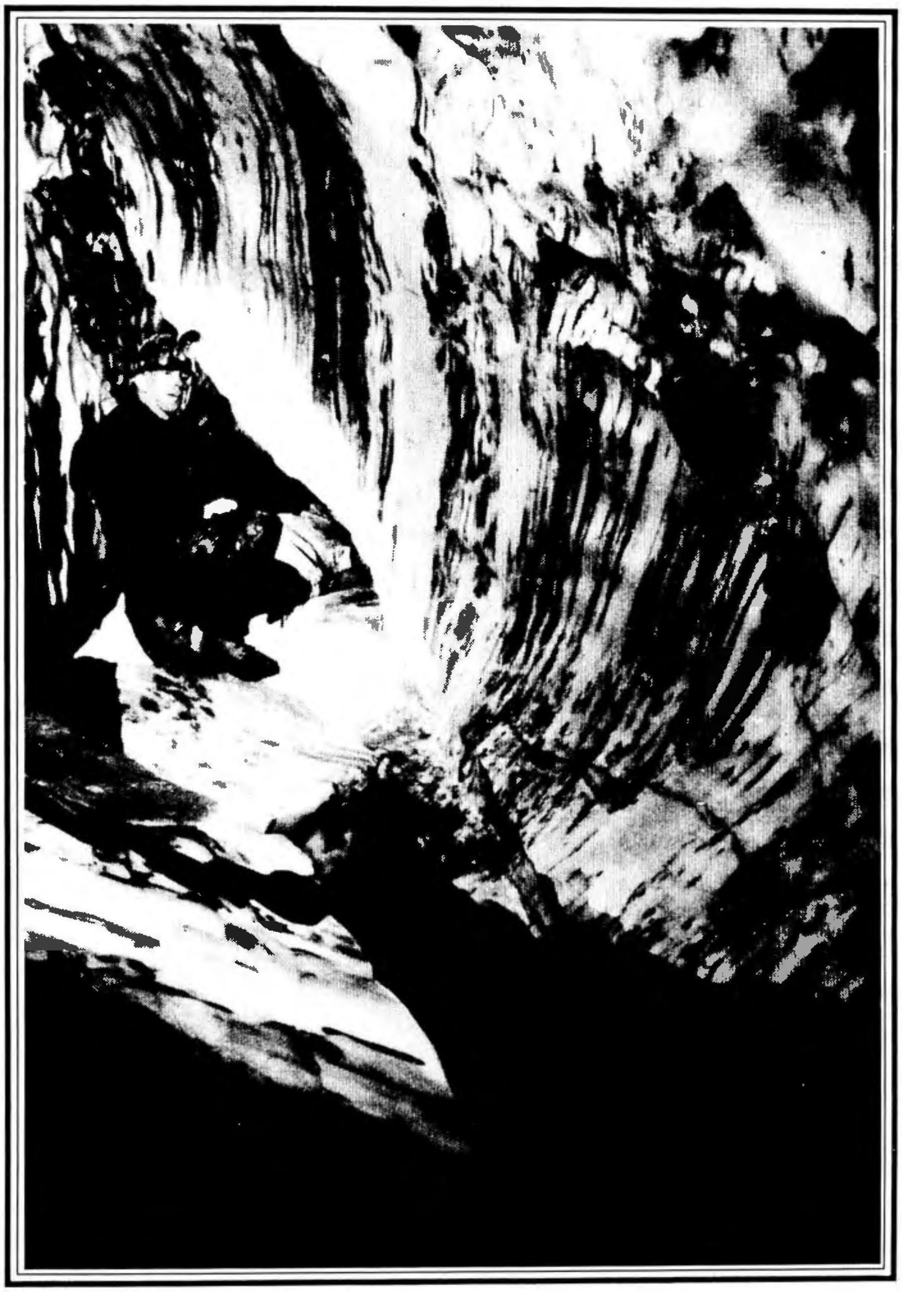
1987 ANNUAL REPORT



CAVE RESEARCH FOUNDATION

Cave Research Foundation
Annual Report
for 1987

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

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

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Karen Bradley Lindsley

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Cover Photo: CRF Treasurer Roger McClure gets a close-up look at the spectacular banded marble found in Lilburn Cave, Kings Canyon National Park, California. *Photo by Pete Lindsley.*

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CAVE CONSERVATION

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

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 Also, many of the processes that formed the cave passages we travel are no longer active in these areas.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

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

CAVE RESEARCH FOUNDATION DIRECTORS

1987

Highlights of 1987

More than 10 proposals were received in 1987 in application to the Karst Research Fellowship program. The Fellowship, which exists to support scientific studies related to karst areas anywhere in the world, awards an annual stipend and provides limited field support and housing in the central Kentucky, Guadalupe Escarpment and Kings Canyon karst areas. The Foundation was pleased to award a total of $7900 during 1987 to Fellowship recipients.

