDB). Vug fill calcite precipitated in equilibrium with formation waters released from buried clays, coupled with increased temperature, would result in a depleted array of data points (i.e., a shift to the left on Figure 8). If vug fill calcite had reprecipitated solely in the presence of marine transgressive waters, the data would be shifted to the right (Figure 8; marine $\delta^{18}O$ value = 0% (PDB)). The most simple and likely scenario to explain the spike of light $\delta^{18}O$ values associated with some vug fill calcites (given the paucity of field evidence suggesting hydrothermal alteration), is re-equilibration in the presence of deep burial fluids released from clays which formed during the exposure event.

O and C isotopes therefore can be used to help deduce the diagenetic history of a carbonate sequence. Problematic vug fill cavities may also be distinguished from episodes of fill which are genetically unrelated to the karsting event.

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Stable Isotope Study of Cave Waters in Carlsbad Cavern, New Mexico

by Jenny B. Chapman, Neil L. Ingraham, John W. Hess

Introduction

Cavern environments offer the hydrogeologist a unique opportunity to study infiltrating water and groundwater. This opportunity was used to study the stable isotopic composition of water in Carlsbad Cavern, within Carlsbad Caverns National Park. The results reveal information about the recharging drips, evaporation from the cave pools, and changes in the cave environment during the last decade.

The stable isotopes of hydrogen and oxygen are useful water tracers because they are part of the water molecule. The analysis, performed with a mass spectrom-

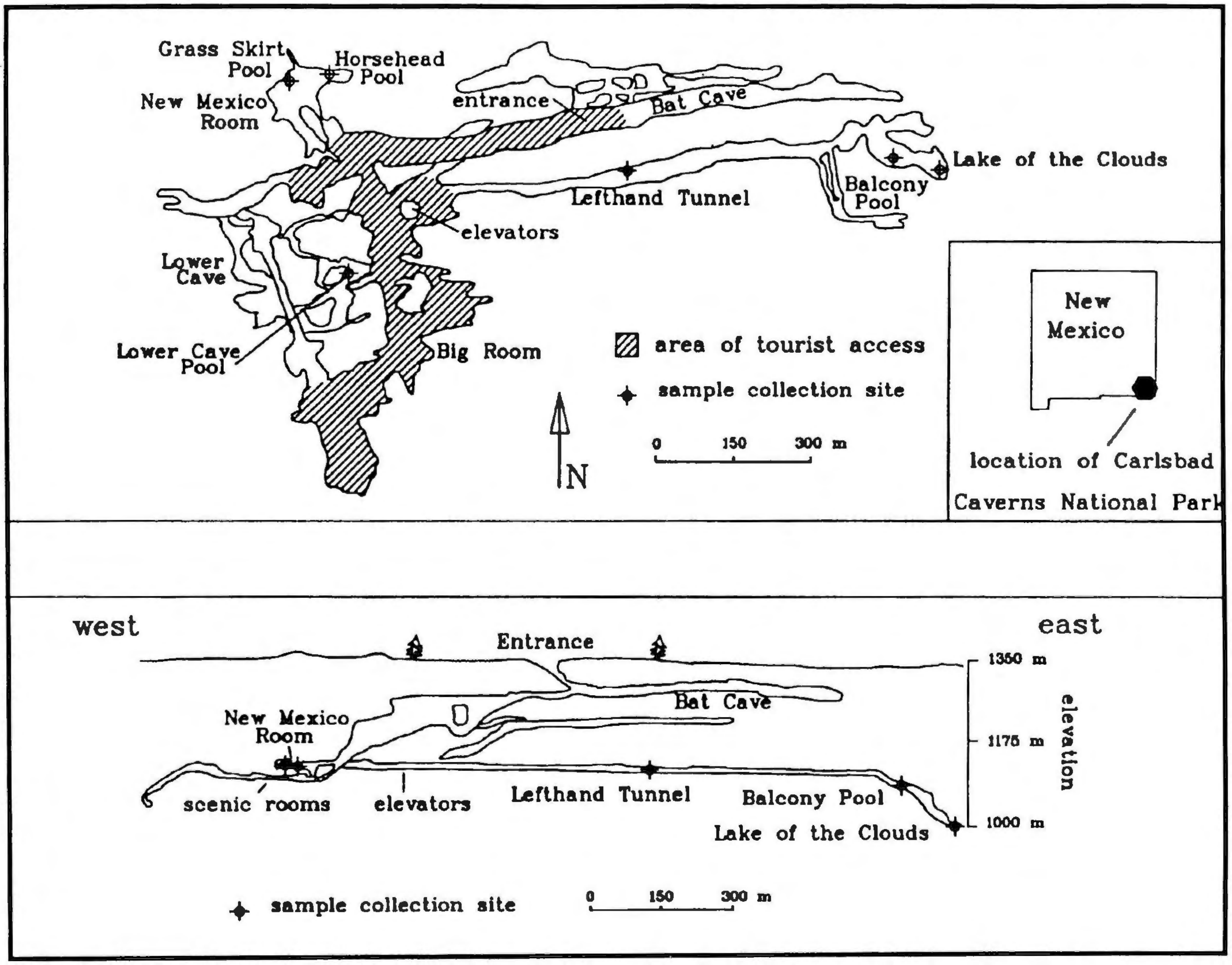

Figure 9: Map and generalized cross section of Carlsbad Cavern, New Mexico showing collection sites and the tourist-visted areas.

eter, yields a ratio of heavy to light isotopes (i.e., $^{18}O/^{16}O$ and D/H) and the data are reported relative to Standard Mean Ocean Water (SMOW). The isotopic content of most natural waters is established during condensation in the atmosphere and is controlled by many factors, such as source and history of the air mass and temperature of condensation. There is a strong correlation of the oxygen and hydrogen isotopic ratios in meteoric waters such that a line develops when δD is plotted against δD. The line has the equation $\delta D = 8\ \delta^{18}O + 10$ and is known as the Meteoric Water Line (MWL). The isotopic content of a water can be altered by only a few processes such as evaporation or mixing with waters of differing composition.

Cave drip water, pool water, and water vapor were collected in three areas: the New Mexico Room, Lower Cave, and Lake of the Clouds (Figure 9). These sites were chosen for their large pools, remoteness from the tourist environment and diversity of cave location (both laterally and vertically). Additional drip and pool samples were collected in Lefthand Tunnel. Stable isotopic analysis and electrical conductivity measurements were performed at the Water Resources Center Stable Isotope Laboratory in Las Vegas.

Infiltrating Water - Cave Drips

A wide variety of drip occurrences were sampled, including those from soda straws and stalactites. Some drips were located close together while others were separated by over 1500 m lateral distance, and more importantly, by over 100 m vertically. There was also variability in flow rate, from rapid to slow.

Despite the wide variety of types and locations of drips, the isotopic compositions of the infiltrating waters are relatively uniform (Figure 10). These results suggest a homogenization of individual recharge events as they move through the thick unsaturated zone at the cavern. In other words, by the time water has infiltrated to the sampled parts of the cavern, it has apparently lost any unique isotopic signature tying it to a particular rainfall event. Rather, infiltration from many rainfall events is mixed as it moves through the thick unsaturated zone, resulting in relatively uniform isotopic compositions for the drips. This hypothesis is consistent with Williams' (1982) concept of a significant amount of water in storage in the upper vadose zone at Carlsbad. A large volume of water in storage would damp out the isotopic signature of individual or seasonal events. Homogenization of Carlsbad Cavern recharge will be further investigated by analyzing the composition of drips collected in other seasons.

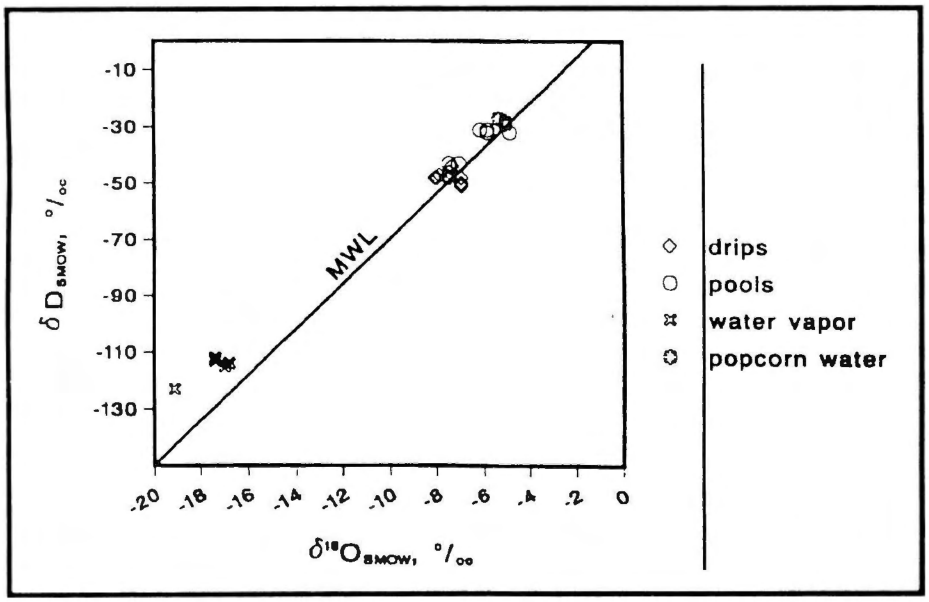

Figure 10: The stable isotopic compositions of the samples collected for this study. The meteoric water line (MWL) is also shown.

Cave Pools and Their Compositions Through Time

While the drip compositions are relatively constant throughout the cave, more variability is found in the pool isotopic compositions. Most of the pools are more enriched in heavy isotopes than the drips recharging them because of evaporation. During evaporation, the lighter isotopes preferentially enter the vapor phase and the remaining liquid water is progressively more enriched in heavy isotopes. Evaporation in the cave occurs under high humidity conditions (r.h.>90%), so that the departure from the MWL due to kinetically induced fractionation is not a major factor here as it is for low-humidity evaporation.

The two pools in the New Mexico Room are different from the other cave pools in that their compositions are virtually indistinguishable from those of the drips recharging them. Both of these pools were observed to lose water by surface outflow, and thus evaporation is apparently not their major discharge mechanism.

Some of the cave pools sampled in May 1989 were sampled in 1977 by Lambert (1987). From 1977 to 1989, several of the pool compositions have changed dramatically (Figure 11). In both the New Mexico Room and Lower Cave, the change has been in the direction of lighter isotopic compositions in 1989. This indicates less evaporative enrichment of the pools at the time of our sample collection. Virtually no isotopic change was noted in the Lake of the Clouds area. Though drip samples were not collected by Lambert (1987), it is unlikely that the isotopic shift observed in the New Mexico Room and Lower Cave is due to a change in the infiltrating water, particularly since the isotopic shift was not noted throughout the cavern. It is more probable that a change within the cavern caused the isotopic shift.

In the late 1960's, water levels in some of the pools in Carlsbad Cavern were dropping. The cause was attributed to air flow up the elevator shaft and heat generated by the cave lighting system (McLean, 1971; 1976). In the 1970's, revolving doors were installed at the bottom of the elevator shaft and most lights were changed from incandescent to fluorescent bulbs. The isotopic change in the pools in the New Mexico Room and Lower Cave may reflect the success of the Park Service efforts to reduce evaporation. The parts of the cave that are the most remote from the tourist environment (Lake of the Clouds and Balcony Pool) are probably not as affected by the elevator shafts and lights and thus no change is observed in those areas.

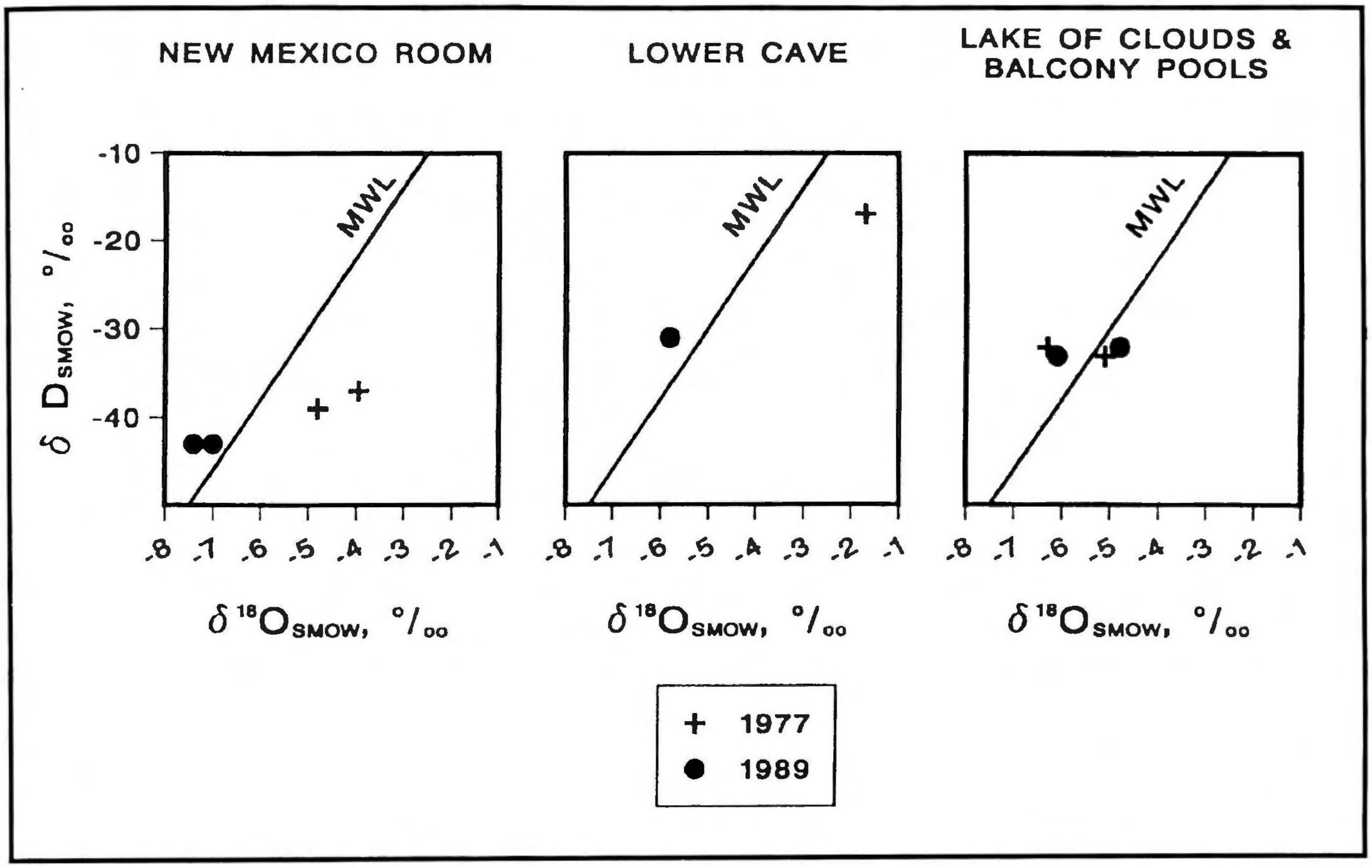

Figure 11: The stable isotopic composition of selected pools in 1977, as reported by Lambert (1987), and those obtained in 1989 for this study.

Water Vapor In the Cave

Water that evaporates from the pools becomes water vapor in the rooms. The vapor is depleted in heavy isotopes as compared to the pools. The amount of depletion between the pools and local vapor is constant in our samples, despite the differences in pool composition. This suggests that the pools control the vapor composition in their vicinity and air flow through the cavern does not homogenize vapor compositions throughout the cave. For example, just as the pools in the New Mexico Room are depleted in heavy isotopes as compared to the other cave pools, the vapor in that room is also more depleted than vapor near the other pools by the same amount. Apparently, the air flow in the cave is slow enough and/or exchange between a pool and vapor is rapid enough, that vapor composition is controlled by any large pool in the vicinity.

The pools control the isotopic composition of not only the vapor but also of small water bodies located nearby. Two examples are popcorn water in Lower Cave and a small pool near Lake of the Clouds. The water found on popcorn speleothems in Lower Cave seeps out of the ceiling and evaporates in place. Using E.C. values as an index of evaporation, it would be expected that the evaporated water (popcorn water and water in the small pool) would be more enriched in heavy isotopes relative to the nearby pools. However, the evaporated waters have stable isotopic ratios similar to the large pools nearby (Figure 12). This indicates that the extent of isotopic enrichment of these relatively small water bodies is controlled by exchange with the water vapor in the room, which in turn is controlled by the large pool nearby.

Conclusions

The stable isotopic data suggest that the compositions of infiltrating rainfall events are homogenized by the time they reach the sampled areas in the cavern. This is consistent with the hypothesis of a large amount of water

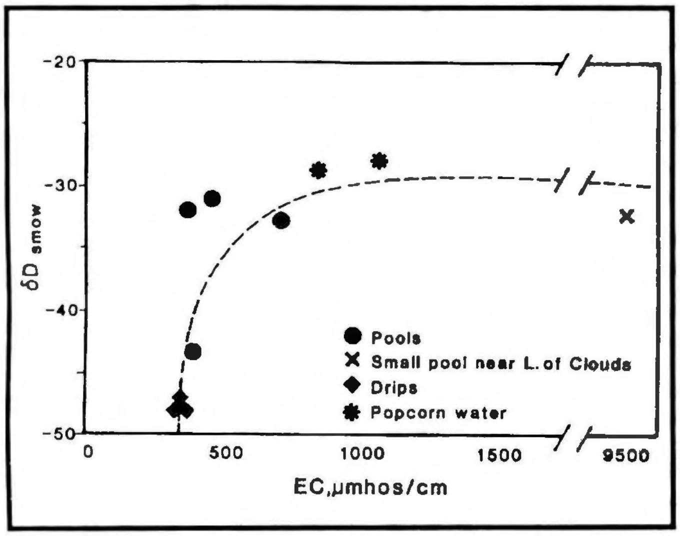

Figure 12. The hydrogen isotopic compositions and electrical conductivity (E.C.) values of the water samples with sufficient volume for measurement. E.C. is continuously increased by evaporation, however, there is a maximum enrichment of the hydrogen isotopic composition of about -30 to -32 per mil.

in storage in the thick unsaturated zone above the sample locations. Most pools are isotopically more enriched than their recharging drips due to evaporation in a high-humidity environment. The degree of evaporation may have changed during the last 12 years in the New Mexico Room and Lower Cave, as evidenced by a decrease in the amount of heavy isotope enrichment in pool water in those areas. However, this isotopic depletion and interpreted decrease in evaporation was not observed for the Lake of the Clouds. The large cave pools control the isotopic composition of water vapor in their rooms and, through the vapor, limit the amount of isotopic enrichment in small, evaporating water bodies located nearby.

Acknowledgements

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Preliminary Report on the Geology and Mineralogy of the Caverns of Sonora, Texas

by Carol A. Hill, David H. Jagnow, Harvey DuChene and John McLean

Geology

The Caverns of Sonora (formerly called Mayfield Cave) is located on the Edwards Plateau in west-central Sutton County, Texas. The cave is developed in the Edwards Limestone, Fredericksburg Group, Comanche series, of Lower Cretaceous age (Tandy, 1962). The cave has over 7.5 km of passage, which trends approximately N25°E

(Figure 13). Four distinct levels exist at 12 m, 30 m, 40 m, and 50 m below the surface. The levels correspond to vertical lowering of spring positions and base level (Kastning, 1983). The cave is developed in undolomitized, unfractured, flat-bedded limestone, but there may be a subtle flexure in the vicinity of the cave. Bedding within the cave was seen to dip a few degrees and slickensides associated with normal-fault displacements of less than a meter were also noted. Classic phreatic solution pockets and domes characterize . the cave. The floor silt appears to be phreatically-derived; that is, it is autochthonous rather than allochthonous sediment. The phreatic solution features cut across calcite spar-filled vugs up to 20 cm across. vadose features are not present except possibly for some local downcutting and fluvial sediment inwash near the natural entrance.