The Foundation submitted two proposals on karst areas to the National Natural Landmarks Program. The primary purpose of this program, which is designed to identify unique areas and features that can qualify as a natural landmark, is to offer long range protection of the resource. Another area in which the Foundation contributed was support of the concept of an underground wilderness for Lechuguilla Cave located in Carlsbad Cavern National Park.

Restoration field camps at Carlsbad Cavern continue to be very popular and show excellent cooperation between the National Park Service, the National Speleological Society and the Cave Research Foundation.

A new area that is reported on in this Annual Report is CRF's project in Missouri. During 1987 the Foundation formalized support of a CRF-Missouri Project which is working in conjunction with the Missouri Speleological Survey and the Missouri Geological Survey. The Missouri Speleological Survey, which has been in existence for more than 30 years, has surveyed approximately 2000 caves.

The Directors held their first California Board meeting in October in the town of Fresno. Following the adjournment of the business meeting, many of the Directors attended an expedition at Lilburn Cave in Kings Canyon National Park (see cover photo).

For 1988, a major foreign caving expedition will be fielded under the leadership of Ron Bridgemon. Approximately 12 expedition members from the U. S. will make an investigative trip to China with emphasis on cartography, scientific observations and good will. This will join with several team members from the Institute of Karst Geology in Guilin, China.

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SCIENCE PROGRAMS

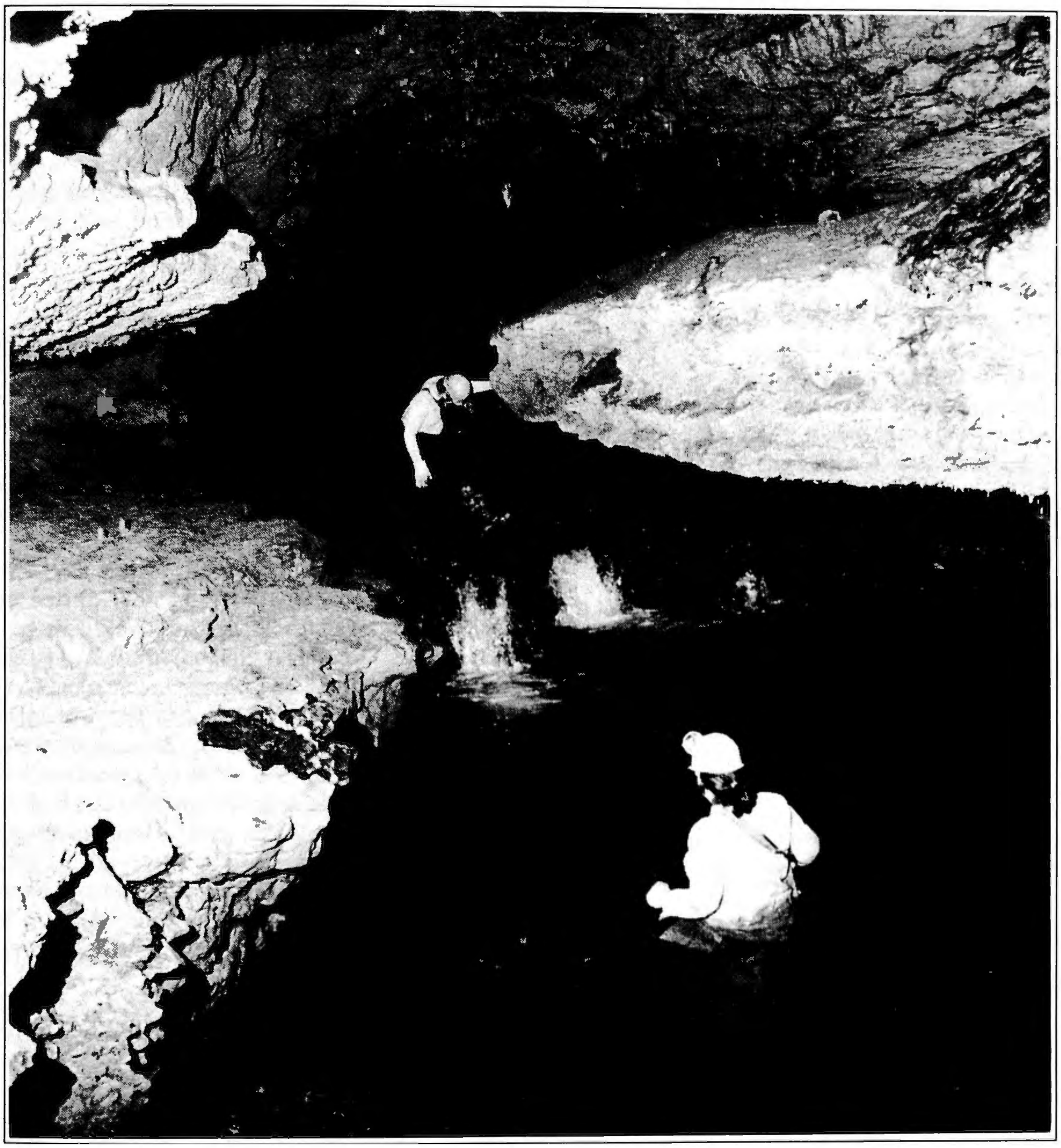

Figure 1: Surveyors working in Powder Mill Creek Cave, Missouri (*Photo courtesy of Jim McCarty and the Rural Missouri newspaper.*)

CARTOGRAPHY PROGRAM

Mammoth Cave National Park Survey and Cartography

R. Scott House

Field Work

Field work has gone ahead in several areas. Much resurvey and considerable amounts of new survey have been done in support of the new 1:600 maps of Mammoth Cave, our highest priority. Maps in progress in Mammoth Cave are Cathedral Domes, Cleaveland Avenue, Kentucky Avenue, Frozen Niagara, and Main Cave. Fair amounts of new passage have turned up in several of these areas as data is rechecked and new leads are pushed. In Flint Ridge field work has concentrated on Unknown Cave where five 1:600 sheets are in progress. A loop through the Unknown entrance was established which has allowed us to close a large surface-subsurface loop and establish permanent coordinates for the area. Resurvey work has uncovered new passages in the Ralph Stone - Ingalls Way area giving us a new picture of that complex area. A new passage, Burns Boulevard, was found to connect Swinnerton Avenue with Gravel Avenue through more than a thousand feet of passage. Additional work has been done in the Pohl Avenue area; most of this has been sketch enhancements and clinometer surveys in an attempt to bring old surveys up to new standards. Work has continued in Crystal Cave; both the tour trails and the Overlook area have been the subject of much resurvey and resketching. Work was begun on updating the Ruth's Room and Gallery areas; careful resurveys has turned up bits and pieces of new passage and several good lower level leads have been located. As a continuation of the new mapping effort, a new survey of the Northwest Passage was begun.

Additional survey work has been done in the Fritsch Avenue section of the Hawkins/Logsdon River area. Passages in this region extend under Toohey Ridge and may lead to more extensive sections. Two sheets at a scale of 1:600 are already underway; plans are for a new series of maps at that scale that will cover the entire river area. Efforts are being coordinated with the Central Kentucky Karst Coalition in order to facilitate large loop closures and provide for continuing cooperation in an important area.

Continuing efforts in Smith Valley Cave have focused on areas that may lead toward Whigpistle Cave; some new passages have been found. Several smaller caves in the park have been mapped as a joint effort of the cartography and small caves inventory programs. Some of the smaller caves were surveyed long ago and are just now being reduced and drawn up in final form. To insure that all of these meet present sketch standards a team is sent out to field check the draft map and do additional survey and/or resketching as is necessary.

Data Managing and Processing

Much progress has been made toward enhancing our user-friendly data reduction program, Cave Recorder. The Apple][program was written, by Eric Compas, originally for DOS 3.3. A considerable number of enhancements have been made to the program and Eric is now rewriting the program to support ProDOS, Apple's newer preferred disk operating system. A hierarchy of file types is being designed with data interchange in mind for the future. Eventually we foresee a massive pair of ProDOS data files: one with the survey data in it and a complementing file with the stored coordinates in it. A need still exists to access the large amount of survey that was typed in on the old CP/M system. We will either convert that data to Apple format or rewrite the CP/M program to work properly. Stan, David, and Steve Sides have converted Cave Recorder to Microsoft Basic, expanding the use of the program to Macintosh computers. Bob Osburn has designed a data reduction template for use with Lotus 1-2-3 and compatible programs for MS-DOS machines which will hopefully allow more people to be able to reduce data.

Surface transit surveys on Flint Ridge were done in the early 1970's by John Wilcox and others. These are being reduced and closed by Paul Hauck and will form the survey framework for the Flint Ridge maps. It appears likely that the elevation data done by the original aerial survey may have some problems in it and this may necessitate some level surveying.

Another important step is the use of the Appleworks integrated software to establish a data base for survey books. Eventually we will have all of the CRF books entered in this data base allowing us to easily maintain the surveyed length of the cave or of any of its components and to keep track of where copies of the survey books are.

To further this data management the Foundation has purchased computer equipment to supplement privately owned equipment. Our cartographers now have access to: 1 64K Apple IIE, 2 128K Apple IIC's, and 2 512K Apple IIGS's. We anticipate increasing the memory on at least three of these computers to match future needs. Eventually we hope to have a 20-40MB hard disk for storing the entire survey net. In addition, we have acquired a photocopy machine for copying all survey books. We plan on keeping the originals filed in one location and the copies at other locations for use by cartographers. Copies not in immediate use will be bound and filed by area for ease of future use.

There is a need to establish a central map repository and duplication service to facilitate the purchase and use of our various maps that have been produced over the years. This is a high priority and we hope to have such a service established within the year.