Meteorology

Carbon dioxide, temperature, and humidity were monitored (Table 2). The relative humidity measured a consistent 93% along or near the tourist sections of the cave, except near the exit where it measured 90%. In the Helictite Room, the lowest part of the cave and off the tourist route, the humidity measured 98%. These readings are all lower than the almost 100% humidity measured in 1957 when the cave had only one natural, 45-cm-wide entrance (J. Burch, pers. comm. 1989}. It is also less than that reported by Tandy (1962) who stated that "the relative humidity is 100 percent throughout Mayfield Cave. The temperature remains steady at 72 degree Fahrenheit throughout the year." It appears that the two unnatural tourist entrances may create an airflow effect which has lowered the relative humidity. The carbon dioxide level in the cave air was measured at greater than 4000 ppm (0.4%} except in the Conrad Hilton Room area (Table 2). 4000 ppm was the limit of detection for the Draeger tubes; however, the rate at which the crystals in the tubes turned purple suggests that the actual CO_2 level in the cave may be somewhere between 6000 and 8000 ppm (0.6-0.8%). The high level of carbon dioxide is responsible for the condensation-corrosion of cave walls, ceilings, and speleothems. Corrosion features noted were rillenkarren, punk-rock residue, air scallops, and fins ("razors") (Figure 14). "Acid rain" has dissolved pits in the concrete floor in the area of the Hall of the White Giants. In this same area a "popcorn line. exists: corrosion occurs above the line and popcorn and trays (flat-bottomed popcorn) occur below the line (Figure 15). In other places bedrock has preferentially dissolved beneath more resistant wall coatings, leaving the coatings in relief. Burch (1967) called this process of condensation-corrosion in the Caverns of Sonora chalkification. and said that: "The floor was found to be

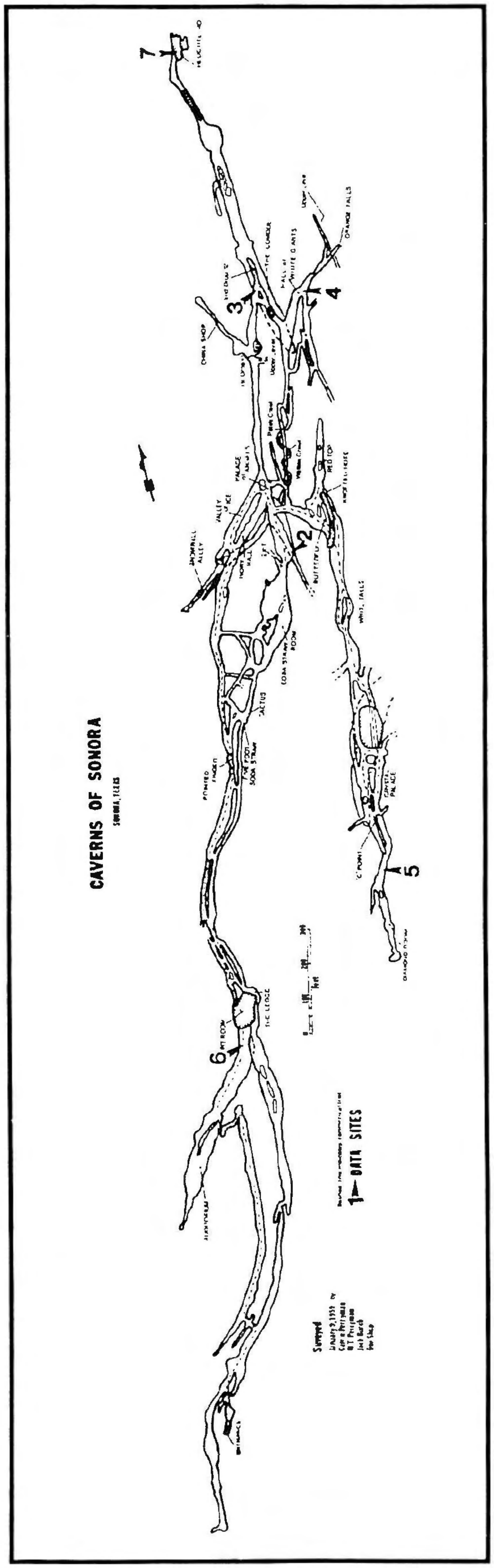

Figure 13: Map of Caverns of Sonora showing the measurement sites for carbon dioxide, temperature, and relative humidity. The numbers on the map correspond with those in Table 2.

Table 2: Carbon dioxide, temperature, and humidity readings, April, 1989, Caverns of Sonora.

Location	CO_2, ppm	dry bulb	wet bulb	Humidity	Notes
1. Parking lot above cave	450	73°F 22.8°C	63°F 17.2°C	57%	9:00 a.m., April 25, 1989.
2. Johan's Trail through	>4000	71°F 21.6°C	69°F 20.5°C	90%	Walls and ceiling highly corroded; corrosion fins near back exit door.
3. The Lower Room	>4000	71°F 21.6°C	69.5°F 20.8°C	93%	150 ft. level; in an area of very little condensation corrosion.
4. Hall of White Giantks					
a. near ceiling	>4000	71°F	69.5°F	93%	120 ft. level; corrosion above "popcorn line"; monocrystalline popcorn and "trays" below line.
b. near floor	>4000	21.6°C	20.8°C		
5. Diamond Room	>4000	71°F 21.6°C	69.5°F 20.8°C	93%	100 ft. level; away from tourist route. Measurement made on floor; passage ceiling about 20 m above floor.
6. Junction, Devil's Pit and Conrad Hilton Room	2800	70°F 21.1°C	68.5°F 20.3°C	93%	100 ft. level.
7. Helictite Room	>4000	69.5°F 20.8°C	69°F 20.5°C	98%	175 ft. level; off tourist trail in area of pronounced drippage.

very soft, like new fallen snow. One would leave footprints a foot deep in this ash-like material. This grainy material has been seen in all the upper levels of this fantastic cavern including the upper level passage used as an exit for the tourist traffic." Burch (1967) also was the first to reference rim speleothems in a United States cave, stating that: "A 1 1/2 foot tube, through which airflow is generous, leads from an upper level to a lower level. The inside edges of the hole are dry, chalky. The rim around the hole remained moist from the wet floor and built upward, making a raised lip. This continued until the lip was more than a foot high, with the inside dry and flaky as we see it today." Rim speleothems are known to form in areas of high condensation-corrosion.

Mineralogy

Calcite comprises at least 95% of the speleothemic material in the Caverns of Sonora. Even the .moonmilk river" in the cave is composed of calcite (Moore and Bukry, 1968). The small amount of aragonite (as needle crusts and beaded helictites) and lack, of magnesium carbonate minerals may be due to the undolomitic nature of the overburden. Neither replacement or speleothemic gypsum was noted. Calcite travertine phosphoresces a vibrant green, sometimes displaying an afterglow of up to 8 seconds. speleothem types and subtypes in the cave are: stalactites, soda straws, stalagmites, flowstone, velvet flowstone, sawtooth flowstone, draperies, coralloids, tray popcorn, coatings, helictites, shields, welts, rims, vent rims, rimstone dams, shelfstone, dogtooth spar, nailhead spar, and boxwork. Almost all these forms are transparent to translucent and macrocrystalline to monocrystalline' these qualities give the speleothems in the Caverns of Sonora their special ethereal character. Even some of the larger stalactites and stalagmites are macrocrystalline or monocrystalline (Figure 16). Crisman (1956) reported a "hexagon-shaped stalactite 15-20.

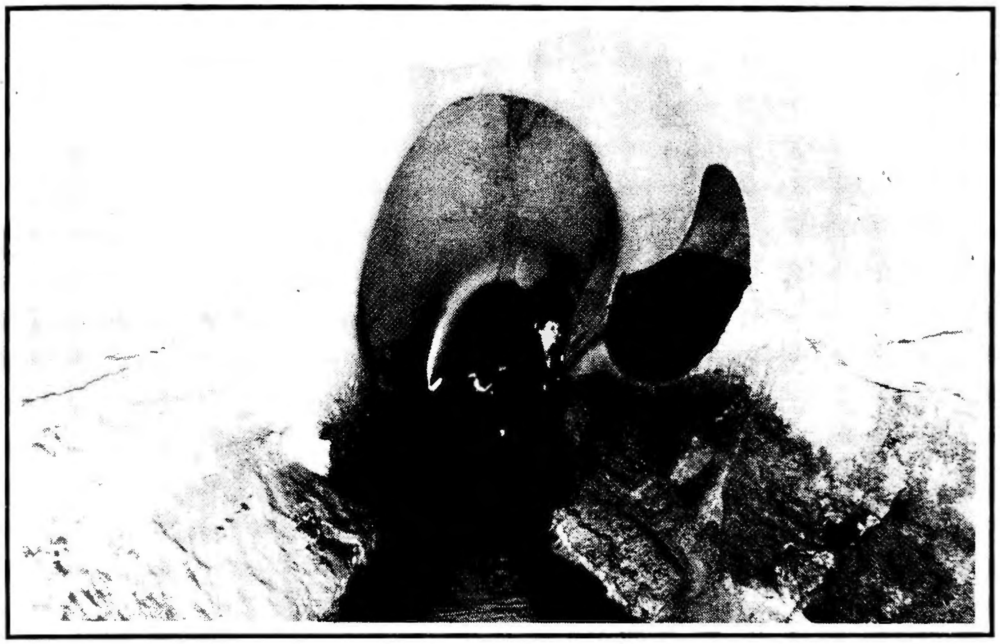

Figure 14: Condensation-corrosion-scoured bedrock in Jonah's Trail through the Whale. Person is standing next to a corrosion fin. (*Photo by David Jagnow*).

Figure 15: Owner Jack Burch standing next to two corroded columns in the Hall of the White Giants: there is a corrosion of travertine above the "popcorn line" and a popcorn build-up below the line. (*Photo by David Jagnow*).

long with a half-inch diameter." The flowstone in the cave is also macrocrystalline and displays triangular, "hopper"-crystal surfaces. Pool spar grows a centimeter or so on a face. The popcorn is coral-like, with well-developed, coarsely-crystalline, scalenohedral faces. Composite helictite-draperies, such as the famous "Butterfly of Sonora," are also translucent and macrocrystalline. The predominance of monocrystalline and macrocrystalline speleothem textures is most intriguing and may result from high humidity and carbon dioxide levels in the cave. The Caverns of Sonora is developed in relatively unfractured limestone, with reduced air circulation in the rock above the cave. It is also a cave which probably had no entrance until recent times when the very small (45 cm) natural entrance formed. In caves with little . or no natural air flow, carbon dioxide can build up so that the difference in the CO_2 level of water dripping into the cave and that of the cave air is small. This, combined with a

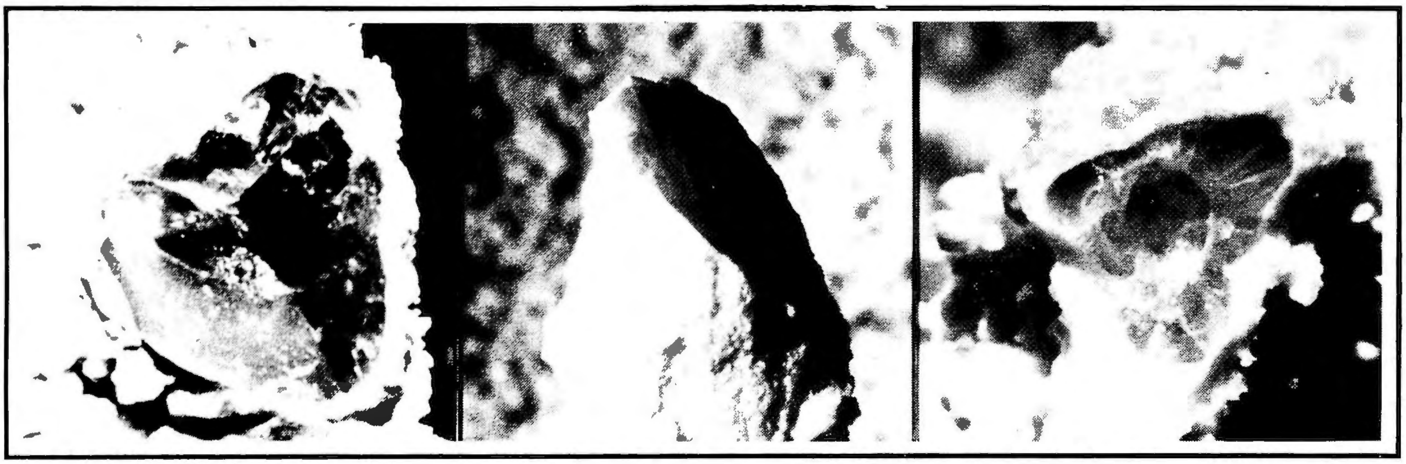

Figure 16: Monocrystalline speleothems in the Hall of the White Giants area: a) looking down on a triangular-faceted stalagmite, b) looking sideways at a monocrystalline cleavage plane of a stalagmite, and c) looking up at a triangular-faceted stalactite. The speleothems occur along the trail and were broken during trail building. (*Photos by David Jagnow*).

relative humidity of almost 100%, means that equilibrium is reached Very slowly and crystal faces have a chance to grow large.

One of the most outstanding sections in the cave is the helictite Room. Here, thousands upon thousands of delicate helictites glitter on the ceiling, walls, and floor in a breathtaking display (Figure 17 and cover). The Helictite Room lies directly below a saddle on the surface where water is diverted along joints and bedding planes into the room. (J. Burch, pers. comm. 1989). Many of the helictites grow at 600 or 900 angles from travertine growth surfaces. since travertine in the Caverns of Sonora is either macrocrystalline or monocrystalline, water easily seeps out along cleavage planes to form helictites, whereas the microcrystalline, tightly-banded nature of travertine in other caves precludes this kind of easy growth. some of the helictites in the Helictite Room are .ricochet" varieties — that is, helictites which bend and grow towards a wall, only to "ricochet" out from the wall again. There are also beaded (aragonite) helictite varieties and soda straws so clear that water droplets are visible within the straw tubes. The Helictite Room is but a reconfirmation of the uniqueness and sublimity of the Caverns of Sonora.

Figure 17: **Travertine** and helictites growing along a bedding plane, Helictite Room. (*Photo by David Jagnow*).

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The authors would like to thank owner Jack Burch for showing us the wonders of his marvelous cave and for supplying much of the background information in the above report.

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Influence of Bedrock Geology and Karst Processes on the Morphology and Short-Term Dynamics of Bedrock Controlled Fluvial Systems, South-Central Indiana

by Jerry R. Miller

Introduction

The influence of bedrock geology on the morphology and dynamics of fluvial systems has been recognized by various geomorphic paradigms for nearly a century. Nevertheless, few detailed investigations have examined the combined and separate affects of bedrock geology and karst processes on fluvial systems underlain by both siliciclastic sedimentary rocks and soluble carbonates. In 1987, a study was initiated to examine the controls of bedrock geology and karstification on the morphology and dynamics of bedrock controlled streams within the Crawford Upland, south-central Indiana (Figure 18).

The Crawford Upland is underlain primarily by siliciclastic sedimentary rocks with a general west to east

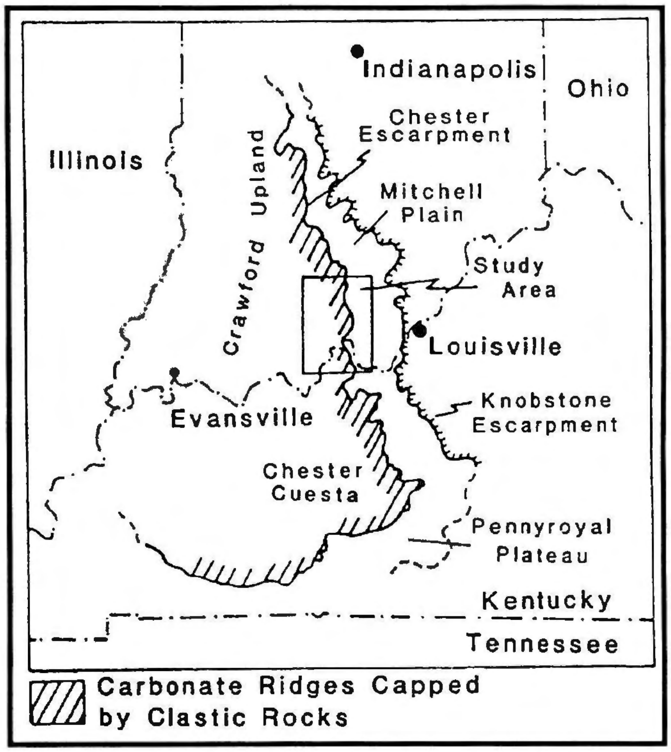

Figure 18. Map showing the location of study area in south-central Indiana (Modified from Miotke and Palmer, 1972).

increase in the areal percentage of exposed carbonates. Associated with this increase in outcrop of carbonate strata is the development of karst landforms. Streams within the Crawford Upland generally exhibit alluvial banks and significant exposure of bedrock along their channel beds. This geologic setting provided an excellent opportunity to accomplish the objectives of the investigation.

Results and Discussion

During 1989, the study primarily focused on the short-term (days to 100's of years), local influence of bedrock geology and karst processes on fluvial systems. The analysis was performed by the quantification and comparison of 12 watersheds underlain by different lithologic units and which vary in their extent of modification by karst processes. Four of the basins are underlain by siliciclastics (CB), while five basins are underlain by carbonates as well as siliciclastics that cap the drainage divides (CCB). The remaining three watersheds are developed in both carbonates and siliciclastics, but exhibit sinking axial channels graded to dry valley floors that occur at elevations 10's of meters above modern channels surficially integrated with the Ohio River.

Longitudinal channel profiles indicated that differences in rock resistance along streams underlain by siliciclastic strata has allowed differential erosion (downcutting) to produce a pattern of concave-up channel-floor lows separated by bedrock-controlled highs. The channel lows are sites of sediment deposition and storage whereas the channel highs represent zones of degradation. Knickpoints are rare along the degradational zones. Apparently, erosion is concentrated over the entire length of the bedrock high and occurs primarily by the stripping of individual siliciclastic beds from the channel floor.

Erosion of carbonate bedrock within CCB and CCSB is predominantly controlled by bedding plane discontinuities and vertical fractures. Karstification may also play an important role in the erosional process by enlarging bedding plane and fracture discontinuities, thereby increasing the potential for clast entrainment. The mode of channel incision (bedrock erosion) varies along the channels of CCB and CCSB. Incision may be concentrated within a short segment of the stream bed by upstream retreat of knickpoints or over long reaches of the channel by the "plucking" or "quarrying" of carbonate clasts from the channel floor. The dominant mode of channel incision at any given location along the stream is primarily controlled by the angle and direction of dip exhibited by the underlying strata relative the orientation of stream flow.

Stream reaches within the investigated basins have been classified on the basis of channel sedimentology into four types. Defined reach types include: 1) bedrock reaches, 2) bedrock and rubble reaches, 3) bedrock and alluvial reaches, and 4) alluvial reaches. The distribution of reach types along streams within CB is primarily controlled by the location of resistant bedrock highs that result from differential rates of downcutting. In contrast, reach distribution along channels underlain by carbonates is controlled predominantly by the abundance of siliciclastic bed material. The quantity of siliciclastic bed material is related to: 1) the distribution of siliciclastic source rocks, 2) localized sediment storage induced by subsurface flow piracy, and 3) the removal of siliciclastic sediments from the basin by the subsurface drainage system via dolines and sinking streams.