Drafting

Considering the problems of data reduction, map drafting is proceeding at a very good pace. Pencil-on-mylar drafts of Kentucky Avenue (by Michael Sutton), Cathedral Domes, and Frozen Niagara (both by Scott House) are well along. The Cleaveland Avenue base map (by Douglas Baker) will be converted from paper to mylar within the coming year and work on it will continue. The Cathedral Domes and Kentucky Avenue tour trail maps should be completed within the early months of 1988. A new version of the Frozen Niagara trail map is planned but remains a low priority at this time. All of the Unknown Cave area sheets are still on paper awaiting a final division scheme based on closure data from the Unknown/Austin loop. Once that is finalized then a veritable explosion of drafting will occur in that area. These maps are being drafted by Scott House, Michael Sutton, and Paul Hauck. Maps of the Hawkins River/ Fritsch Avenue area are at last under way (by Bob Osburn) and will initially be done on paper until the coordinate system can be extended to that area. Art Palmer reports good progress on his map of Crystal Cave.

Several smaller caves have been drafted and lettered. A large number of small caves have either been surveyed or are in drafting progress and will probably be finished in 1988.

Coming Efforts

During 1988 we will be working on several new maps as well as finishing up several others. We will expand our coverage of the trails by beginning to draft these maps in Mammoth Ridge: Main Cave, Marion Avenue, and Rhoda's Arcade. It is possible that field work will begin on the Historic and Echo River routes as well. We also anticipate beginning maps of the Bishop's Dome and Cocklebur Avenue areas. In Flint Ridge we plan on getting much of Unknown Cave caught up before we move to other areas. We anticipate continuing to produce small cave maps. A new map of Running Branch Cave has been started, Moonshine Cave is well on its way to being finished, and several other small caves have had the drafting process begun on them. It seems likely that we will start a resurvey of Long's Cave during the coming year.

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Missouri Cave Survey and Inventory

R. Scott House

Cave survey and inventory has been conducted under various operating agreements on state and federal lands in Missouri since 1980. It will be continuing as a joint project of the Cave Research Foundation and the Missouri Speleological Survey. All maps and data created by the projects are reposited with the Missouri Geologic Survey which provides curatorial and reproduction services.

Missouri has many areas of karst development. Much of the southern part of the state has deep karst systems. The input points for these systems are usually buried beneath many feet of chert and clay residuum. The giant active spring systems of the Ozarks are very deep; Blue Spring along the Current River has been explored to a depth of over three hundred feet. Air filled cave systems represent an earlier stage (or stages) of cave development. The longest caves are those which are in a state of transition from water filled to air filled. Although these caves frequently have long sections requiring wet suits they rarely flash-flood because of the discreet nature of the recharge points.

Ozark National Scenic Riverways

Within this 80,000 acre linear park there are nearly 280 known cave entrances. Most lead into caves that are less than 100' long; others lead into extensive caves as long as four miles. The ongoing survey project continues to identify and map all caves irregardless of length. Many of the caves are heavily visited by canoeists who can see the entrances (Figure 2) from the Current or Jacks Fork Rivers. This has created several management concerns: some of the concerns deal with safety but most of them deal with protecting the resource. Many of the caves

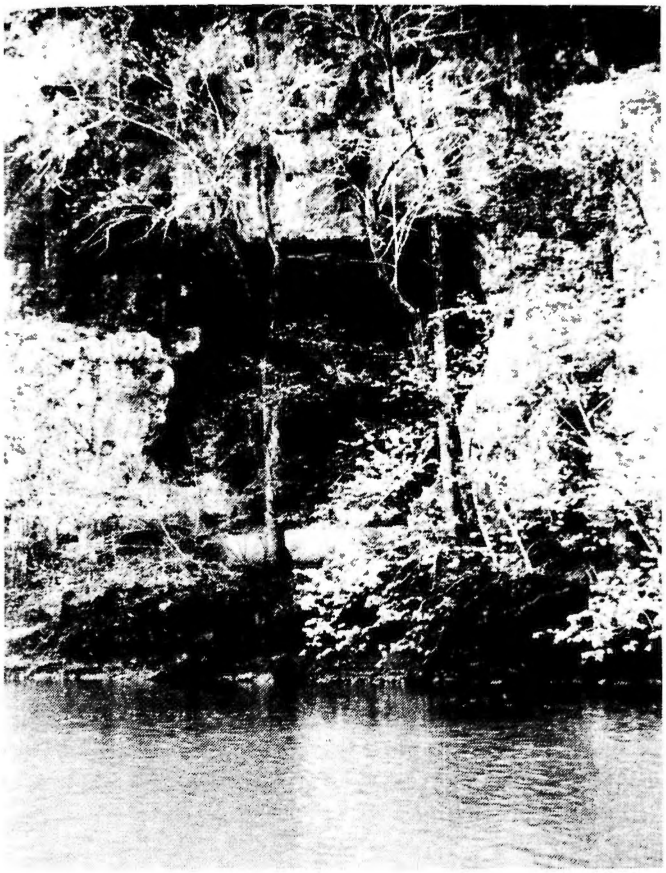

Figure 2: Entrance to Courthouse Cave. This entrance is typical of those that can be observed from the rivers.

exhibit spectacular speleothem development, several are critical habitat for gray and Indiana bats as well as blind cave fish and crayfish, and archaeological and paleontological resources abound.