In all basins, the dominant bed material load is sandstone, possibly because: 1) upper Mississippian siliciclastic strata, in general, exhibits thinner bedding than carbonates of the Blue River Group, and therefore, the siliciclastics are more easily eroded and abraded, and 2) sandstone gravels may be more durable than carbonate clasts. As a result, the amount of mobile bed material load is greater in CB than in either CCB or CCSB.

Valley floors within CB are locally characterized by abandoned anastomosing channel systems associated with avulsion. Avulsion requires high rates of bedload transport and the presence of topographic bedrock highs that result from differential rates of downcutting. Abandoned channels rarely occur upon valley floors of CCB. Rather, the valleys are characterized by several surfaces that are discontinuous upstream. The elevation of the surfaces are related to knickpoints, and therefore, are topographically separated by only a few meters. The data from CB and CCB suggest that differences in valley floor morphodynamics are primarily related to the abundance of mobile bedload and the entrenchment process. Axial portions of valley floors with CCSB may have developed in a manner similar to those of CCB. However; valley floor morphology within CCSB is highly diverse due to the modification of fluvial landforms by karst processes.

Channels within both CB and CCB presumably adjust their form (width, depth, slope) to transport the sediment provided to them given the present hydrologic regime. The adjustment in channel form occurs primarily by changes in local gradients within CB, whereas adjustment within streams of CCB occurs predominantly by changes in the width-depth ratio. Differences in channel adjustment mechanics may be related to the size, quantity, and composition of the bed material load.

The lack of correlation between channel form elements and basin area for streams within CCSB suggests that these channels are not adjusted to transport the sediment load delivered to them under the present hydrologic regime. Rather, sediment is stored along unconfined reaches of the valley floor. The change in channel hydrology that brought about sediment storage is presumably related to flow piracy associated with subterranean drainage development.

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Dolomitization and Karstification of the Seroe Domi Forereef/ Periplatform Carbonates (Plio-Pleistocene?), Curaçao and Bonaire, Netherlands Antilles

by Bruce W. Fouke

Project Description

Introduction

We are conducting a detailed petrographic and geochemical study of the extensively dolomitized Plio-Pleistocene(?) Seroe Domi Formation, Netherlands Antilles, through integrated field (stratigraphy, facies, dolomite distributions), petrographic (plane-light, cathodoluminesence, SEM, fluid inclusions), geochemical (O,C,Sr isotopes; Mg,Ca,Sr,Fe,Mn,Na,Zn,Cu) and paleomagnetic techniques. Our approach is to geochemically characterize grains and diagenetic phases with high-precision elemental and isotopic analyses, and evaluate observed spatial and temporal geochemical distributions with respect to the geologic framework in order to reconstruct the composition, timing, distribution, selectivity, and flow paths of the diagenetic fluids. Combination of the chronostratigraphic, distributional and timing constraints available in the Seroe Domi Formation should permit quantitative estimates of the rate of dolomite production and karst formation, the volume of dolomite and calcite dissolved or precipitated by each diagenetic event, and directly relate massive dolomites with modern marine and meteoric processes.

Geologic Setting

The Netherlands Antilles are the emergent portions of a 115 km-long Cretaceous island arc volcanic ridge (Beets *et al.*, 1984; Speed, 1985), lying 35-75 km off the northern coast of Venezuela (Figure 19). Uplift and eustatic sea-level fluctuations have exposed the 120 m-thick Seroe Domi Formation as 1 to 3 km-wide belts of elevated ridges along the leeward coasts of Curaçao and Bonaire onlapped by Quaternary limestone terraces (Figure 20).

Statement of Goals

Previous work on the Seroe Domi Formation (Deffeyes *et al.*, 1965; Murray, 1969; DeBuisonje, 1974; Bandoian and Murray, 1974; Sibley, 1980, 1982) has set the geologic stage for a detailed study of dolomitization processes. Our specific research goals are:

1) To better-define the chronostratigraphic framework of the Seroe Domi Formation by reevaluating the original biostratigraphy by Debuisonje (1974), and by applying absolute Sr isotope and paleomagnetism dating techniques.

2) To evaluate and further develop the petrography of diagenetic features as established by Sibley (1980, 1982).

3) To geochemically characterize diagenetic phases, allochems and whole-rock samples within this well-defined geologic framework to determine spatial and temporal changes in composition.

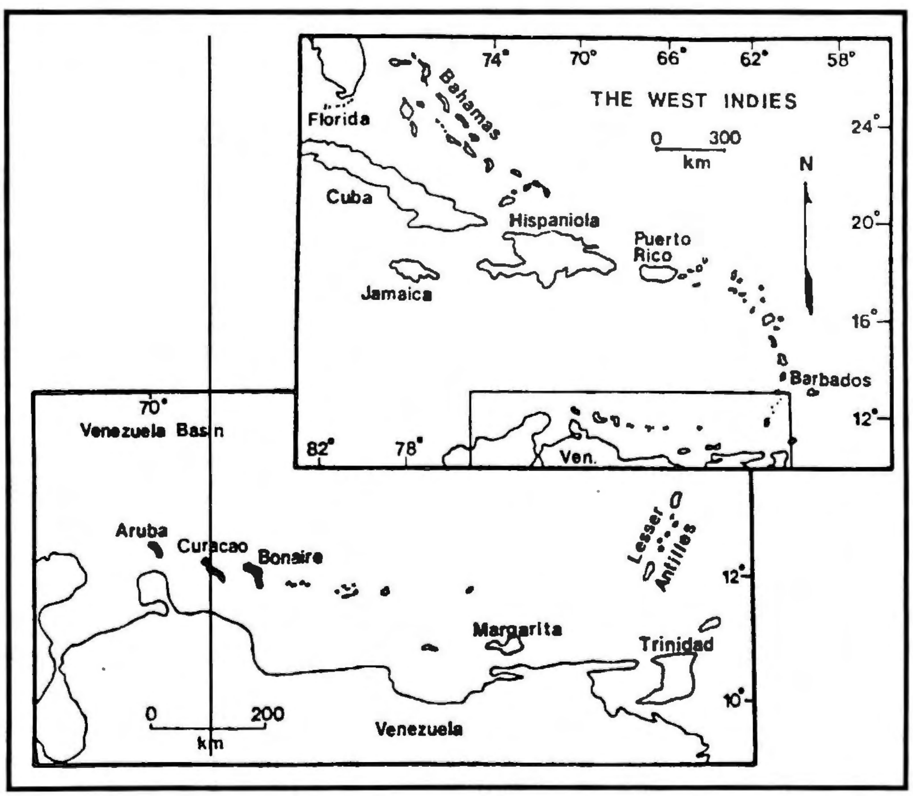

Figure 19. Geographic setting of Aruba, Bonaire and Curaçao, Netherlands Antilles, in the southern Caribbean Sea, 35 to 75 km off the northern coast of Venezuela.

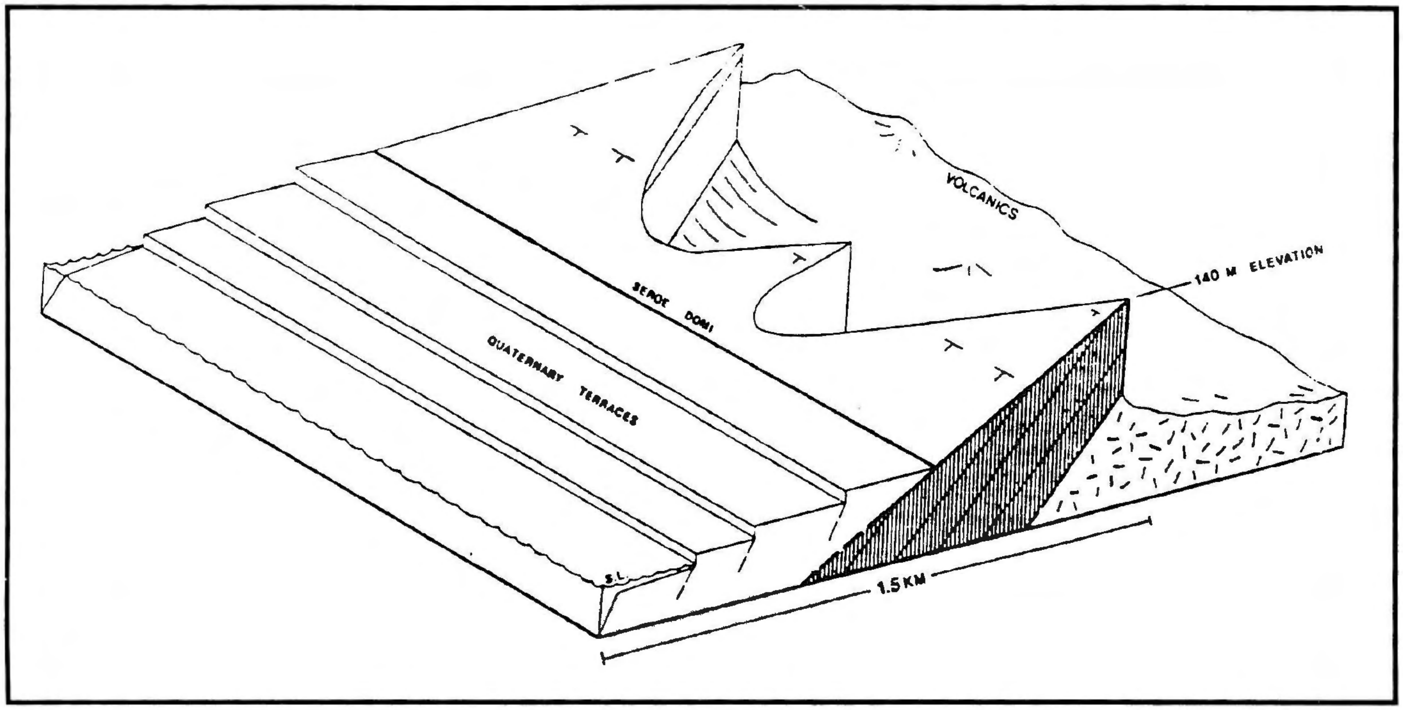

Figure 20: Schematic diagram of the inclined Seroe Domi flatirons standing in topographic relief around the leeward periphery of the eroded volcanic cores of the Netherlands Antilles. Modified after DeBouisonje (1974).

4) To model observed variations in composition across vertical and lateral dolomite-limestone fronts with water-rock interaction computer programing techniques developed at Stony Brook.

Current Research Progress

Our field work has focused on establishing a concise sedimentologic and stratigraphic framework, and on detailed mapping of dolomite distributions and karst features. Laboratory work to date has consisted primarily of hand specimen sedimentologic descriptions, biostratigraphic identifications, reconnaissance petrography, stratigraphic correlations and depositional interpretations.

Lithofacies

The Seroe Domi Formation is composed of six interbedded and variably dolomitized carbonate and volcaniclastic lithofacies, including: 1) a Coralgal Grainstone Facies; 2) a Globigerinid Wackestone Facies; 3) an Alveolinid Wackestone Facies; 4) a Coralgal Packstone Facies; 5) a Red Algal Dolomite Facies; and 6) a Volcaniclastic Facies.

Chronostratigraphy

Difficulties in stratigraphic correlations observed in our field work result from lateral changes in facies compositions and distributions, and a 90 m variation in elevation of the basement over distances of less than 10 km (Figure 21). Our reevaluation of foraminifer, mollusc and coral fauna (DeBuisonje, 1974) suggest that the Seroe Domi Formation ranges in age from at least Early Pliocene through the Pleistocene (Sr isotope and paleomagnetic absolute age refinements are in progress).

Depositional Setting

Lateral discontinuities and variation in basement elevation imply that the volcano had an undulatory reentrant surface, creating a series of local, discontinuous basins of carbonate deposition. Erosion has dissected these basins to different landward extents, creating the observed heterogeneity in sedimentology, bedform and elevation. Vertical increases in the content of volcaniclastics, and the eventual deposition of the Volcaniclastics Facies, suggest increasing exposure and erosion of the volcanic pedestal, with sediments transported via fluvial point sources along paleoshorelines.

Our study suggests that lithofacies represent depositional mixtures of: 1) sediments transported from platform source areas to deeper water (i.e. rounded abraded grains, disturbed geopetals in coral heads, wedge-shaped bedding geometries, off-lap, allochthonous blocks, and deep water forams mixed with shallow water corals), and 2) sediments produced and trapped on the forereef slope (i.e. *Stylophora* boundstones, *Agaracia* boundstones encrusted with delicate bryozoans and brachiopods, *in situ Montastrea* and *Siderastrea* geopetals, lack of grain abrasion). An upward-shallowing sequence at St. Michaelsberg and Seroe Blandan, Curaçao, with deep water peri-platform Globigerinid Wackestone Facies overlain by shallow water forereef Coralgal Grainstone Facies deposited in shallower water forereef environments. High mud content, *Porites, Stylophora, Siderastrea* and *Montastrea* coral assemblages and nearly horizontal bedding suggest that the anomalous Coralgal Packstone Facies is a lagoonal platform deposit in water depths of less than 30 m. The lack of fauna and depositional textures precludes a conclusive interpretation for the Red Algal Dolomite Facies.

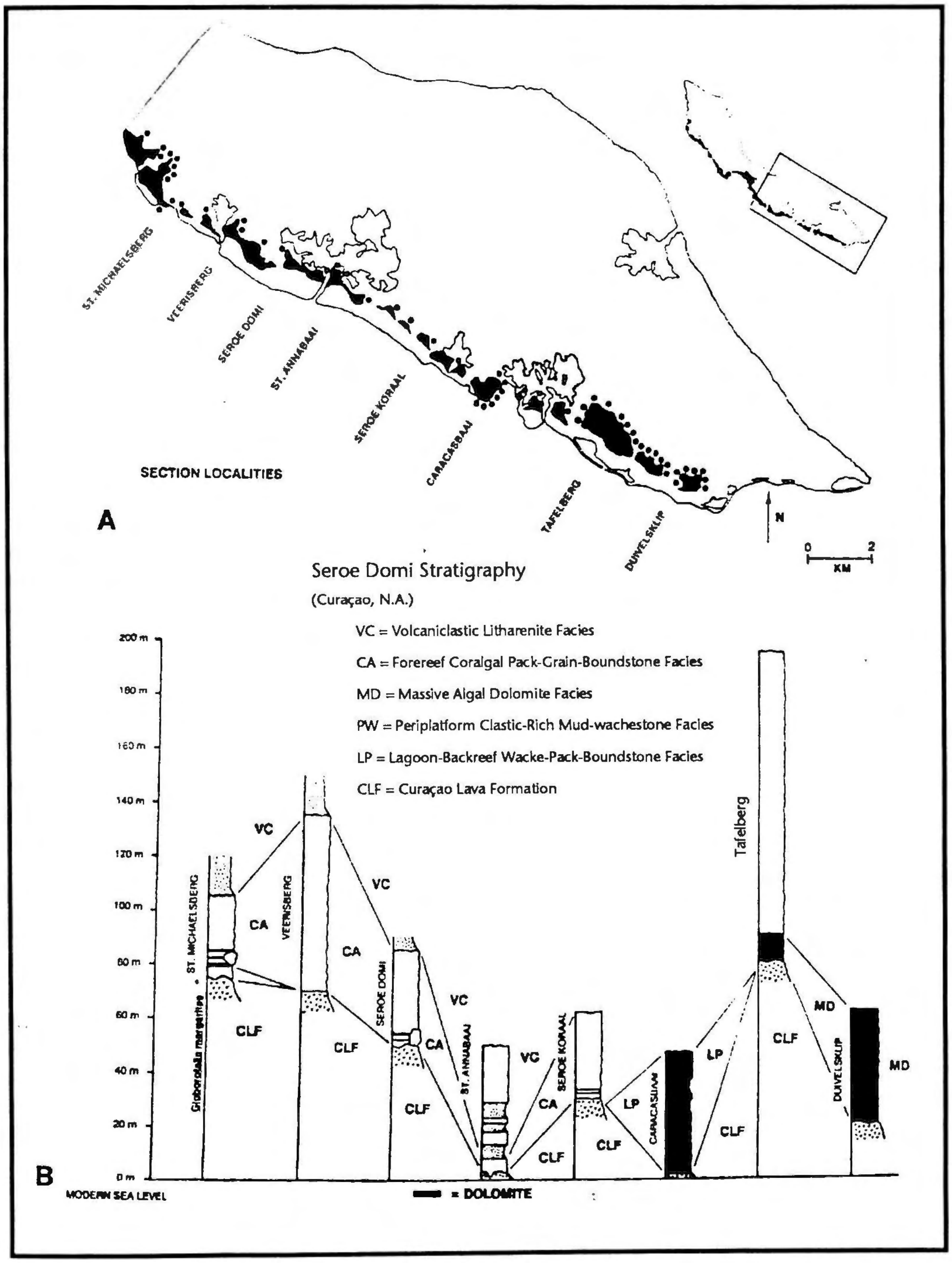

Figure 21. (A) Geographic location of measured and correlated sections on SE Curaçao, Netherlands Antilles, depicted in figure 8B. Section localities are laterally separated by 3 km or less, yet exhibit ±90 m differences in elevation over these short distances. (B) Fence diagram of facies comprising the Seroe Domi limestone on SE Curaçao and their relative lithostratigraphic correlations.

Dolomite Distributions

The stratigraphic distribution of dolomite occurs in two modes: 1) partial stratiform dolomitization within the interbedded periplatform and forereef facies (high porosity dolomite cement and replacement), and 2) flatirons composed entirely of the massive algal dolomite facies (lower porosity, pseudomorphic and fab-

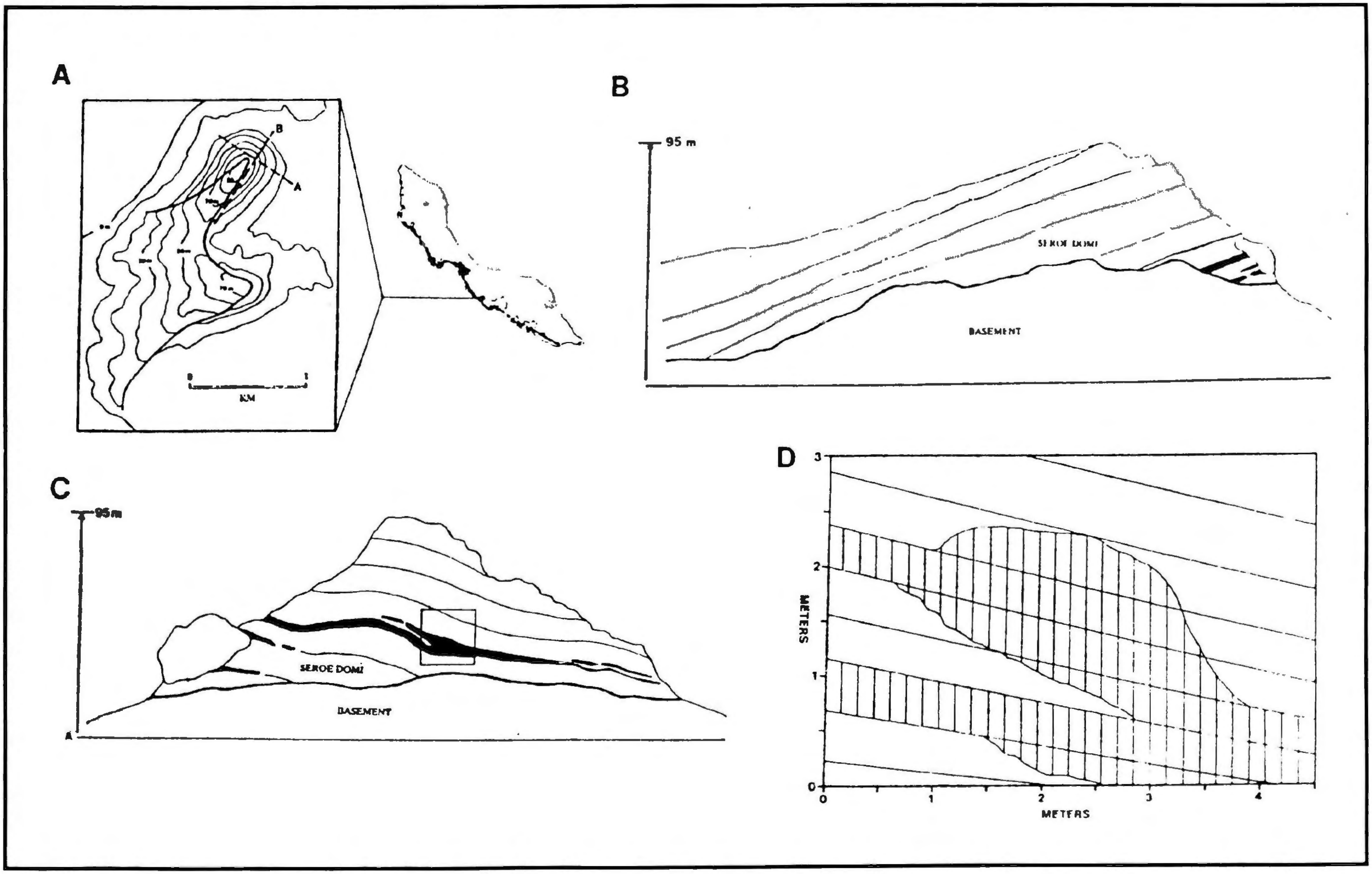

Figure 22. The three-dimensional stratigraphic distribution of dolomite within the upward-shallowing sequence of Periplatform Clastic-Rich Mud-Wackestone Facies through Forereef Coralgal Pack-Grain-Boundstone Facies of the Seroe Domi carbonates exposed at St. Michealsberg, Curaçao, Netherlands Antilles. (A) Locality map and topography at St. Michealsberg. (B) Southeastern face of the flatiron exposure (Section B), with dolomite horizons (black), inclined bedding planes and an allochthonous block depicted. (C) Northeastern face of the flatiron exposure (Section A), with dolomite horizons (black), inclined bedding planes and an allochthonous block. (D) Enlargement of exposure within box on diagram C. Dolomitized horizons are shaded (vertical lines) and bedding planes (inclined lines) exhibiting both stratiform and cross-cutting dolomite distributions.

ric-destructive replacement dolomite). Stratiform dolomites occur in 3 to 5 selectively dolomitized 0.5-1 m-thick horizons in the lower third of sequences of Globigerinid Wackestone and Coralgal Grainstone Facies (Figure 22). These planar to undulose dolomite bodies pinch-out or grade downslope into either: 1) equivalent non-dolomitized facies, or 2) equivalent, variably dolomitized facies with geometries that locally expand in thickness and cross-cut bedding planes (Figure 22).

Petrography

Our preliminary analysis of 30 thin sections from St. Michaelsberg and Seroe Blandan yield the following paragenetic sequence: 1) intraskeletal non-cathodoluminescent (CL) fibrous isopachous carbonate cements (100 um); 2) calcite micritization and dissolution of high-Mg calcite and aragonitic skeletal fragments; 3) biomoldic and interparticle mottled-CL bladed calcite cements (25-150 um); 4) biomoldic and interparticle CL-banded intragranular blocky calcite (100-200 um); 5) moderate to dull CL euhedral dolomite, with inclusion-rich bright-CL cores and hairline banding (25-50 um); 6) a bright-CL euhedral dolomite cement overgrowing and engulfing early bladed calcite cements (50-100 um); 7) amorphous to microcrystalline phosphate; 8) dull to non-CL blocky calcites (100-200 um); 9) botryoidal non-CL calcite speleothem cements (several mm); 10) fibrous mottled-CL botryoidal chalcedony cements (several mm).

Dolomite Distributions and Modern Groundwaters

We have observed a striking correlation in the geographic distribution of massively dolomitized Seroe Domi Formation flatirons, gravity anomalies, basement faulting and MgO content of the Curaçao Lava Formation in SE Curaçao (Figure 23A). One working hypothesis is that dolomitizing fluids (seawater?) may have thermally convected through the Mg-rich volcanic core via fracture-porosity conduits prior to entering the Seroe Domi Formation (Figure 23B). The $^{87}Sr/^{86}Sr$, trace element, and stable isotopic signatures of the dolomites in conjunction with the distributional data should permit evaluation of this hypothesis. Modern groundwaters in SE Curaçao exhibit locally elevated conductivities from inland wells (up to 1000 meq/l), suggesting that a similar hydrology may still be active (Figure 23B). Our preliminary alkalinity measurements exhibit similar anomalous distributions (up to 7 meq/l), with further analyses for minor and trace elements currently being completed. Thermodynamic computer modeling (PHREEQE) of water data provided by the Government of the Netherlands Antilles has been initiated (Fouke supervised by Dr. M. Schoonen, Stony Brook), suggesting the fluids are supersaturated with respect to stoichiometric dolomite in these inland conductivity anomalies (Figure 23B).

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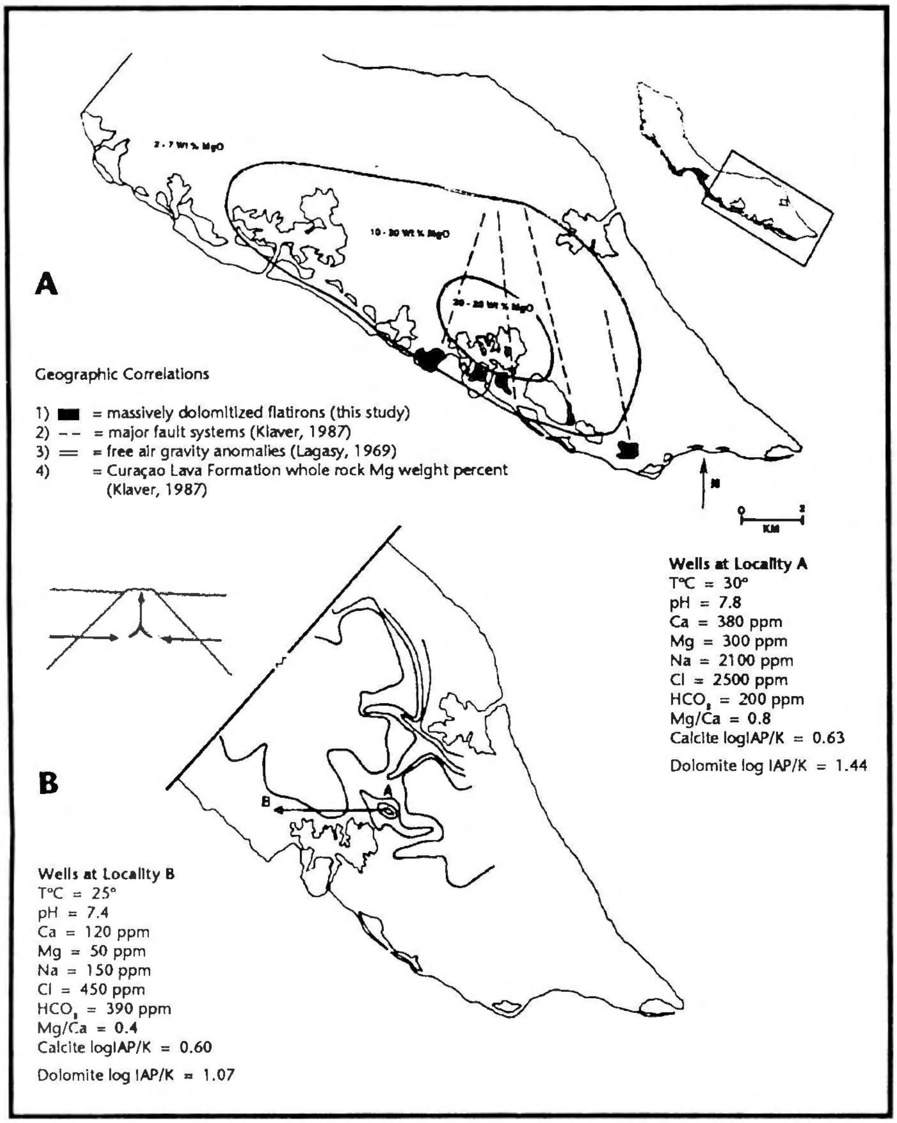

Figure 23. (A) Geographic correlations on SE Curaçao, Netherlands Antilles, of the following: 1) Geographic distribution of flatirons composed of the Massive Algal Dolomite Facies and the massively dolomitized Lagoon-Backreef Wacke-Pack-Boundstone Facies (present study); 2) Major fault systems within basalts of the Curaçao Lava Formation; 3) Free-air gravity anomalies depicting the core of the volcano comprising SE Curaçao (Lagaay, 1969), and 4) Wholerock MgO weight-percent content of Curaçao Lava Formation basalts (Klaver, 1986). (B) Geographic distributions of anomalies within modern groundwater conductivities in SE Curaçao. Data provided by the Netherlands Antilles Groundwater Ministry (LW). Diagram in upper left depicts hypothetical thermal seawater convection pathways in the Curaçao volcanic pedestal. Equilibrium calculations for well sites A and B completed with PHREEQE thermodynamic computer-generated models in collaboration with Dr. Martin Schoonen.

Observations About Karst Development in a Tropical Area of Colombia

Eliseo Amado Gonzalez and Ludis del Rosario Morales Alvarez

The Guácharos National Park is located in the southwest of Colombia, at 76° west longitude, 1°22′ north latitude, covering approximately 90 km^2. The Park was established to preserve the forest and fauna, especially the unique ornithological diversity, the same as the fluviokarst features developed on the Suaza River valley.

The fluviokarst is made up of lower Cenomian and upper Albian limestones of marine sediments, middle Cretaceous (probably 100-165 million years ago). Over these beds overlies argillaceous rocks often highly siliceous; specific details of these rock layers, from the bottom upward, are shown on a stratigraphic column (Figure 24).

Many of the solutional landforms in the Guácharos Park have been produced by water moving along fractures and bedding structures in the limestone. The

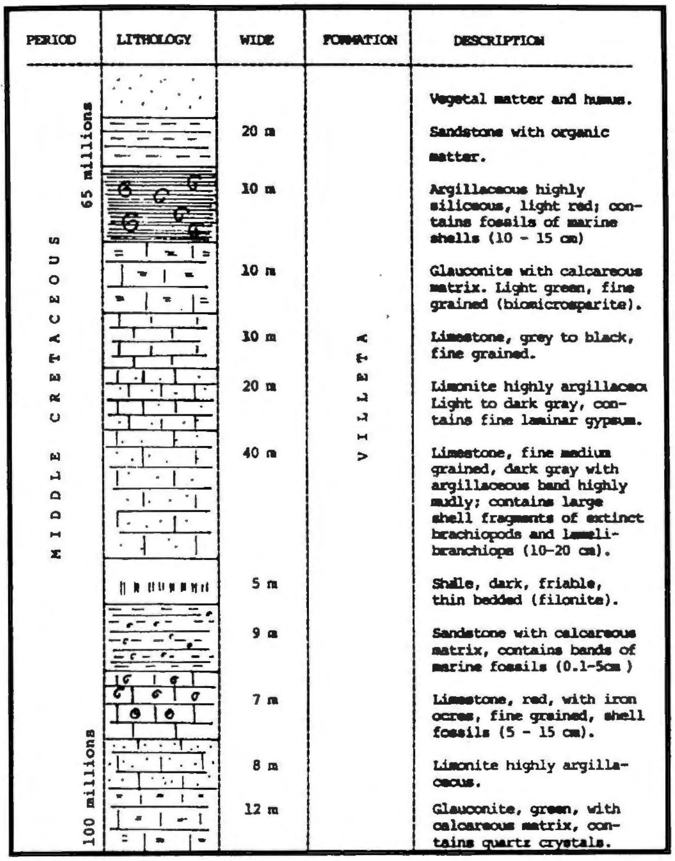

Figure 24: Stratigraphic column showing the rock formation in which the Cueva del Indio system is located.

opening up of subsurface drainage routes did not preserve the initial geologic structure because of several teluric phenomena; and it has it origin not only by allogenic streams of the Suaza River but also by the action of the root of big trees over the fractures (Figure 25).

In fact, the rock is concealed by plant growth which produces a wide humus strata (A: 0-45 cm); therefore, a hardness increase along streamways. The water samples, taken from 30-06-89 to 06-07-89, from a spring at Cueva del Indio were analyzed in situ using an Aquamerck kit. The results were: total hardness = 28.83 ppm $CaCO_3$; alkalinity = 1.25 HCO_3 meq/lt; CO_2 = 7.68 ppm/lt; pH = 7.1; Q = 294 lt/seg. The karst denudation is 55 mm/1000 years.

The evolution of the landforms at Suaza River valley began roughly 3000 years ago. Many factors interacted to control the nature and geomorphological features on this tropical covered karst. Between the mean features of this karst morphology are some caves which include Cueva del Indio (3507 m), Cueva del Hoyo (552 m), Cueva de los Guácharos (450 m) plus other small caves. The doline formation is not very common, just a few bowl-shaped solutional dolines and alluvial dolines which seldom exceed 10 m in diameter and a few meters in depth, and are always hidden by natural forest. An interesting karst phenomena is the field of karren where the respiration of plants produces corrosion over the grooves (Figure 26).

The analysis by means of rosettes from the cave maps gives the major rosette sector between N30°-40°E to Cueva del Indio; N20°-30°E and N20°-30°W to Cueva de los Guácharos; and N10°-20°E and N30°-40°E to Cueva del Hoyo. This implies that a set of fractures between N10°-40°E was especially used by the flow of ground water. so the cave development is essentially controlled by joint networks. This is the case at Cueva del Indio, where passages are nearly parallel and are intersected by a second set of parallel passages spaced regularly.

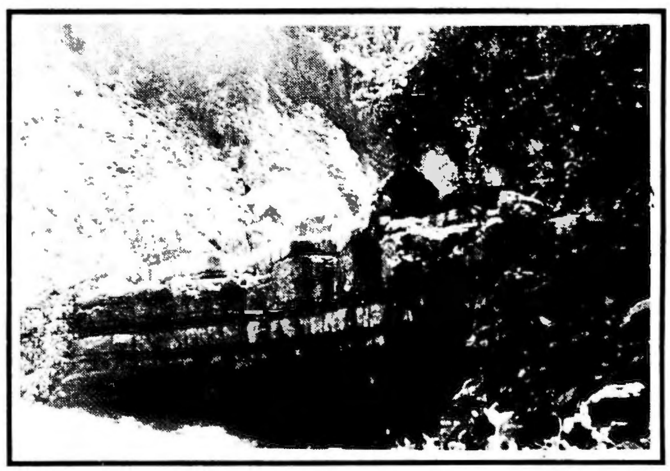

Figure 25 - Fluviokarst at Guácharos Park. The Suaza River is, among others, a main factor in the erosion process.

The passage to the three caves trend in the next directions: N35°E, 67%; N5°E, 63.4% and N25°W, 54%. Cueva de los Guácharos and Cueva del Hoyo have patterns that reflect the geological folding. The correlation coefficients (r_{xy}) is 0.98 in the NW quadrant and 0.67 in the NE quadrant (Figure 27).

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Figure 26. Field of karren. The rocks are highly eroded by the biogenic action of humus-water-plants.

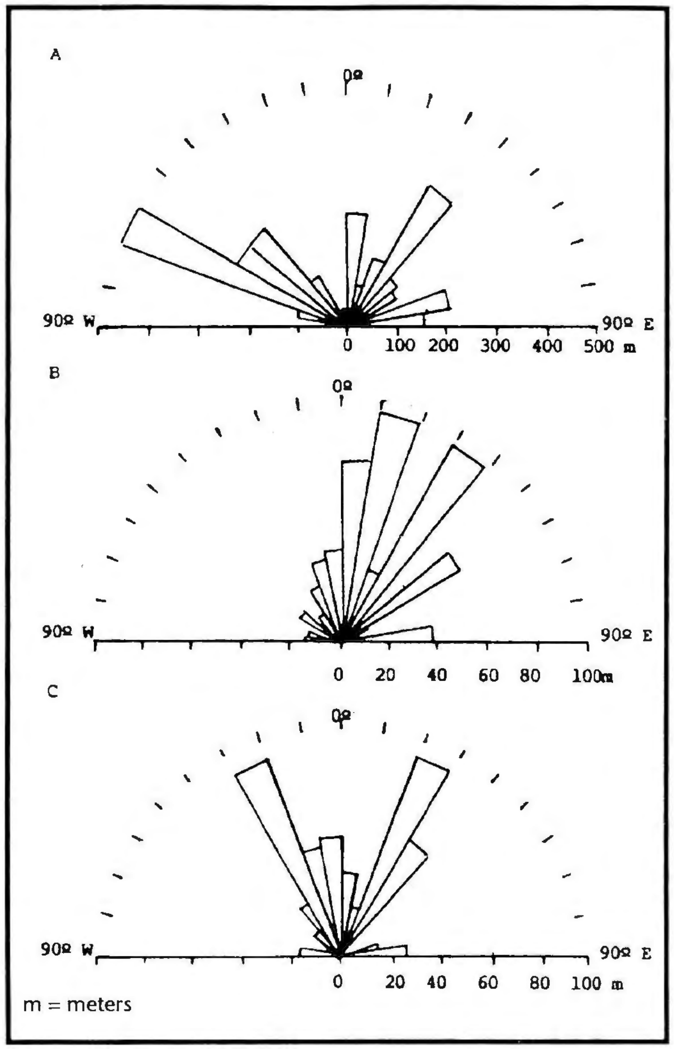

Figure 27. Length of mapped fractures by 10° orientation class. A = Cueva del Indio; B = Cueva del Hoyo; C = Cueva de los Guácharos.

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Acknowledgement

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Ecology

Cave Invertebrate Inventory and Monitoring at Lava Beds National Monument
Initial Progress and Observations

by Rodney L. Crawford

Background

Cave invertebrates are the most numerous cave animals and arguably the most characteristic and important members of subterranean ecosystems. Knowledge of the invertebrate species present, their roles in the cave ecosystems, and some means of monitoring them are essential prerequisites for proper management and conservation of cave resources, a goal of Lava Beds National Monument. The many and diverse caves of the Monument should harbor a much richer invertebrate faunathan is now known; for comparison, a study of cave invertebrates in Mt. St. Helens National Volcanic Monument, Washington, yielded 256 species in 23 caves (Crawford and Senger 1985). To date, aside from woodrat nest fauna recorded by Nelson and Smith (1976), only 5 cave invertebrate species have been recorded from Lava Beds National Monument, based on casual collection (Peck 1973, Senger 1984). The present study is essentially a pioneering effort; no North American cave invertebrate study has previously addressed lava tube caves in terrain of this type (continental, semi-arid climate and relatively high elevation, 1200-1600 m).

Methods

Ten caves were selected in consultation with Charisse Sydoriak, the Resources Management Specialist at Lava Beds, to include a variety of cave types and management situations. The initial phase of field work was from 20-25 November 1989. During this period, I attempted to do the following for each cave: 1) Take notes on environmental factors affecting invertebrate fauna, such as surface and twilight flora and dark zone moisture and food sources. 2) Collect for identification any fauna found visually in the cave by searching of walls, ceilings, and organic substrates, and under rocks, and shining lights horizontally across pools and lakes. 3) Extract fauna, by means of Berlese funnels, from standard samples (l/2 of a 1-gallon plastic food storage bag) of organic detritus and twilight zone moss. 4) Set baited pitfall traps for subsequent retrieval, these traps consisting of plastic cups set with lip level with the substrate, containing antifreeze as a preservative and with Limburger cheese spread on the underside of a flat rock that covers the trap and is elevated on pebbles ca. 2 cm above the substrate.