Since 1980, over 150 caves have been surveyed and drafted. New ideas about the development of caves in the area have been formulated and much vital data has been transmitted to the National Park Service.

Mark Twain National Forest

The Mark Twain National Forest comprises over 1.5 million acres of land, mostly in the Ozark plateau of southern Missouri. Survey work has concentrated on some of the larger caves, generally spring caves, scattered across the southern part of the Forest. Three of these, Still Spring Cave, Turner Mill Spring Cave, and Falling Spring Cave, have been surveyed to over a mile in length. Additionally, numerous smaller caves have been surveyed.

Missouri Department of Conservation

Over the last ten years a number of caves have been purchased and protected by the Missouri Department of Conservation. Generally this is done to protect unusual or excellent biotic systems such as bat maternity caves, blindfish sites, etc. Mapping efforts have concentrated on certain caves that are of prime importance to the Department. Approximately three miles have been mapped in Powder Mill Creek Cave (located within the borders of the Ozark N.S.R.) which is another large Ozark spring cave (Figure 1). Other projects of priority include the completion of the Great Scott Cave survey (approximately two miles long) and Little Scott Cave (less than 1 mile in length.) Other, smaller caves have also been done as time permits.

Missouri Department of Natural Resources

One of the divisions of the DNR is the operation of the state park system; numerous caves lie within those parks. Several of them have been surveyed by MSS and CRF personnel. These efforts are continuing where requested by the state parks. Among the more interesting projects is a large-scale topographical map of Grand Gulf State Park with the caves overlaid on it. Grand Gulf is a deep sinkhole canyon caused by the collapse of an enormous cave. The water from it resurges in Arkansas at the second largest Ozark spring.

Research

In recent years relatively little independent research has been done on the caves of the Ozark Plateau. Most of the work done is under government contract and is usually concerned with the identification and management of the biologic resources. Thus, opportunities abound for researchers interested in a relatively unstudied area. Much can, and should, be done with the geologic relationships between landforms, geologic formations, and cave development. Good facilities are available for researchers, particularly within the Ozark National Scenic Riverways. Interested persons should contact the author.

Personnel

Most of the above survey work has been coordinated and led by Doug Baker, Mick Sutton, and to a lesser degree, Scott House. About fifteen other joint venturers are presently involved to a high degree with these projects. Most of the cartographic work is done by the above three with other work done by Paul Hauck, Eric Compas, Bob Osburn, Jim Kaufmann, and Mark Temple.

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Fitton Cave Survey Project

Pete Lindsley and Gary Schaecher

Field work in Fitton Cave, Arkansas, was de-emphasized in 1987 as efforts concentrated on the cartographic portions of the project. Only three expeditions were fielded with emphasis on clean-up surveys required for completion of the map quadrangles of the major trunk passages. Areas surveyed included Crystal Passage, Grand Central, Millipede and ties to the New Maze area.

Five of the quadrangles were prepared in preliminary draft form and the closure was checked around the major East Passage - Crystal Passage loop. Approximately 2 miles in length, this loop has a closure error of only 0.25%. Gary Schaecher, acting as the Chief Project Cartographer, is coordinating the combination of the work sheets of the various Project Cartographers and is drafting the quadrangles. An additional 4-6 quadrangles are expected to be completed during 1988 with emphasis on Bat Cave (Entrance), portions of the East Passage and Tennouri passage. Other Project Cartographers include Jack Regal, John Brooks, Robert Taylor, and David Hoffman.

A preliminary Project Manager's computer tool and database system is under development by Gary Schaecher. Written using the Omnis 3 development system for the Macintosh, we have been experimenting with the format and user interface as it applies to the Fitton Cave Survey Project. The database can output several survey reports including a list of the X, Y and Z coordinates of each survey station. When combined with graphing programs, a form of a simple cave map is easily obtained. Figure 3 illustrates a typical plan view of the cave at a scale of approximately 1000 feet per inch. A total of 254 survey points is illustrated in this figure which was totally generated on the Macintosh. Figure 4 shows the same dataset displaying X versus Z data for a traditional profile view of the cave. This same concept could be applied for other computer systems. For instance, Lotus 123 on MS/DOS machines and 2020 on VAX machines have the ability to import data (and even generate the data) for a similar data display. Of course such programs would probably choke on a large database (like Mammoth Cave) and other techniques would be more useful.