Progress

Notes were taken in all 10 caves. Hand collection was attempted in all 10 caves, and varied widely in the number of specimens found. Berlese extraction on organic detritus (primarily brought in by woodrats) from two caves yielded no fauna; apparently the material was too dry. Only three caves had twilight moss sufficiently lush to warrant collection of a Berlese sample; all yielded fauna, which has yet to be analyzed. From 2 to 5 pitfall traps were placed in each cave, depending chiefly on the cave's length but partly on the variety of habitats. In all, 31 traps were placed in the 10 caves, which, when picked up December 9-11 by Clyde Senger and Dave Cowan all traps were intact except two which were destroyed by woodrats.

Initial observations and reflections

My initial impression is that the primary factor regulating presence or absence of invertebrates in these relatively dry caves is moisture. At Lava Beds, the ubiquity of woodrats means that some organic detritus is present in every cave, whereas the semi-arid, continental climate leads to a much lower average level of moisture in the caves; moreover, lower winter temperatures outside the cave lead to "winter effect" (Howarth 1980), which reduces relative humidity in areas of the cave accessible to outside air. Thus, in caves with multiple entrances all passages connecting two entrances are apt to experience periodic drying. This was particularly noticeable in one cave having three entrances where only the area past the third entrance had adequate moisture for dark zone fauna. Troglobitic invertebrates, in particular, usually have special adaptations to a saturated atmosphere that make it very difficult for them to survive in unsaturated air, even if the humidity is as high as 90% (Howarth 1980). This means that if a cave passage has less than saturated air much of the time, it will probably have no permanent troglobitic fauna. If the unsaturated air is due to circulation of outside air, with moisture otherwise adequate, troglobitic fauna may enter cave passages when moisture allows from permanent populations in the small openings, "mesocaverns," that permeate the bedrock surrounding the cave (Howarth 1983). Millipedes were reportedly common on a previous occasion in one passage of Valentine Cave, but when checked by me on 22 November, the passage was much too dry for troglobitic fauna. Even non-troglobitic invertebrates do require moisture to combat a severe desiccation hazard resulting from their small size and high surface area to volume ratio. Thus, very dry cave passages will likely have few or no invertebrates.

During the November field work, the twilight zones of most caves and much of the dark zone of several caves were too dry to contain much fauna. The chief members of the twilight invertebrate fauna were spiders which draw moisture from prey of non-cave origin. In five caves, dark zone areas had some moisture but not enough for the humidity to be saturated. A clear indication that adequate moisture is present year-around would be lava tube slime, a soft bacterial film on walls and ceiling which (at Lava Beds cave temperatures) has a surface layer of hydrophobic spores that cause water to bead up. Slime, ubiquitous in Washington lava tubes, was found in only 3 areas in the Lava Beds caves studied. All three areas were carefully searched for larvae of the fungus gnat *Speolepta*, which feed on slime and are an important link in cave food chains. They were found only in one cave. Also, the slimy section of Catacombs Cave was the only non-ice cave passage where pools of water were found; trapped in these pools were interesting and possibly troglobitic collembola (springtail insects).

Ice caves, of which three were sampled, appear to be a special case. When visited, each had a temperature just above freezing (ca. 34° F.) and the ice floors in each were covered with about 3 cm of water. Thus, the icy lower levels in these caves presented ideal conditions for moisture-dependent fauna, and each yielded interesting specimens to hand collection, including troglobitic millipedes, mites, and dipluran insects, as well as various interesting troglophilic species. Merrill Ice Cave was included in the study partly because it is the type locality for the grylloblattid insect *Grylloblatta gurneyi*. I collected an immature grylloblattid there, probably the same species, but mature specimens will be required to confirm this. Unavailability of free moisture and saturated humidity at times of year when the ice caves are well below freezing probably accounts for the lack of slime in these caves. At such times, troglobitic fauna probably retreats into the mesocaverns.

Future reports of this project will include fuller identification and more detailed discussion of specimens collected, as well as the all-important results of the pitfall trapping project.

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Detection and Quantification of Viable *Salmonella* sp. in Flowing Underground Streams*

by K. J. Rusterholtz and L. M. Mallory

Salmonella sp. may be found in many environments, ranging from food processing plants to relatively "pristine" waters. This wide and diverse distribution of an enteric pathogen is significant due to the potential health threat to humans and other animals. This study sought to detect and quantify the presence of *Salmonella* sp. in an underground drainage system located in and around Mammoth Cave National Park, KY. Water and sediment samples were collected from three sites in Mammoth Cave. The three sites were flowing underground base level streams. To detect and quantify *Salmonella* sp., a most probable number technique with a nonselective preenrichment step was used. Inoculated broths Were incubated in the cave at ambient temperature (15°C) for 2 to 4 hours. Subsequent manipulations were performed at Mammoth Cave National Park facilities and at the University of Massachusetts, Amherst, MA. *Salmonella chloera-suis* subsp. *chloera-suis* (*S. enteritidis*) was recovered in water samples from the Hawkins River and Owl Cave sites at densities of 0.7 cells/100 ml (approximate 95% confidence limits: 0. 10-7.0 cells/100 ml) and 11 cells/100 ml (2-60 cells/100 ml), respectively. *Salmonella* sp. were recovered from Owl Cave sediment at a density of 4 cells/100 ml (0.5-40 cells/100 ml). *Salmonella* sp. were not detected in either water or sediment collected from Echo River, a popular tourist destination. A possible source of these salmonellae are failed septic systems.

* Published in *Abstracts of the 90th Annual Meetings of the American Society for Microbiology*, Anaheim, CA, May 13-17, 1990.

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Winter Report on *Plecotus Townsendii* Hibernacula Survey

by J. Mark Perkins

Plecotus townsendii townsendii (Townsend's Big-eared Bat) is presently a Federally listed (Category II) species, and is similarly listed in California, Oregon, and Washington. This listing is official recognition that populations of this bat may be threatened or endangered and that the species should receive further study. In major portions of its life cycle, (hibernation, raising young) the bat is dependent upon caves or cave-like structures (Perkins, 1987). There are many recorded sightings of this bat in the caves of Lava Beds National Monument, including accounts of both nursery colonies and hibernacula. It is essential that this population be surveyed and monitored so that the caves can be managed towards the perpetuation of this sensitive species.

This report covers the first part of the winter hibernacula searches, which took place November 1989. To begin narrowing the list of caves to search, Mark Perkins, Janet Sowers, Bruce Rogers, Mike Sims, and Donald Denbo reviewed each cave for its potential as a hibernacula based on past observations. Caves in which bats had been previously encountered were given an "A" priority and were searched first. Those caves which appeared to be suitable habitat for winter torpor, but for which no data existed were given a "B" priority and searched second. All other caves were given a "C" priority to be searched if there were sufficient field time.

This November 35 caves were searched. A total of 561 *Plecotus* were sighted, with two caves containing 95% of that number. Five other caves contained "significant numbers" (<5 bats). The total number counted constitutes about 85% of the local population estimated from nursery colony populations (650-750 individuals in colonies of 100 and 300). When the winter searches are complete, I estimate that we will have counted 90% of the total population.

For future monitoring, the population in ten caves should be counted to watch winter population trends. One of these caves, located in a remote area of the monument, contained 460 bats, making it the largest known hibernacula on the west coast! Initiation of ideas to protect this cave and monitor activity in this part of the monument need to begin immediately. Protection of this bat population so far removed from the monument headquarters will take careful thought and planning.

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Attenuation and Annual Femur Length:Mass Relationships in Cavernicolous Crickets (Insecta:Orthoptera)

by Eugene H. Studier and Kathleen H. Lavoie

The general perception of elongated appendages and a fragile appearance are widely regarded as being characteristic of cave animals, but few studies have been done to compare cave-limited species with surface relatives and ancestral species (Culver 1982). Elongated appendages, particularly antennae, could increase sensory perception, while elongated limbs could be an adaptation for metabolic economy, i.e., with longer legs, the animal could move further with each step.

In association with physiological studies (see CRF Annual Reports for 1986, 1987, and 1988), we have collected data on hind femur length (HFL, a measure of attenuation) and crop empty live weight (CELW, a measure of mass) in several orthopterans which are variously adapted to a cavernicolous existence. This report examines seasonal changes in the extent of attenuation in *Hadenoecus subterraneus* and the relationship of leg attenuation to apparent degree of adaptation to cave life in a broad range of orthopterans.

Species used in this study include commercially obtained house crickets, *Acheta domestica*, and field crickets, *Gryllus pennsylvanicus*, which are not adapted for cave life as well as several species which are variously adapted to cave life from Kentucky, New Mexico, and Hawai'i. Kentucky species include the cave cricket, *Hadenoecus subterraneus*, and camel cricket, *Ceuthophilus stygius*. *H. subterraneus* are a long-lived species which appear to be highly attenuated, copulate and lay large eggs in caves, reproduce in all seasons, and forage outside caves at irregular, long intervals when epigean conditions are favorable. Few adaptations to cave life are shown by *C. stygius* which complete their life cycle in a year, copulate in cave entrances in the Fall, are found deeper in caves only as young instars in the Winter, leave caves nightly to forage and appear to be very robust. Species studied from New Mexico are *Ceuthophilus longipes, Ceuthophilus conicaudus* and *Ceuthophilus carlsbadensis*. Of these, *Ceuthophilus longipes* appear to be the most highly adapted to cave life while *Ceuthophilus conicaudus* seem to be the New Mexican equivalent of *Ceuthophilus stygius*. *Ceuthophilus carlsbadensis*, which feeds on surface material in the massively abundant guano deposited by the Mexican free-tailed bat, *Tadarida brasiliensis,* appear to be the least cave adapted (Northup, 1988). Of the Hawai'ian crickets, *Caconemobius varius* occupy old lave-tube caves and are more highly cave adapted than the lava flow crickets, *Caconemobius fori*, which occupy recently formed caves (Howarth, 1972). An undescribed species *Caconemobius* found on Hawai'ian beaches which is presumed ancestral to the other two forms (Howarth, personal communication) is included for additional comparison.

Multiple regression analyses show a curvilinear relationship between HFL and CELW for cave and camel crickets where we had a broad range of sizes to measure. Our results indicate that female *H.subterraneus* are larger than males in all seasons, that individuals of identical HFL are lightest in the Spring and heaviest in the Fall, and that these differences are progressively greater as HFL increases. In *C. stygius*, females of small HFL are slightly lighter, and of large HFL, slightly heavier, than males. Since gonad mass is markedly greater in females than males (Studier *et al.*, 1986), mature females would be expected to have greater CELW than males of similar HFL. Seasonal differences appear to relate to epigean foraging frequency and reproductive effort. *H. subterraneus* exhibit extreme metabolic and water budget sensitivities to ambient relative humidity and temperature (Studier and Lavoie, 1990). Epigean feeding appears limited to nights where outside air is water saturated, or nearly so, and is near cave temperature of 12-14° C. Such conditions occur most frequently in late Summer and Fall in Kentucky; and, we expect, therefore, that cave crickets exhibit positive energy budgets and greatest secondary productivity and mass in the Fall. Although *H. subterraneus* are reproductively active throughout the year, they exhibit a peak in occurrence of mature gonads and rates of egg laying in Winter months (see CRF Annual Reports for 1987,1988).

These activities coupled to infrequent appropriate conditions for epigean feeding account for the individual loss of biomass through the Winter and extending into Spring. The combined stress of infrequent foraging and great energy expenditure for reproductive effort, in addition to explaining loss of individual biomass, may account for the apparent marked mortality of adults which occurs in the Winter to Spring time span (1987 CRF Annual Report).

Data on HFL and CELW in the species studied are illustrated in Figure 28. Relationships between these variables are curvilinear in those species in which a range of sizes of individuals were studied. In both *Hadenoecus subterraneus* and *Ceuthophilus stygius*, the ratio of CELW to HFL changes greatly with size and, therefore, does not provide a useful index of attenuation. Since mass or volumes are related to linear measures cubed, we compared the ratio of CELW to HFL^3 as a potential attenuation index. In *Hadenoecus subterraneus*, the ratio of CELW/HFL^3 averages 0.0334, is essentially constant with a total range of 0.0296 to 0.0380, and is independent of size. This ratio has, therefore, been used as an index of the extent of attenuation which is useful in species comparison. The attenuation index (CELW/HFL^3) ranks the species with respect to their level of adaptation to a cavernicolous existence with low values indicating a high degree of cave adaptation. Comparison of the attenuation index within groups shows good agreement with actual adaptation of each species to life in caves. For *Ceuthophilus*: *C. longipes* = 0.602; *C. stygius* = 0.0996; *C. conicaudus* = 0.1546; *C. carlsbadensis* = 0.1879. For *Caconemobius; C. varius* = 0.1474; *C. fori* = 0.1571; and *C. sp.* = 0.1998. By way of comparison *Gryrllus pennsylvanicus* = 0.2831 and *Acheta domestica* = 0.3543. The situation with *Caconemobius* from Hawai'i is particularly striking considering the short evolutionary time (<750,000 years) for such changes to occur. *Ceuthophilus* crickets from New Mexico and Kentucky cover a wide range of level of adaptation and show increased level of attenuation with increased life in caves. Further comparative studies of adaptations to cave life in these crickets would be useful.

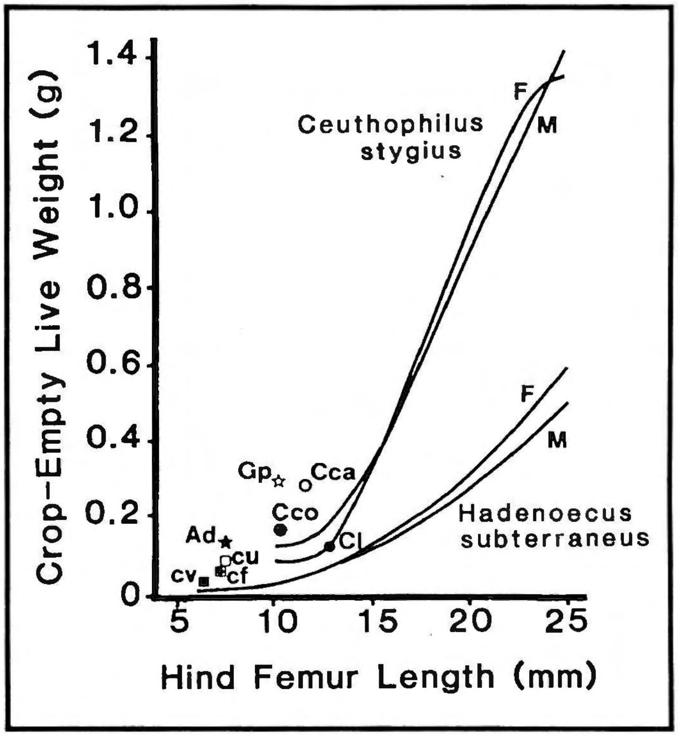

Figure 28: Relation of hind femur length (HFL) to crop-empty live weight (CELW) in male and female cave crickets, Hadeno*ecus subterraneus*, (equations for spring: males; CELW = 0.001283 HFL^3 - 0.01426 HFL^2 + 0.04856 HFL; and for females; CELW = 0.001699 HFL^3 - 0.02202 HFL^2 + 0.07896 HFL); in camel crickets, *Ceuthophilus stygius* (equation for males; CELW = -0.0004101 HFL^3 + 0.02481 HFL^2 - 0.3824 HFL + 1.881; and for females; CELW = - 0.0008709 HFL^3 + 0.04734 HFL^2 - 0.7233 HFL + 3.459). *Ceuthophilus longipes* = closed circle (Cl); *Caconemobius varius* = closed square (cv); *Ceuthophilus conicaudus* = circle with cross (Cco); *Caconemobius fori* = square with cross (cf); *Ceuthophilus carlsbadensis* = open circle (Cca); *Caconemobius* sp. = open square (cu); *Gryllus pennsylvanicus* = open star (Gp); and *Acheta domestica* = closed star (Ad).

Acknowledgments

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Cave Cricket (Hadenoecus subterraneus) Egg Laying Rates

by Kathleen H. Lavoie, Eugene H. Studier, and Michelle M. Cyr

This report presents information about egg-laying rates and discusses possible strategies used by the cave cricket, *Hadenoecus subterraneus*, to avoid egg predation. Earlier reports have dealt with characteristics of copulating pairs and analysis of reproductive components (McMillin, *et al.*, in the 1987 CRF Annual Report). Studies of egg laying rates of caged *H. subterraneus* were performed from April 1987 to July, 1989, extending studies reported by Cyr, *et al.*, in the 1988 CRF Annual Report.

Caged adult female *H. subterraneus* laid more eggs in the first two days than in later intervals at both Sophy's Avenue and Frozen Niagara (Table 3). More false oviposition holes are invariably made than eggs laid, except for the February 1989 Frozen Niagara sample, where there were no holes or eggs. Table 3 also shows the high ratio of holes made to eggs laid. The ratio is usually lower in the first interval compared to the remaining intervals.

Caged adult female *H. subterraneus* laid many more eggs in the first two days than in later intervals (Table 3). The large number of eggs laid in the first interval may be normal or due to stress from being captured and caged. Some females, however, did not lay any eggs from the first interval to the last. These females may have already laid eggs before being placed in the cages. Dissections were not done on caged females. Studier and Lavoie (personal communication) found that female crickets used for weight loss studies in January occasionally laid eggs against the glass of jars in which they were caged, suggesting that females reach a point where they cannot refrain from laying eggs even in the absence of suitable substrate.

Assuming the stress of being caged is equal at all times of the year, inspection of Table 3 shows some interesting patterns. Seasonal differences in the Sophy's Avenue data are obvious, with many more eggs laid from October to February (4.3 ova/day on days 0-2) than in April and July (0.6 ova/day on days 0-2). Rates of egg laying correspond to the number of eggs found in gravid females in those time spans and agrees with the frequency of copulating pairs and appearance of newly hatched instars from that cave reported by Hubbell and Norton (1978). These data support a seasonal peak in reproductive effort in January and February. Studies done at another deep cave site in Great Onyx Cave on 27 July 1986 showed that cave crickets there laid an average of 1.04 eggs/female/day over a five day period and in December laid 3.80 eggs/female/day over a three day period (Griffith, personal communication).

Data from the Frozen Niagara Entrance area are incomplete for comparison, but the influence of environmental conditions is readily seen in the February 1989 data, where the greatest number of eggs were laid in Sophy's and no eggs were laid in Frozen Niagara. At that sample time, the entrance door to Frozen Niagara was damaged, allowing cold, dry air to enter the cave. Half of the caged females died, and none of the survivors laid any eggs or even made any test oviposition holes. The greatest number of eggs were laid in July, but differences are non significant in the number of eggs laid in April and July ($t=1.81$; 11 df, $p<0.1$) and July and October (by inspection).

The temporal pattern of oviposition hole making is approximately the same as the pattern of egg laying with more holes made than eggs deposited. This egg-laying behavior is probably an adaptive strategy by *H. subterraneus* to cope with egg predation by a rhadine cave beetle, *Neaphaenops tellkampfii.* One cricket egg completely fills a *Neaphaenops* for approximately a week (Norton *et al.*, 1975), and a reduction in predation rates has been shown to be associated with high egg densities (Kane and Poulson, 1976).

Female crickets may exhibit two strategies to avoid egg predation. One strategy is predator satiation, in which timing of egg production results in an overabundance of eggs for a short duration. Predators become satiated during this short period, and surviving young quickly grow beyond a size easily handled by the predator. Cave cricket eggs that escape predation hatch into nymphs which move to the ceiling where they are less vulnerable to predators (Norton *et al.*, 1975). The second predator avoidance strategy involves making large numbers of ovipositor holes to increase search time for *Neaphaenops* beetles, which dig in areas of disturbed substrate. Both of these strategies may increase egg survival rate. We placed 23 eggs laid by *H. subterraneus* in April 1988 in cages, and checked them occasionally for hatching. None had hatched by 10 July 1988, an interval of 72 days. Cages were not checked again until 16 October 1988, an interval of 105 days, at which time 19 second instar crickets were observed. Based on our data, unpredated eggs have a minimal hatching success rate of 82.6%, with an approximate time to hatching of 12 weeks.

False holes arguably may also represent test probes to find appropriate egg laying substrates (Poulson, personal communication). If this were the case, the numbers of holes made in the uniform substrate of our cages would be expected to decrease with time. No decrease was observed. Crickets appear to exhibit a stereotypic behavior in making false holes to reduce the probability of egg predation.

Using data from Table 3, calculations of total annual egg production by H. subterr*aneus* varies. In a very rough estimate of annual egg production, we assume that during February, 20-30 eggs were laid in a 2-3 day period of rapid egg laying. In April, the rate was 1-3 eggs laid every eight days. If average eggs laid per year is based on maximum egg-laying rates for each period of observation, then the annual egg production is 371 eggs laid per year per female. If instead we use the average eggs laid for the rest of each period of observation, average annual egg production is 96 per year. Since it is unlikely that crickets maintain measured maximum egg-laying over extended time periods, the later calculation number (96 per year) is probably more accurate. We estimate a range of 96-371 eggs laid per year per female cave cricket. In comparison with other Orthopterans, this number is low. *Acheta domesticus* lays 728 eggs in approximately a year, *Blattella germanica* 218-267 eggs, *Melanoplus sanguinipes* 300-400, and *Periplaneta americana* 200-1000 eggs (Altman and Dittmer, 1972). In a 154 day interval, three pairs of caged cave crickets laid an average of 0.46 eggs/day, corresponding to an annual egg-laying rate of 167 eggs/year. The time span studied was March to August, which is not the peak time for egg production, and the 154 day interval is also longer than the estimated twelve weeks needed for eggs to hatch, so this number is probably low.

Further studies should concentrate on differences in populations of *H. subterraneus* from deep cave vs entrance sites. Comparisons of the success of beetle predators from the two areas would also be interesting. Movement of crickets between deep and entrance sites remains to be investigated.

Acknowledgements

We thank the following persons for their assistance in the field: Michael DeLong, Eric Wildfang, Michelle Labbe, Chad White, Shirley Pichey, Stephanie Phillpotts, Denise Nevin Caretto, Ernest Szuch, Annie Szuch, Tom Poulson, Dave Griffith, Patty Jo Watson, Tom Brucker, William Wares II and Steve Sevick. National Park Service personnel at MCNP provided access to caves. We especially thank George Gregory for his assistance. We also thank the Cave Research Foundation for the use of their field facilities. This work was done as part of MACA-N-103 with the cooperation of the National Park Service. Financial support was provided by a University of Michigan-Flint Faculty Development Grant.

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Table 3. The number of oviposition holes made and eggs laid per day by caged gravid female *Hadenoecus subterraneus*. Numbers in parentheses are standard errors of the mean.

Date/Interval		Sophy's Avenue 0-2	Sophy's Avenue 2-4	Sophy's Avenue 4-6	Frozen Niagara 0-2	Frozen Niagara 2-4	Frozen Niagara 4-6
II 88(n=14)							
	Eggs/Day	5.93	0.22	0.25	0	0	0
		(1.51)	(0.10)	(0.07)			
	Holes/Day	18.43	5.88	6.18	0	0	0
		(2.06)	(2.44)	(2.47)			
	Holes/Egg	3.12	26.7	24.7			
IV 87(n=6)							
	Eggs/Day	0.38	0.12				
		(0.50)	(0.24)				
IV 88(n=8,8)							
	Eggs/Day	0.81	0.12	0.25	0.12	0.06	0.06
		(0.46)	(0.12)	(0.13)	(0.08)	(0.06)	(0.06)
	Holes/Day	2.50	6.25	4.81	4.94	1.50	9.25
		(1.30)	(2.68)	(1.47)	(3.01)	(0.67)	(3.35)
	Holes/Egg	3.01	50.00	19.24	41.12	25.00	154.17
VII 89(n=8,5)							
	Eggs/Day	0.69			1.40		
		(0.62)			(0.70)		
	Holes/Day	2.00			9.90		
		(0.84)			(2.82)		
	Holes/Egg	2.90			7.07		
X 88(n=7,8)							
	Eggs/Day	2.71	0.36		0.75	0.37	
		(1.64)	(0.14)		(0.57)	(0.38)	
	Holes/Day	10.71	6.41		4.81	6.06	
		(4.75)	(2.43)		(2.38)	(2.03)	
	Holes/Egg	3.95	17.80		6.41	16.38	
XII 88(n=8)							
	Eggs/Day	4.33	0.75	0.26			
		(0.93)	(0.25)	(0.12)			
	Holes/Day	12.63	10.37	18.66			
		(4.51)	(3.86)	(6.31)			
	Holes/Egg	2.91	13.83	71.77			

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Predation in the Cave Rat Fecal Latrine

by Paul Richards

A preliminary three month study of the effects of predation in the cave rat fecal community was conducted in Mammoth Cave National Park, from January through March of 1989. Little Beauty Cave, White Cave, Great Onyx Cave, and Davis Hall in the Flint Ridge portion of Mammoth Cave were chosen as study sites. These sites were deemed appropriate because of available data and for the presence or past presence of the cave rat *Neotoma magister*. The cave rat fecal community is useful for investigating the effects of predation because it is relatively simple but also complex enough to allow generalization to much more complex non-cave communities. There are a number of trophic levels, sizes of species within each trophic level, and potentials for indirect interactions.

The cave rat's fecal piles in latrines are the basis for the invertebrate community of interest. The major invertebrate predator, as calculated from Importance Value (size x frequency x density), in the rat fecal community is the staphylinid beetle (*Quedius microsaurus*) (Poulson and Lavoie 1978). The only major prey types, as calculated from Importance Values, are sciarid fly larvae of the genus *Bradysia* sp. and the catopid beetle *Ptomaphagus hirtus* (Poulson and Lavoie 1978).

Lavoie (1982) has studied this community in detail. In the field she studied successional decomposition and in the laboratory she studied competitive interactions among the prey species and fungi. However, she did not study the effects of *Q. microsaurus* predation even though she made some strong inferences concerning the importance of predation based on her field experiments.

In order to begin a detailed investigation of predation in this system a preliminary field manipulation was designed. I established five rat fecal pile sizes with various numbers of replicates in each of the four study sites. The fecal pile sizes were one pellet, 12 pellets, 120 pellets, 240 pellets and 480 pellets. The rat fecal pellets were acquired from laboratory rats kept under sterile conditions. At intervals of one month, four trips to the field site were made. During the first trip I established the various pile sizes in Little Beauty Cave, White Cave, Great Onyx Cave and Davis Hall of the Flint Ridge portion of Mammoth Cave. During the three subsequent months I removed one half of each pile for censusing, replacing it with an equal portion of new fecal pellets. I counted all *Bradysia* larvae, *P. hirtus* and *Q. microsaurus* in each sample. Densities of organisms were calculated by dividing the census data by the number of pellets in the sample from which they came. A total of 53 piles were sampled in the three month period with no more than 21 gathered during any one trip.

The average prey densities, summed over all study sites, are presented in Table 4. I have grouped the data into fecal piles in which predators were present (at least one *Q. microsaurus*) and fecal piles in which predators were absent at the time of censusing. The data suggest that *Q. microsaurus* has a dramatic effect on *P. hirtus* populations in manipulated fecal piles. This result is consistent for all three months, *P. hirtus* density is always depressed in the presence of predators. The effect of predators on *Bradysia* larvae is inconsistent. In January the average *Bradysia* density is higher in the fecal piles with predators present than in the fecal piles with predators absent, but in February and March average *Bradysia* density is lower when predators are present than when they are absent.

Table 4. Average prey densities when predators are present and when predators are absent from fecal piles for each census date from 1989. (P. = *P. hirtus*; B. = *Bradysia* larvae).

	Jan.		Feb.		Mar.	
	P.	B.	P.	B.	P.	B.
Predators present	0.035	2.128	0.013	0.865	0.000	0.352
	(n=4)		(n=6)		(n=5)	
Predators present	0.0258	0.276	0.271	2.012	0.189	1.975
	(n=8)		(n=9)		(n=9)	

Pearson's Product-Moment Correlation coefficients between all pair-wise combinations of *Q. microsaurus*, *P. hirtus* and *Bradysia* larvae were calculated and are presented in Table 5. All double-zero matches between species were eliminated to reduce the chance of spurious correlations. A one tailed t-test was used to estimate p-values for the *Q. microsaurus* and *P. hirtus* combination, a two tailed t-test was used on the other two species combinations. A significant negative correlation was found between predators and *P. hirtus* for February and March but not for January, although the coefficients are consistently negative across all three months. Except for a significant positive correlation between *Bradysia* larvae and *P. hirtus* in March, the other coefficients in the table are not significant. The positive correlation in this case is difficult to interpret, due mainly to the inconsistency of the other coefficients in that row.

My data, as well as Lavoie's (1982), show that *P. hirtus* coexists with *Bradysia* larvae in fecal piles in which predators are absent, thus suggesting that competition is not important in the field. If competition is important in the cave rat fecal community a negative correlation between *P. hirtus* and *Bradysia* larvae would exist independent of predator densities. Table 5 shows that no significant negative correlation exists between *P. hirtus* and *Bradysia* larvae. On the other hand, *P. hirtus* shows a significant negative correlation with *Q. microsaurus*, thus suggesting causation. *Bradysia* larvae do not demonstrate any consistent correlations with regard to predators or *P. hirtus*. These results suggest to me an apparent competition hypothesis. If the large populations of *Bradysia* are causing a numerical increase in predator populations which causes the elimination of *P. hirtus* from the community, then *Bradysia* larvae have an indirect negative impact via predation on populations of *P. hirtus*. Although detailed analysis of the preliminary data are not possible, due to low replication, the data presented does not reject the hypothesis.

The apparent competition hypothesis is further strengthened by my preliminary laboratory experiments in which the survivorship of *P. hirtus* in single prey species, single predator treatments is greater than the survivorship of *P. hirtus* when it is present with *Bradysia* and predators. The critical experimental test of this hypothesis will be a numerical increase of predators in a field experiment when *Bradysia* densities are increased resulting in the reduction or exclusion of *P. hirtus* from the community.

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Table 5. Pearson's Product-Moment Correlation coefficients between all pair-wise combinations of *Z. microsaurus*, *P. hirtus* and *Bradysia* larvae. Correlations were calculated on the density of each species and eliminating all double-zero matches between species. (• p<.05; **p<.005)

	Jan.	Feb.	Mar.
Q. microsaurus* and *P. hirtus	−0.383 (n=9)	−0.720 ** (n=13)	−0.554 * (n=12)
Q. microsaurus* and *Bradysia larvae	+0.522 (n=11)	−0.307 (n=12)	−0.450 (n=13)
Bradysia* larvae and *P. hirtus	**−0.120 (n+12)**	**−0.116 (n=13)**	**+0.633 * (n=11)**

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I would like to thank Dr. Tom Poulson, David Griffith, Jeannette Griffith, Laurie Graham, Keshab Bhattacharya and Mary Geraghty for providing field assistance. This work would not have been possible without the cooperation of the National Park Service at Mammoth Cave National Park, the assistance of the Cave Research Foundation and the use of their facilities.

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ARCHAEOLOGY

Depositional Reconstruction and Dating of Bering Sinkhole: A Stratified Vertical Shaft Cemetery in Central Texas

by Leland C. Bement

The University of Texas at Austin Bering Sinkhole is a solution cavity formed along a north-south trending fault expanded by water erosion. The surface opening is 2 meters east-west by 4 meters north-south (Figure 29). Initial investigation of this karst feature was summarized in the 1987 Cave Research Foundation Annual Report (Bement, 1987). Continued excavations in this important site have yielded a wealth of information on prehistoric lifeways, Holocene mammalian fauna, and the environment. Sediments, washed into the opening from the surrounding hillslope, filled the solution cavity to within 3 meters of the entrance. The size and configuration of the fault and solution cavity have not been determined, however, benching along the fault and an alcove ceiling trending to the east suggests the chamber could be quite large.

Excavations were conducted by the Texas Archaeological Research Laboratory, the University of Texas at Austin. Preliminary results show the sinkhole was used as a burial locus during the past 7000 years. A minimum number of individuals of both sexes has been set at 27. The corpses appear to have been lowered through the vertical entrance and left uncovered on the depositional cone directly beneath the opening. Subsequent decomposition, rodent activity, and surface runoff entering the cavern disarticulated and distributed the skeletal and cultural material along the cavern floor where they were eventually buried by water borne sediments. The recovery of partially articulated remains support the interpretation that the skeletal material represents primary interments. Secondary interments are also represented by the recovery of cremations.

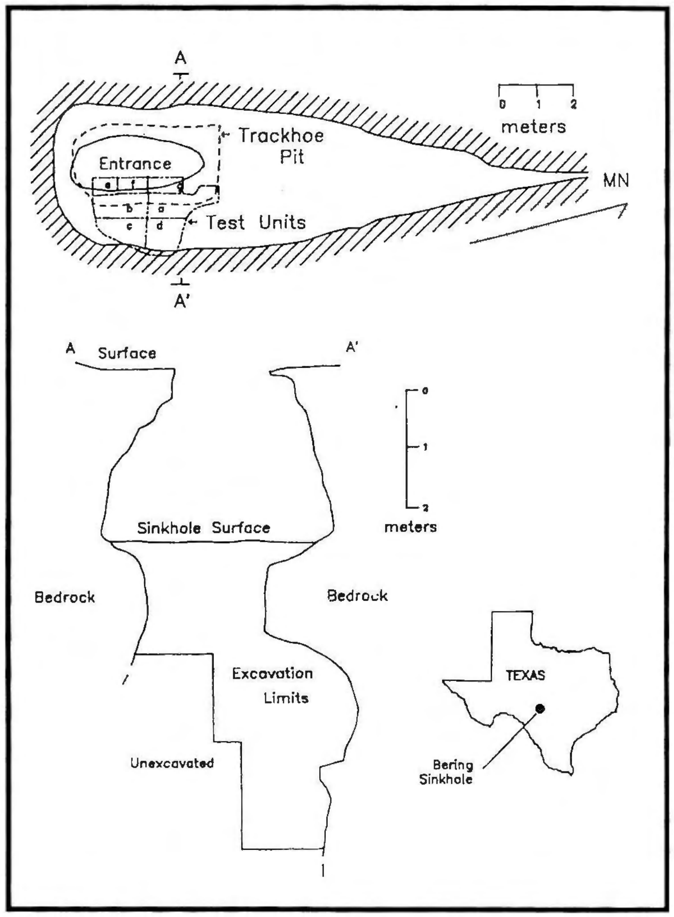

Figure 29: Plan and profile of Bering Sinkhole, west central Texas.

Depositional Reconstruction and Dating

The excavation identified four distinct depositional units. Since excavation has not reached the floor of the cavern, the depositional units are numbered from the top to the bottom. The uppermost unit, Unit I, is a black clay loam with limestone cobbles and pebbles, that extends from the interior sinkhole surface to an approximate depth of 2.3 meters. Four C-14 dates were obtained from this deposit: 990 + 140 (Tx-6525) and 1,085 + 60 (Pitt 0073) at 190 cm, 2,560 + 80 (Tx-5877) and 2,610 + 280 (Tx-6167) at 220 cm. When calibrated, using the computerized calibration program of Stuiver and Pearson (1986), the Unit I samples date the deposits to 929, 978, 2,742, and 2,752 yrs BP. The first two dates were from charcoal recovered halfway through the upper deposit, and the other two were from immediately above the Unit I/II contact. The nearness of the centroids of the latter two dates suggests that both samples originated from a single cremation that distributed charcoal as it rolled or bounced down the debris cone surface. If both samples are from the same cremation, the slope of the cone surface at the time of deposition was approximately 33%. Cultural material recovered from this unit includes elements from at least 9 individuals, at least one cremation, a burned dart point, bone beads, and a Frio dart point.

The second unit, Unit II, is approximately 80 cm thick and consists of a matrix of dark brown clay loam enveloping limestone cobbles and pebbles. The single uncorrected date of 3,420 + 100 yrs BP (Tx-6135), was obtained from charcoal collected from a 10 cm square area. The origin of this charcoal is uncertain although the recovery of burned bone in this level suggests that it too, is from a cremation. Calibration of this sample produces a date of 3,689 yrs BP. Three zones of human remains accounting for approximately 10 individuals were identified in this depositional unit. Cultural materials recovered include two dart points and a cache of fourteen early stage bifaces and drill. The in-situ plotting of bones and artifacts during the excavation of Unit II indicates the sinkhole surface was a half cone, with slopes ranging from 50% along the N-S axis to 25% along the E-W axis of the cavern. Articulated skeletal remains from this unit indicate that, except for cremations, the interments were primary, and composed of complete corpses.

Unit III is 1.2 meters thick and consists of a reddish brown clay with limestone cobbles and pebbles. The slope of the Unit II/III contact is 10% along the N-S axis. Two uncorrected radiocarbon dates of 5,840 + 190 yrs BP (Tx-6282) and 6,860 + 170 yrs BP (Tx-6526 have been obtained from large pieces of charcoal recovered at a depth of 60 cm and 110 cm below the Unit II/III contact, respectively. When calibrated, these samples date to 6,708 and 7,676 yrs BP. As with Unit II, three separate levels of human burials, representing at least 6 individuals, have been identified. Cultural materials include dart points, cores, chert cobbles, one uniface, six unaltered freshwater mussel shell halves, one bone awl, one biface and two marine shell pendants.

Unit IV consists of friable limestone spalls partially cemented in tan clay flowstone. This unit has not produced any cultural material although numerous small animal remains have been recovered. The bottom of the cavern has not been reached. No datable samples have been recovered from this deposit.

In summary, excavations have plumbed a depth of 5.25 meters below the depositional surface within the sinkhole. The Unit IV deposits are devoid of human remains and possibly date to the late Pleistocene. Unit III is between 7,600 and 4,900 years old. Unit II deposits date between 4,900 and 2,900 years ago and the uppermost deposits, Unit I, date from 2,900 years ago to the present.

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CRF Fellowship and Grant Support

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

The Fellowship competition cycle is geared to the academic year. An announcement of the competition is mailed in early Autumn stating the application requirements; the deadline for receipt of the proposal, supporting documents, and letters of reference is January 31. Awards are made by mid-April of the calendar year.

The Cave Research Foundation received 10 proposals in 1989. Of these, one proposal was awarded a Fellowship; two proposals received grants. The awardee, graduate school, and title of the proposal are given for each proposal funded.

1. **For his proposed research entitled "Stable isotopic ratios from carbonate and chert of modern and paleo karst exposure surfaces: implications for early terrestrial micro-organisms and Precambrian paleoclimatic temperatures"**, Mr. Ray Kenny, Department of Geology, Arizona State University, Tempe, AZ 85287 was awarded a 1989 CRF Karst Research Fellowship in the amount of $2500.00. Mr. Kenny's proposed study will examine the stable isotope records of Precambrian chert deposits to evaluate the stability of such records as potential indicators of paleotemperatures.