Interested qualified workers are invited to participate in the Project and should contact the Area Manager, Mr. Gary Schaecher; #17 Oakridge; Maumelle, AR 72118 for additional information.

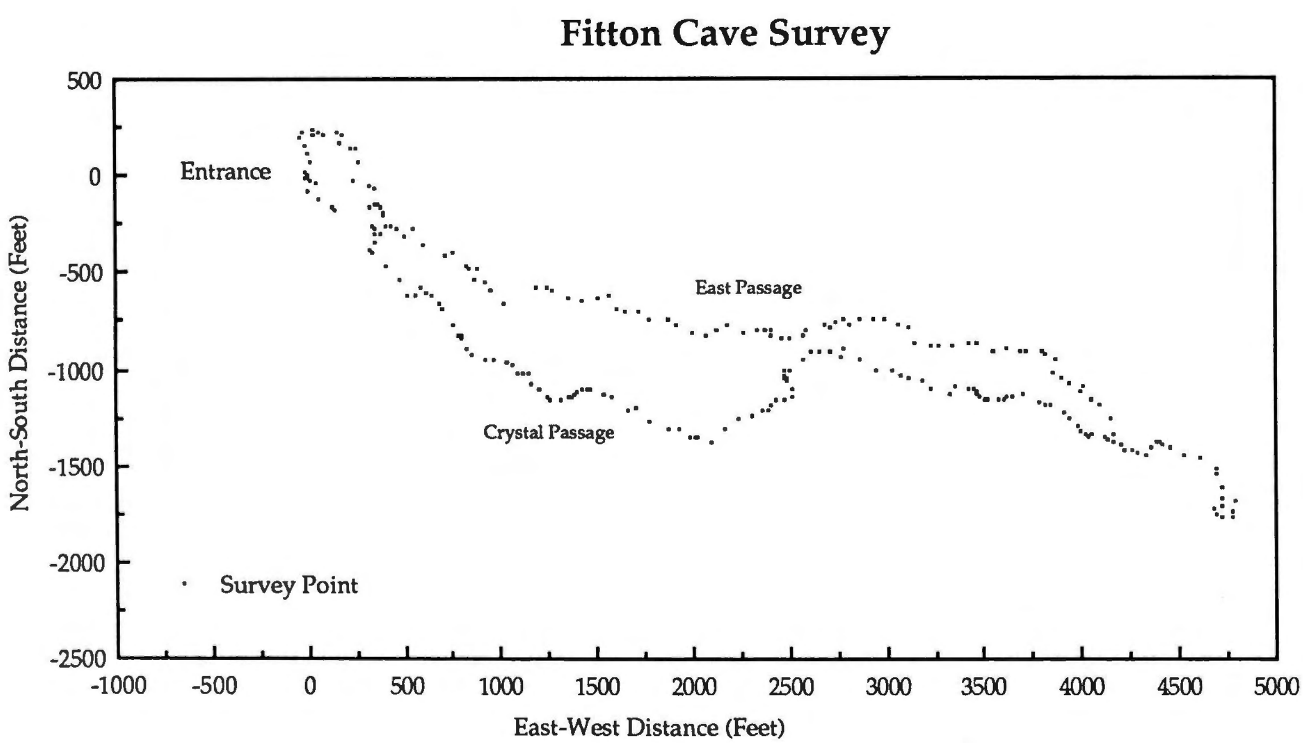

Figure 3: Plan view of Fitton Cave generated on a MacIntosh computer.