2. **For his proposed research entitled, "Taphonomy and paleoecology of San Josecito Cave, Nuevo Leon, Mexico"**, to Mr. Joaquin Arroyo-Cabrales, Museum of Texas Tech University, P.O. Box 4499, Lubbock, TX 79409 was awarded a CRF Karst Research Grant in the amount of $1500.00. Mr. Arroyo-Cabrales' research promises to be an outstanding evaluation of a remarkable occurrence of paleontological and paleoecological remains preserved in San Josecito Cave, Nuevo Leon, Mexico.

3. **For his proposed research entitled, "Dolomitization and karstification of the Seroe Domi periplatform carbonates, Aruba, Bonaire, and Curaçao, Netherlands Antilles"**, Mr. Bruce W. Fouke, Department of Earth and Space Sciences, State University of New York at Stony Brook, Stony Brook, N.Y. 11794-2100 was awarded a 1989 CRF Karst Research Grant in the amount of $1000.00. Mr. Fouke's research offers prospects for gaining keen insights into the timing and processes accompanying dolomite formation and karst development in the Netherlands Antilles.

Research summaries and progress reports submitted by these and by other CRF investigators are published elsewhere in this volume. Please refer to those summaries and feel free to contact the respective authors (see addresses of contributors, elsewhere, this volume) for additional details concerning the research.

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INTERPRETATION AND EDUCATION PROGRAMS

Figure 30: Vats used in the processing of saltpetre, Booth's Ampitheatre, Mammoth Cave, Kentucky. (*Photo by Diana Emerson George*).

EDUCATION

Overview of the Lava Beds Project

by Janet Sowers, Project Manager

The year 1989 was an eventful one for the fledgling CRF organization at Lava Beds National Monument. The organization is a little over one year old and already nine studies are underway. We began our relationship with Lava Beds by signing a Working Agreement with the monument in November 1988. The monument wanted a cave inventory, some biological surveying, and a monitoring program put in place to keep track of the condition of the caves and their resources. During the winter and spring of 1989 we assembled a team of people who could get the job done and wrote nine project proposals, submitting them in June. In designing the projects we worked closely with the monument staff to ensure that our work would provide the critical information the monument needs.

Below is a summary of each project:

1. **Cave mapping** .... Mike Sims and Bruce Rogers
   A surveying and cartography project concentrating on previously unmapped caves over 100 feet in length. A minimum of twelve caves will be mapped.

2. **Reconnaissance cave inventory** .... Mike Sims and Dan Weinberg
   Locate and briefly describe as many caves as possible, concentrating on previously undocumented caves. Cave locations will be marked on a master map or air photo; a card will be filled out which will give a brief description of its location and features.

3. **General cave resource inventory** .... Janet Sowers and Bill Devereaux
   Conduct a thorough resource inventory of twenty-four significant caves. Data will include location, historical information, developments, biology, hydrology, geology, cultural resources, hazards, impacts, and management recommendations.

4. **Cave invertebrate inventory and monitoring** .... Rod Crawford, with Clyde Senger, Dave Cowan, & Libby Nieland
   Survey populations of cave invertebrates in ten caves and design a population monitoring program.

5. **Inventory and monitoring of cave-roosting bats (*Plecotus townsendii*)** .... Mark Perkins
   Survey populations of Townsend's Big-eared Bat and design a population monitoring program.

6. **Photomonitoring of cave resources** ..... Bill Frantz
   Set up a photomonitoring program to monitor geologic, hydrologic, cultural resources in representative caves and specific localities of concern.

7. **Dust monitoring and sedimentology** .... John Tinsley, with Ken Miller and Bob Johnson
   Determine sources and quantities of dust and sediment introduced into the caves by visitors, and design a program to monitor sediment inputs.

8. **Ice level monitoring** .... Mike Sims
   Set up a program to monitor ice levels in the six most significant ice caves (except Crystal Cave).

9. **Monitoring of speleothem breakage** .... Janet Sowers
   Set up a program to monitor the rate of speleothem breakage in localities of concern.

The National Park Service approved these proposals and signed a Cooperative Agreement with CRF in September providing funding for the projects. Work is to be completed in 1992. Our first expedition under the Cooperative Agreement took place over Thanksgiving weekend and drew 25 participants. We got a good start on every project, except the ice level monitoring project, which will not begin until February when ice levels should be at their maximum for the season. Reports from each principal investigator can be found elsewhere in this publication.

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

by John C. Tinsley, Robert Johnson, and Kenneth Miller

Lava tubes at Lava Beds National Monument, northeastern California, are impacted by deposition of clastic sediment within and around the caves. Sedimentation occurs in result of natural processes and also reflects effects of recreational visitation at the caves. Examples of these impacts include (1) particulates that accumulate and obscure lava features near tourist trails; (2) deposition of clastic components in ice deposits in ice caves owing to sediment contributed by the feet of visitors; and (3) sediment mantling the floor to depths of several centimeters and extending plume-like into caves from heavily-traveled entrance areas.causing floor details to be obscured. Recognition of the relative importance of natural dust sources versus contributions from recreational use of the caves is of interest to Monument management. Recreational use of the caves is an important element in the role of Lava Beds National Monument.

Appraisal of the human-wrought effects on the caves using sedimentology as a yardstick is the principal goal of this research. Study of the distribution, composition, rate of deposition, and geologic circumstances of sedimentation in selected caves of Lava Beds National Monument commenced in November, 1989, and should provide an objective basis for evaluating sediment accumulation in relation to background aerosolic dust influx, levels of visitation, type of trail tread, and loci and rates of sediment deposition within the caves. In result of this study, the National Park Service at Lava Beds will have a locally-tested methodology and protocol for identifying and evaluating dust accumulation and sediment deposition in the Monument's caves, should additional monitoring seem advisable, as well as a basis for continuing monitoring of the caves selected as pilot studies during this project.

In November, aerosolic dust traps were installed at at three above-ground locations to monitor influx of aeolian dust. The traps are not visible from trails, but are reasonably close to caves of initial interest to this study. The above-ground aerosolic dust traps are patterned after a design developed by Marith Reheis of the U.S. Geological Survey, who is monitoring influx rates of aerosolic dust across the southern Great Basin as a component to a regional study of soil genesis. Each Reheis-type apparatus consists of a 6 foot T-type steel fence post which is driven into the ground; this can be a sporting adventure in a lava flow. The trap proper is an angel food cakepan that demurely perches atop the fencepost (the fence post is just a bit larger than narrow end of the tapered axial tube of the cakepan – a fortuitous circumstance of designs, to be sure, but one must take every advantage!). The cakepan contains a platform of hardware cloth covered with about 400 to 500 marbles. This configuration prevents the wind from eddying about within the pan and blowing out the dust that falls into the pan. Strap steel bands arced above the trap are coated with Tanglefoot-brand bird repellent, as one must endeavor to discourage bird eliminations from the aerosolic dust measurements. Semi-annual forays to recover the trapped dust are anticipated. Dividing the mass of the trapped dust by the cross-sectional area of the trap will yield an estimate of the dust flux expressed as grams per unit area per unit time.

In order to inaugurate the in-cave phases of this study, two caves, Valentine Cave and Skull Cave, were visited and preliminary notes and observations were obtained concerning the distribution of sediments in the caves; key decisions were made concerning types of sediment traps thought most likely to be successful at the various in-cave settings. Within the caves, two-legged packrats of the genus *Homo* would make short work of angel food cake pans. To reduce the attractiveness of our in-cave traps, we plan to use concave-shaped pieces of lava as catch-pans, plus natural depressions in floor areas which have been painted with liquid latex rubber (in essence a removable lining), to catch falling particulates. Hopefully the four-legged packrats (*Neotoma* sp.) will not be making meals of the latex.

Several samples will be analyzed to determine the composition of the particulates, on a seasonal basis. Binocular microscopy, petrographic microscopy, scanning-electron microscopy are among the techniques available for analysis of the composition of the particulates.

Anticipated products are several and include a written report of the study and a series of annotated maps of the monitored caves, showing the present distribution of sediment, locations of monitoring points or traps, and (assuming a successful research endeavor) sedimentation rates and/or changes in sediment distribution measured during the study. A "how to" manual describing the techniques and interpretations of the data will be supplied to the management at Lava Beds National Monument some 33 months hence. The results of the study should afford valuable insights concerning the role of trails in processes of dust accumulation in the caves and may indicate areas in which paving or other modifications to trails might better reduce dust accumulations. The information may also have value in the interpretive sphere.

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Photo-Monitoring at Lava Beds National Monument

by Bill Frantz

The photomonitoring project at Lava Beds National monument got off to a good start during the 1989 Thanksgiving weekend expedition. The purpose of the project is to develop a set of photos of cave features with enough documentation of how and where each photograph was made to allow the photographs to be easily retaken. Comparing two photographs will allow researchers and Park Service personnel to monitor changes in the caves. In addition, where old photographs exist and the scenes can be relocated, new photographs will be made to monitor changes that have already occurred.

With the aid of other CRF investigators and Charisse Sydoriak, Resources Management Specialist at Lava Beds, we have selected thirteen caves for initial monitoring efforts. These include examples from all the monument's management classes. During the Thanksgiving expedition, with the able help of Jo and Charlie Larson, we were able to establish six sites in five caves. Areas monitored include floors and ceilings in a rarely visited cave, a petroglyph at the entrance of a frequently visited cave, paleo-ice in a frequently visited cave, dust accumulation on the floor near the entrance of a frequently visited cave, and slime growth in a frequently visited cave. We were also able to rephotograph a lava block surrounded by a later lava flow (an "island") that appears in Lewis' 1936 paper on the geology of the Lava Beds area.

During the spring we plan to refine and test our site documentation methodology and finish making the initial photographs.

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Monitoring Formation Breakage at Lava Beds National Monument

by Janet Sowers

Broken formations are a common sight in Lava Beds caves. Shark's tooth stalactites, small blade-shaped lava formations (Figure 31) which taper to a slender point, are particularly susceptible to breakage. They are probably broken both by souvenir hunters and by accidental head bumps. Shark's tooth stalactites are thought to form when the ceiling of the lava tube partially melts and drips as hot lava flows beneath it. The stalactites are frozen drips. Many are quite beautiful and delicate, and are often remarked upon by visitors. They may cover a ceiling completely.

Figure 31: Shark's tooth stalactites form in lava caves from the melting and dripping of the ceiling. These, in Catacombs Cave, are 6-10 cm long. They are easily broken; note those on the left of the photograph

The monument is concerned that shark's tooth stalactites may be disappearing. The purpose of this project is to monitor the breakage of these formations in caves of concern. With this information the monument may be able to take appropriate action before more breakage takes place.

Our procedure for establishing monitoring sites is a variation of a technique used in other caves including Carlsbad Caverns. To mark the sites we use a gray waterproof fluorescent paint which blends in well with the rock but glows bright lavender under a portable ultraviolet lamp. We first mark the corners of a 1/2 meter square area of the ceiling, then mark the tips of each broken stalactite in the square. Next we count and record the numbers of broken and unbroken stalactites. To monitor, we recount regularly and mark any new broken formations as they are counted (Figure 32).

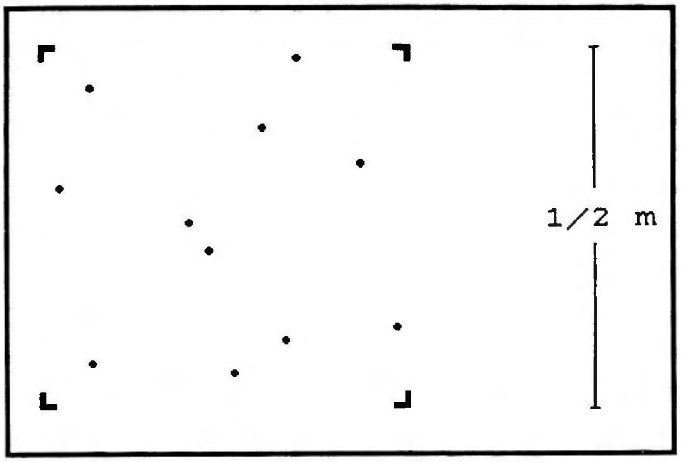

Figure 32: Ceiling plot for monitoring formation breakage. Corners of plot and tips of broken stalagmites are marked with grey fluorescent paint.

Four monitoring sites were established this year in two popular caves, Catacombs and Valentine. The initial counts on these sites show a great deal of impact already; the percentage of broken formations at these sites ranges from 23% to 91%. Monitoring of breakage in the most extreme of these highly impacted areas is unlikely to show meaningful trends in the future. Further sites will be concentrated in areas of relatively low previous impact.

During the coming year we plan to establish an additional six sites. Three types of sites will be selected: (1) sites vulnerable to accidental damage (formations at head height or lower), (2) sites vulnerable to vandalism (within easy reach), and (3) sites that are fairly inaccessible.

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Names and Places in Mammoth Cave

by Mick Sutton

Assembly of an annotated gazetteer of place names and of passage descriptions of Mammoth Cave progressed through 1989.

Gazetteer

At the end of 1988, we had information on 840 place names. The place name database now contains 1,475 entries. The information ranges from the simple fact that a name appears on a map to a detailed description of the feature with a background on the history of its name. All names, whether in current use or not, are recorded. Names may be as old as Flatt's Cave (1790's) or as recent as Rhonda's Route (1989). The obscurer place names added during 1989 include the Devil's Blackboard (aka Devil's Looking Glass) - the Devil appears, ominously, 13 times in the gazetteer if one includes Old Scratch Hall - , the Great Sepulchre (Giant's Coffin), and George Washington (Martha Washington's Statue). Field trips have gone in search of such mythical beasts as Saint George's Dragon and the Giant Anteater, or oddities such as Newman's Spine and the Rat Hole Branch. Many places have become lost in obscurity - where now is the Hall of Thunders or the Holy Sepulchre? All of the most common names from Mammoth Cave *per se* (those passages underlying Mammoth Cave Ridge) are now included, and account for about 1000 of the total. Most of the major written sources have been consulted, and the majority of entries contain substantial background information. Many uncommon names from obscure sources remain to be entered, and a few major sources still await analysis. The Flint Ridge section is fairly close to completion, though there are still substantial gaps in the Colossal and Salts sections. The River system (Proctor Cave, Morrison Cave, and Hawkins/ Logsdon River) has some information but is far from complete. A modest start has been made on the Roppel section. Jim Borden will help to flesh this out - he anticipates the addition of many place names. The history of Roppel Cave is so recent that a large majority of the names should be explicable.

The process of assembling data will continue through 1990. Since previous projections (guesses) of the expected number of entries have proved to be underestimated, we will not speculate on the final size of the database. The gazetteer is already proving useful as a general reference source. A separate bibliographic database is being assembled in parallel with the gazetteer; currently it contains a modest 102 entries.

We greatly appreciate the interest and assistance of the Mammoth Cave guide staff, especially Lewis Cutliff, (Chief Guide) and Ray France (past Chief Guide).

Passage Description

The writing of passage descriptions takes a two-tiered approach. The main emphasis is on a systematic description of a particular area. During 1989, we continued to concentrate on passages included in the Half Day tour. Second, descriptions are assembled opportunistically for scattered passages and areas, when it is convenient to do so in combination with other projects, usually the mapping program. Areas for which we collected data in this way in 1989 include the Grund Trail (a complex series of pits and canyons in Flint Ridge) and the Marion Avenue area.

Several special purpose trips were taken along the Half-day tour route to write and refine passage descriptions. A description of the passages from Carmichael Entrance to the Frozen Niagara Entrance is now complete. The description includes historical and geological background on each passage, together with a fairly concise description of the passage and its most notable features, with particular attention to junctions. Descriptions of the passages included on the Wild Cave tour are underway, and will be the first priority for 1990. The descriptive work is intended to complement the 1:600 tour trail maps.

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Tandem Pump Tower In The Rotunda, Mammoth Cave, Kentucky

by Angelo I. George

Personnel of the Historic American Engineering Record (HAER) of the National Park Service, and the Cave Research Foundation conducted a level survey of the saltpeter pipeline in Mammoth Cave (Mullins, 1986). This was done to establish the elevation relative to the pipelines and pump towers to sea level datum. Engineering drawings were prepared showing this relationship (Mullins, 1986, Plates 2-12 and 9-12). The Rotunda pump tower presented an unexpected problem. The HAER team (Mullins, 1986, p. 17) discovered that the pump tower was

> about four feet too low for gravity feed. Perhaps the pumptower post has been shortened, but this does not appear to be the case. It does not appear to have been burned, which is what destroyed most of the Rotunda pumptower. Possibly the water inlet and outlet pipes are buried several feet below the gate or the entrance at the gate was lower at the time of the saltpetre operations.

George and O'Dell (in manuscript) have discovered why the pump tower is too short. On 16 December 1811, the worst earthquake in historic times caused great damage in the mid-west. The New Madrid (Missouri) earthquakes produced damage to engineered structures in Mammoth Cave. The quake "threw down several hoppers" and "sunk the pump three feet" (McCall, 1812). There is only a one-foot difference between information supplied by Charles Wilkins (part owner Mammoth Cave) to Archibald McCall (purchasing agent for the du Pont Powder Works) and data gathered from the HAER level survey. Therefore, the damaged pump tower is the one in the Rotunda. This presented a major engineering problem in the cave. Without gravity feed from the Rotunda, leachate could not be drained out to the cave entrance. Because the discharge port in the holding tank would have been lower that the pipeline elevation at the entrance gate (Figure 33).

The beer pipe at the gate was not found at the time of the HAER survey. It has since been excavated and is visible immediately inside the gate, to the right near the cave wall.

Reinterpretation of pioneer saltpetre artifacts in the Rotunda presented clues as to how the drainage problem was solved. by building a taller pump tower around the existing small pump tower and by installing a second pump of short length the drainage to the entrance was once again established (Figure 33). All that remains of this double tandem pump tower are two legs, averaging twenty-three and one half feet long and a six and one half feet long pump column section.

Duane DePaepe (1975, p. 68) conjectured that these large square-cut timbers were once part of the entrance pump tower. They may have been transported into the Rotunda during commercialization. The high degree of dry rot on these timbers lead DePaepe to believe they had been part of the entrance pump tower. These timbers have been in physical contact with the cave soils. This condition is enough to promote dry rot. See for example the dry rotted wood walls in any of the Mammoth Cave saltpetre hoppers.

Part of a hollow pump log is found across from the Corkscrew in Broadway. The lower pump body is about six and a half feet long and is thought to represent the segment below the pump handle and valve section.

Legs from the taller pump tower have mortises located about four feet below the top. The mortises probably represent joist positions for a platform. The discharge port from the holding tank on the platform would then be 3.4 feet above the highest pipeline elevation in Houchens Narrows (Figure 33). The top of the tank would be about 0.4 feet above the pipeline at the Gate.

Thor Borrensen's (1942, p. 5) description of Booth's Amphitheatre processing center says that the air chamber below the rectangular hoppers "was also used for the placing of supports if the bottoms of the vats become weakened. There are several thus repaired or reinforced." Structural support consists of vertical logs placed around the inside perimeter directly below where the floor boards join the wall joist. The floor boards sit on a 2 1/2-inch wide shoulder cut into the wooden wall joist. He is referring to Vats Number 1 and 2 (Mullins, 1986, Plate 5-12). They may be the ones that were reported (McCall, 1812) as being "thrown down" and later repaired after the first earthquake. The rectangular hoppers are constructed on a high foundation of dry, stone-laid masonry. These stone walls could have collapsed or shock rebounded. The earthquake could have sufficed to move the floor boards out of the shoulder cut, thereby plummeting the hopper floor and eight to ten tons of saltpeter earth to the bottom of the air chamber.

Seismographs had not been invented at the time of the 1811-1812 New Madrid quake. By using the Modified Mercalli Intensity Scale, and by comparing frightened human activity in the cave and the reported physical damage (George and O'Dell, in manuscript) gives an estimated Mercalli intensity closer to VIII on the scale.

Arthur N. Palmer (1983) conducted a geophysical gravity survey adjacent to the Rotunda, at the entrances to Broadway and Audubon Avenue. His survey shows unconsolidated sediments to a depth of eighty-two feet. Presence of the saltpetre apron may have been the direct contributor to pump tower and hopper damage. The apron for all practical purposes is classified as artificial fill. Engineered structures built on these deposits fare even less during an earthquake than if built on natural unconsolidated sediments (U. S. Geological Survey, 1990, p. 291-292). The site around the First and Second Hoppers was probably very muddy from leaking pipes, tanks, pumps and wet discarded lixiviated earth. These findings are significant and explains why the damage occurred to the saltpetre machinery in the cave. Stream bed and artificial fill deposits have a tendency to accentuate the transmission of earthquake waves (U. S. Geological Survey, 1990, p. 291; Nuttli, 1973, p. 246; and Keller, 1988, p. 185). Damage to the saltpetre works could have been caused by liquefaction in the saltpetre apron.

Acknowledgements

Many thanks are extended to Mr. Gary A. O'Dell for his help and suggestions in studying the 1811-1812 earthquakes in Mammoth Cave. Mr. Gordon L. Smith provided access to his Mammoth Cave photo archive. The Hagley Museum and Library gave permission to quote from du Pont manuscripts. The National Park Service for permission to study pioneer artifacts in Mammoth Cave. Cave Research Foundation gave field support during the course of this investigation. Mrs. Diana Emerson George took many high quality photographs of the saltpetre artifacts in the cave.

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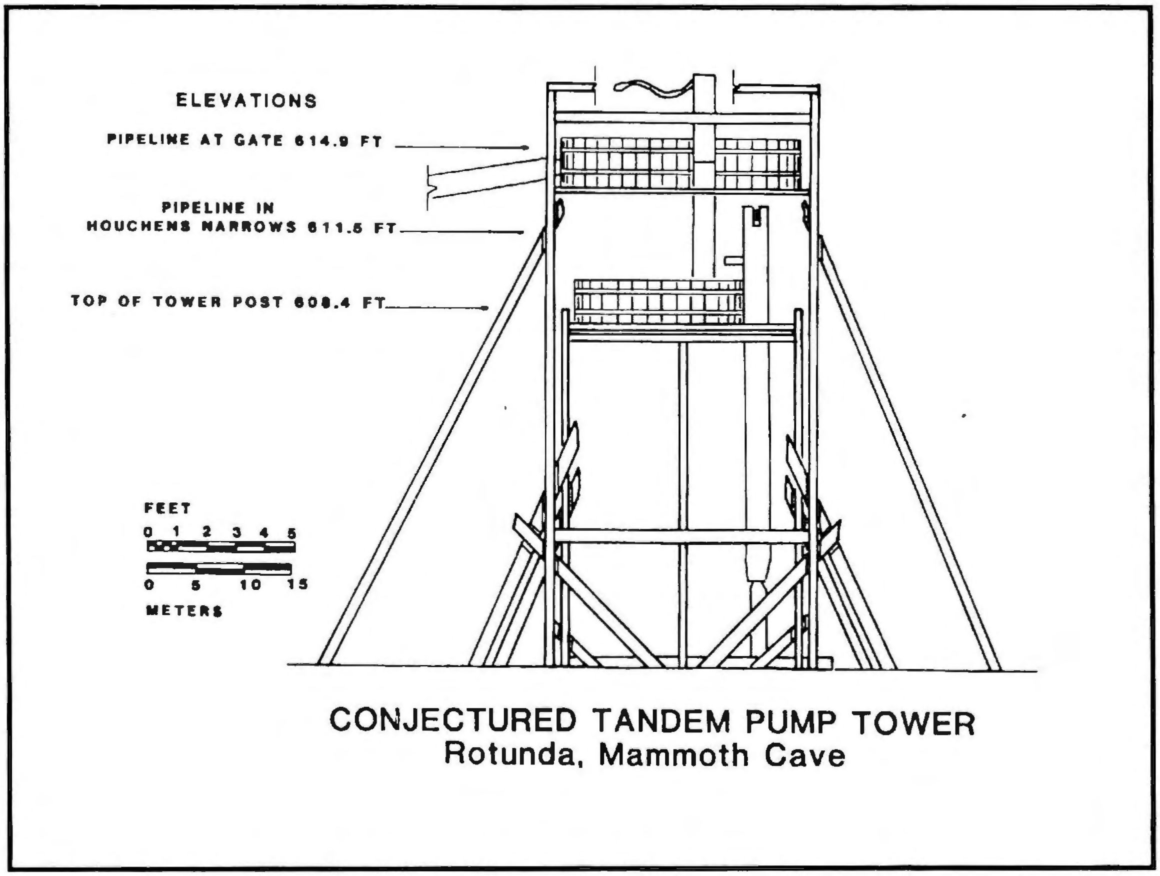

Figure 33: Conjectured tandem pump tower construction in the Rotunda, Mammoth Cave (adapted from Mullins, 1986).

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The Outlook for Reclamation of Hidden River Cave, Hart County, Kentucky

by Julian J. Lewis

The central Kentucky karst encompasses not only the world's most extensive cave system, but also a diverse assortment of cases of groundwater degradation. Examples range from the mild nutrient enrichment crated by the collapse of a wooden staircase into the stream in Cathedral Domes, in Mammoth Cave (Lewis, 1988); sulfur-containing well contamination in Parker Cave, near Park City (Quinlan and Rowe, 1978); and domestic sewage containing creamery waste and heavy metals in Hidden River Cave, Horse (Quinlan and Rowe, 1977).

In these caves the biological response is proportional to the type and quantity of pollutant. In Cathedral Domes, the large, vestigially-eyed troglobitic amphipod *Crangonyx packardi* dominates the community. In streams in the Mammoth Cave area with lesser nutrient levels this species is absent, with isopods typically being the dominant member of the community (Lewis, 1989). In Parker Cave, a thickly matted, microbial community including sulphur oxidizing bacteria is present (Thompson and Olson, 1988). The epitome of pollution cases, however, may be Hidden River Cave.

Groundwater degradation of Hidden River (Figure 34) has been documented in some detail (Quinlan and Rowe, 1977; EPA, 1981). The cave was formerly a tourist attraction famous for its large dome rooms and subterranean river. Problems with groundwater pollution became apparent in the 1920's, with the occurrence of typhoid ending the cave's use as a water source. In 1944, a creamery began discharging waste into the cave, necessitating closing Hidden River as a commercial cave. Subsequently, the Cave City and Horse Cave sewage treatment plants began discharging their effluents into the cave. The Cave City treatment plant received primarily domestic waste, while the Horse Cave plant attempted (mostly unsuccessfully) to treat a mixture of domestic sewage, creamery waste and heavy metals from a plating plant.

Biological reconnaissance of Hidden River starting in 1983 revealed that in the South Branch the troglobitic community had been extirpated. Formerly, Hidden River had been well known for its cavefish population (Bailey, 1933). Two other organisms replaced the troglobites, tubificid "bloodworms" and sewage bacterium. A check of the stream's oxygen level revealed only about one part per million oxygen available (i.e., nearly anaerobic conditions). The stench in the cave was over-powering.

The water quality improved below the confluence of the East Branch of the river with the South Branch. Flowing from under the entrance breakdown (Figure 35), the East Branch contributed water coming from both the Cave City Sewage Treatment Plant and L&N Cave (also in Cave City). However, the water travelled several miles underground prior to reaching Hidden River. In this distance some degree of purification occurred and the dissolved oxygen levels of water flowing from the East Branch were good. The combined waters of the South and East branches flowed a short distance (through a now breached dam) and formed a deep, wall-to-wall pool. In this pool the tubificid worms were present in large numbers along the edges, but the sewage bacteria were no longer present in the quantities seen upstream. Over two dozen large, surface crayfish (*Cambarus*) were present. Their presence was presumably allowed by the reasonable oxygenation of the water, and encouraged by the quantities of worms available for food.

These conditions had probably been present for decades. However, on December 16, 1989, new facilities at the Cave City and Horse Cave sewage treatment plants were dedicated. At this time the effluents from both plants were routed directly to the Green River via pipeline. Both plants have been totally rebuilt, including the installation of modern equipment for primary and secondary sewage treatment.

The question of Hidden River's recovery remains. A visit to examine the stream community after the rerouting of the sewage effluent revealed little change. The sewage community remains in the South Branch, with the stream still having the characteristic appearance of sewage graywater. Prediction? With the reduction of nutrients in the stream the oxygen demand of the water should decline, allowing the dissolved oxygen to rise to levels acceptable to non-sewage organisms. Likewise, heavy metal input has been stopped, but the effect of residuals stored in the substrate is unknown. As the oxygen level increases it would be expected that the South Fork would be invaded by the epigean crayfish abundant downstream. These crayfish have migrated to the very edge of the upstream oxygenated zone created

Figure 34: The polluted stream in the South Branch of Hidden River Cave. The edges of the stream are inhabited by large numbers of tubificid worms. (*Photo by J. Lewis and M. Tilford*)

by the input of the East Branch. This zone is quite distinct (Figure 35) as there is a color change where the graywater meets the cleaner water from the East Branch.

Perhaps the best that can be hoped for will be the establishment of a community similar to that of L&N Cave, an upstream feeder of Hidden River. In L&N Cave the community includes the blind fish *Typhlicthys subterraneus*, the cave crayfish *Orconectes pellucidus*, the troglobitic isopod *Caecidotea bicrenata* and the amphipod *Crangonyx packardi*. An occasional epigean crayfish is present. A brown, presumably microbial, scum occurs on the exposed surfaces of rocks in the stream. This slippery scum alters the habitat of the isopods, which prefer to cling onto the undersurfaces of the rocks. Common elsewhere in Mammoth Cave area caves, the troglobitic isopods can be difficult to find in L&N Cave. The presence of *Caecidotea packardi* also suggests increased nutrient levels, as does the presence of the surface crayfish.

Although the major source of the problems in Hidden River has now been stopped, pollutants are undoubtedly entering both Hidden River and L&N caves from a variety of domestic and agricultural origins. In the final analysis, only time will tell to what degree Hidden River will recover from many decades of severe pollution.

Figure 35. The confluence of the East and South branches of Hidden River, in Hidden River Cave. The East Fork water flows from below the breakdown joining the flow from the South Branch. A distinct line visible in the foreground of the photograph is created at the point where the gray water from the South Branch meets the cleaner water of the East Branch.

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I would like to thank Ms. Marie Tilford for her field assistance at Hidden River and L&N caves.

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CRF Contribution to Blueprint for the Environment

by Sarah Bishop

A coalition of conservation and environmental groups joined forces to present a briefing book on environmental issues to President Bush that they felt he should be aware of and take action on. Sarah Bishop represented CRF in this effort. One recommendation addressed encouraging private sector support of national parks and public participation in park programs and projects. Among others, CRF certainly plays the role of support group for national park research programs and we encourage other groups with similar interests. Another recommendation called for the protection of outstanding Park Service caves under the Wilderness Act.

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Federal Cave Resources Protection Act

by Sarah Bishop

The Federal Cave Resources Protection Act was signed by the President in November, 1988. This law applies to the U. S. Forest Service and all the land management agencies within the Department of the Interior, in particular the National P{ark Service, and the Bureau of Land Management. Throughout 1989 the three agencies most affected by the law (USFS, NPS, BLM) wrote several drafts of regulations in consultation with representatives of the caving community including the Cave Research Foundation.

The purpose of FCRPA is "to secure, protect, and preserve significant caves on Federal lands for the perpetual use, enjoyment, and benefit of all people; and to foster increased cooperation and exchange of information between governmental authorities and those who utilize caves located on Federal lands for scientific, education, or recreational purposes."

The three principal agencies are seeking a way to bring their differing versions of the draft regulations into close similarity with each other before issuing the final regulations.

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U. S. Forest Service Recreation Meeting

by Sarah Bishop

As a representative of CRF and NSS, Sarah Bishop joined members of a number of recreation interest groups in presenting program objectives and opportunities for cooperation to Forest Service recreation managers from all over the country (Figure 36). Among the interests expressed by the forest managers were how to locate and identify significant caves and the need for management and interpretation plans for caves. It was clear these managers were eager to work with anyone knowledgeable about caves and their appropriate use.

Figure 36: Participants exchange management and interpretation ideas at the U. S. Forest Service meeting held in 1988.

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Cave Wilderness

by Sarah Bishop

Toward the end of 1987, interest in designating Lechuguilla Cave a cave wilderness arose in several quarters. At that time, Lechuguilla was an exciting new discovery in Carlsbad Cavern National Park. It was pristine, full of wonderful and amazing sights, and promised to be a big cave to those who would push back its frontiers.

By 1989, cave wilderness designation had become a hot topic. Sarah Bishop, Chair o the NSS/CRF Cave Wilderness Subcommittee, tried to keep a growing list of concerned cavers and others adequately informed about issues arising from many quarters.

Senator Domenici of New Mexico introduced a bill calling for a feasibility study of the cave's management as a wilderness cave versus one made accessible to the average tourist. Senator Bingaman of New Mexico introduced a bill calling for a cave research institute that featured Lechuguilla as a research cave. The Mayor of Carlsbad convened an advisory committee to "report on the current and potential impact of the Lechuguilla Cave on Carlsbad and what steps should be pursued to maximize the benefits of its discovery."

Carlsbad Cavern's management reviewed its position concerning wilderness designation for Lechuguilla and decided that because the cave was within existing wilderness boundaries, it was already a cave wilderness. The question of whether the Congress had contemplated caves when it passed the wilderness Act was set aside. Cavers were happy to support his new position and did so in testimony before Congress on the two cave-related bills as well as before the Mayor's committee. A remaining concern, what happens if the cave should extend beyond the wilderness boundaries, will have to be addressed at a future date.

Because members of the Mayor's committee seemed to favor development of the cave, CRF, NSS and the Lechuguilla Cave Project cavers made several presentations to the committee that focussed on wilderness values. They also presented their view of the economic and logistical difficulties to be overcome should the cave be developed for easier access. In September the committee recommended that Lechuguilla be preserved in its current state and that development of the cave for general use not be considered at that time.

Senator Domenici's bill was amended to authorize "a study of the most appropriate ways to protect and interpret Lechuguilla Cave" as well as other caves in the park. The Senate passed this bill and Senator Bingaman's Cave Research Institute bill in September 1989.

David Jagnow, a CRF member and Chair of the LCP research committee, has assumed the responsibility of following up on Lechuguilla cave wilderness issues. Sarah Bishop will continue to look at other cave wilderness opportunities.

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National Wilderness Management Conference

by Sarah Bishop

In celebration of the 25th anniversary of the passage of the Wilderness Act, a large conference was convened in Minneapolis in September, 1989. Sarah Bishop joined George Huppert, former American Cave Conservation Association President, in presenting a poster session on cave wilderness. A number of conference attenders stopped by the cave wilderness exhibit to inquire about the novel idea. Many were convinced cave wilderness designation had merit. They saw the upcoming review of significant caves on federal lands as an opportunity for designating the most worthy as wilderness areas. A paper about cave wilderness will be published in the conference proceedings.

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Partners in Parks

by Sarah Bishop

In May, 1989, the CRF-sponsored Partners in Parks project became an independent organization. The purpose of Partners is to bring talented people to national parks to work in partnership on exciting projects of national significance. Projects of research or resource management top the organization's list of priorities although opportunities in other areas are also welcome. The success of CRF working in partnership with a number of national parks prompted Sarah Bishop, founding Director and President of Partners in Parks, to launch the organization. Surely parks with features other than caves could attract the interest and support of special interest groups. Partners in Parks seeks to play the broker role in establishing such partnerships.

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Commission on Research and Resource Management Policy in the National Park Service

by Sarah Bishop

After a year of deliberations, the National Parks and Conservation Association's Commission on Research and Resource Management Policy in the National Park Service presented its report. Titled, *National Parks: From Vignettes to a Global View,* it called for "action on an unprecedented scale" to apply ecosystem management concepts to parks, bring about a "quantum leap in both the quantity and quality of research" in the parks, achieve a higher degree of professionalization with the National Park Service, and adopt an expanded NPS educational mission to nurture "a conservation ethic among all segments of society, including those traditionally underpresented in park constituencies, in order to lead the nation toward an environmentally sane future." Sarah Bishop, a CRF Director, served as vice-chair of this Commission.

The Cave Research Foundation's partnership with Mammoth Cave National Park was cited in the report as the type of relationship parks should seek to establish to help them accomplish research and resource management goals.

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Speleo-education Seminar

by Sarah Bishop

The organizing committee of the NSS Western Region speleo-education seminar invited Sarah Bishop to speak at their May 1989 banquet. Her topic, "Forging Partnerships in Cave Protection," used four recent events to focus the audience's attention on partnership opportunities.

Senator Domenici's bill to study the most appropriate way to protect and interpret Lechuguilla Cave gives cavers the opportunity to join with the Park Service, conservation organization and others to be sure the standards for protecting Lechuguilla are optimum. Senator Bingaman's bill for a cave research institute at Carlsbad Caverns opens the way for cavers to help shape cave protection standards that are based on sound information gathered from actually working in caves.

A year ago, for first time, about a dozen cave park superintendents met to discuss cave management. They agreed there was much they could learn from each other as well as from the caving community. Park administrators are becoming more aware of the cave management needs and should be more receptive to offers of assistance in cave protection.

Federal land managers need to know more about managing caves. We are their natural partners because of our knowledge and experience. Let us find the opportunities to make lasting partnerships to ensure the protection of caves in this country both for our edification and our enjoyment.

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Tinsley, John C., 1989, Recent sinkhole activity near Lilburn Cave: Talk presented to Western Region Speleoeducational Seminar, Berkeley Tuolumne Camp, vic. Groveland, CA, May.

Special Services and Awards

Bosted, Peter – Recipient of Certificate of Merit from the National Speleological Society for co-authorship of *Atlas of the Great Caves of the World,* published by Cave Books, 1989.

Hill, Carol A.. – Consultant to the Arizona Conservation Project, Inc., to work on the mineralogy of Kartchner Cavern, Kartchner Cavern State Park, Bensen, Arizona.

Lindsley, Karen – Recipient of Certificate of Merit from the National Speleological Society for co-authorship of *Atlas of the Great Caves of the World,* published by Cave Books, 1989.

Watson, Patty Jo – Inducted into the National Academy of Sciences in 1988.

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Cave Books

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

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

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

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

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

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

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

Bibliography of Cave Books Publications to Date

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Carlsbad, Caves & a Camera – by Robert Nymeyer, 1978, (Illus.) 318 p.

Cave Research Foundation: Origins & the First Twelve Years, 1957-1968 – Richard A. Watson (ed.), (Illus.), 495 p.

Cave Research Foundation: 1969-1973 – Richard A. Watson (ed.), (Illus.), 265 p.

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1980 Annual Report – Margaret V. Palmer (ed.), 1981, (Illus.) 51 p.
1981 Annual Report – Karen B. Lindsley (ed.), 1984, (Illus.) 55 p.
1982 Annual Report – Margaret V. Palmer (ed.), 1984, (Illus.) 45 p.
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Cave Research Foundation Personnel Manual (3rd ed.) – Diana O. Daunt-Mergens (ed.), (Illus.), 176 p.

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CRF Management Structure 1989

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Tom Brucker
R. Scott House

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Annual Report Editor .... Karen Lindsley

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Finance and Supply Coordinator .... Bill Ziegler
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Science Officer .... Dave Jagnow
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Manager .... Robert G. Babb, James Hardy
Hooter editor .... Barabara amEnde

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

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

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

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

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

Roger E. McClure, *Chairman*
Thomas A. Brucker
Karen Lindsley
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