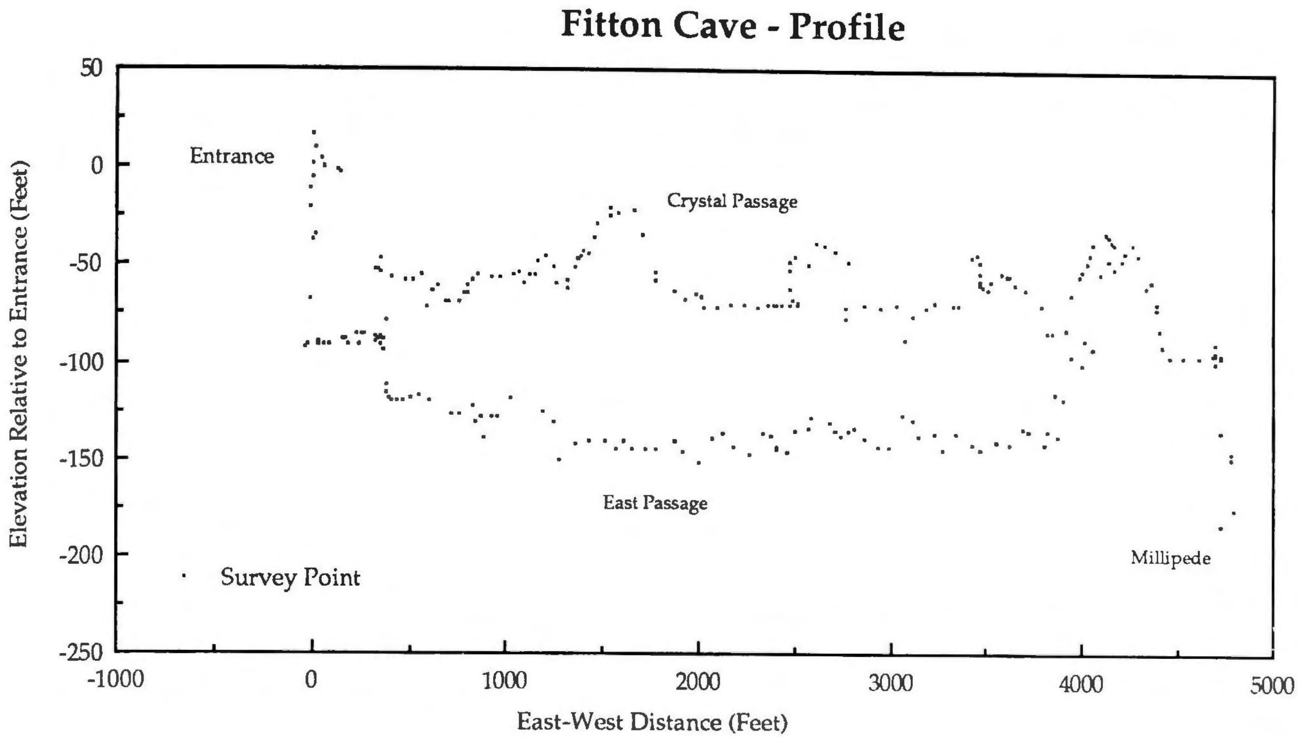

Figure 4: Profile view of Fitton Cave generated on a MacIntosh computer.

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1987 Highlights at Lilburn Cave, California Area

John C. Tinsley

Cartographer Peter Bosted delightedly reports that the surveyed length of Lilburn Cave presently exceeds 9 miles; additional footage from Mays Cave and Cedar Cave surveys accomplished late in 1987 will be processed during Spring of 1988. More than 40 unsurveyed leads, many in the southern portion of the cave system will entice joint venturers who survey this year. Color graphics has come to the Lilburn cartographic program; initial efforts to use the traditional line plots plus passage dimensions noted at each survey station to define passage dimensions, plus coloring the passages to reflect 20 m increments of depth subsurface, produced a striking set of maps that was displayed during the CRF Board of Directors meeting convened in the California area at Fresno and Kings Canyon National Park during October 9-12.

The CRF Board of Directors meeting was an informal but spirited affair organized by Howard Hurtt, Michael Spiess and Pat Witt. Directors arrived on Thursday, conferred Friday and on Saturday morning at the conference room at Spiess' place of business. Evening socials were held chez Spiess and chez Hurtt. Breakfasts were designed to sample the finest Fresno traditions in the style of "American Graffiti", including an overcrowded breakfast restaurant developed around a railroad station theme (waiters and waitresses were armed with ticket punches and carved wooden train whistles, and would perform tonic splendors when approaching your table and when turning in orders to the cooks; the cooks, in turn, would impersonate a schedule-caller a la Grand Central Station, rattling off a long list of placenames. The other delight on Saturday morning was breakfast at a 1950's style diner, replete with surly waitresses and suitable greasy spoons for all concerned—classical American breakfast fare.

Directors then journeyed from Fresno to Grant Grove for the open meeting. Peter and Ann Bosted prepared a marvelous slide show to introduce the splendor of Redwood Canyon and Lilburn Cave to the Directors, using slides gleaned from their collection plus selections from slides by Stan Ulfeldt, Dave DesMarais, John Tinsley, Dave Bunnell, and Gary Mele. Following the meeting and the slide show, a delightful wine-and-cheese luncheon was held under the big trees by the firestation; the affair attracted a contingent of party crashers: a large number of relatively docile but persistent hornets who wished to share in the meat courses. The hornets ate what they wished, but no one was stung. Those persons who were mobile following the luncheon were driven to the trail-head at Redwood Mountain Saddle, saddled with their packs, and pointed down the trail. The field station was reached without incident; the directors soon proved themselves adept with compass, tape and notebook; all conceded that navigation within the 3-d mazes of Lilburn Cave was not immediately obvious.

Overview of Scientific Progress

The hydrochemistry and hydrology studies are poised to take a quantum leap out of the Stone Age. Automated digital recording stations for monitoring the time, duration, and intensity of precipitation (courtesy of Gary Mele) and water stage, electrical conductivity, and temperature should commence this year, using Campbell data logging equipment. The October 1988 through September 1988 water-year would be the first full water year to be thus monitored. A proposal covering this study will be forwarded to the National Park Service in June or July, 1988.

The sedimentology studies continue to bear fruit. Numerous localities of radiocarbon-bearing sediment have been mapped and the sections described. Selected collecting of radiocarbon samples will commence during 1988. Hopefully some measure of time control for the stratigraphy will be obtained during the coming year.

Pygmy type current meters have been procured and calibrated. As a result, in-cave measurements of discharge of tributaries are now being made. Gary Mele's long-contemplated study of modern versus paleo-flow current velocities deduced from flutes and scallops, using the methods of Rane Curl appears ready to commence in earnest.

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Geoscience Programs

Hydroxylapatite Crusts in OSO Cave

James R. Goodbar & Carol A. Hill

Hyroxylapatite, $Ca_5(PO_4)_3(OH)$, has been found as a thin (1-2 mm), light-brown to reddish-brown, crustal floor deposit (Figure 1) in Oso Cave, located in the Guadalupe Mountains, New Mexico. The crust covers the upper surfaces of breakdown and speleothems, but not the lower sides (Goodbar, 1981). At the time of collection (11-28-87) the temperature at the site was 16.4° C and the relative humidity was 89-90% for two separate measurements made with a sling psychrometer. The sample was kept in a closed container and then in a humidified container before x-ray analysis. The five primary d-spacings were found to be 2.815 (100), 2.780 (60), 2.724 (60), 1.846 (40), and 3.462 (40), plus there is a diagnostic line at 8.17 (12) that distinguishes hydroxylapatite from carbonate-hydroxylapatite.

Hydroxylapatite is a common phosphate cave mineral occurring where bat guano comes in contact with limestone bedrock (Hill and Forti, 1986). It most usually forms as light-brown to dark-brown coatings or crusts on floors or on bedrock ledges underneath bat roosts. However, the Oso Cave hyroxylapatite is not associated with significant recent bat guano deposits; perhaps it derived from a small colony of bats that resided in the cave some time in the past.

This is the first confirmed occurrence of hydroxylapatite in any Guadalupe Mountain cave. Similar-looking crusts have been found in Dry Cave (in the Boulder Room and Half Vast Chamber) and, although not yet x-rayed, it is likely that these crusts may also be composed of hydroxylapatite.

References

Goodbar, J. R., 1981, The description and origin of crusts in Oso Cave, New Mexico: unpublished report fulfilling partial requirements for a M. S. degree, University of Kentucky, Bowling Green, 11 p.

Hill, C. A. and Forti, P., 1986, *Cave Minerals of the World*: National Speleological Society, Huntsville, Alabama, 238 p.

Celestite in Carlsbad Cavern

Carol A. Hill

Celestite ($SrSO_4$) crusts have been found associated with gypsum crusts in Pickle Alley, off of Left Hand Tunnel near the junction with the Big Room, Carlsbad Cavern. The crusts occur on the ceiling in two separate patches, one about 2 m^2 and the other about 0.5 m^2. The celestite crystals are a light-blue color, tabular, transparent, and up to 5 mm long. The smaller patch of crystals was first found by John Roth, NPS Cave Specialist, and then, later, the larger patch of crystals was found by Rich Wolfert, Barbara Mende, and Dave Milligan of CRF.

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Hydrogeologic Factors Associated with Recent Doline Development in the Orlando Area, Florida, U.S.A.

William L. Wilson and Barry F. Beck

Abstract

The city of Orlando and its surrounding environs are situated on an active, thickly-mantled, karst area. On the average, 11 dolines collapse each year, and many damage buildings, roads, and other property. Eighty-five percent of the new dolines occur in high recharge areas. Low potentiometric elevations in the limestone aquifer coincide with more frequent doline development. New dolines occur most frequently at sites where the overburden has an intermediate thickness. No statistically significant relationship was found between the location of new dolines and either high or low altitude photo linears.

Introduction

Doline collapse is an infamous natural hazard in the Florida peninsula. The impact has steadily increased as man urbanizes more of Florida's land surface and makes more intensive use of groundwater resources. The purpose of this study was to analyze the causes of doline development in the vicinity of the city of Orlando and to suggest appropriate strategies for developing the groundwater supply without exacerbating the danger of doline collapse. This study was performed for, and funded by, the South Florida Water Management District.

The study area consisted of all of Orange and Seminole Counties, which cover 3,432 km^2 in east-central Florida. Within the area, a number of distinct geomorphic regions may be identified ranging from river lowlands to topographically elevated sandy ridges. All are underlain by a karstified limestone aquifer mantled by unconsolidated sediment. White (1970) and Brooks (1981) described the' physiography of the area. The western side of the study area is dominated by three relict beach and dune ridges that generally exceed 32 m above NGVD. Most of the ancient and recent dolines occur on the ridges. No consistent relationship is apparent between surface topography and the elevation of the underlying limestone (Scott and Hajishafie, 1980).

Doline development in the Orlando area must be considered within the context of two very important hydrogeologic conditions. First, Orlando is a thickly mantled karst area, and second, the area is characterized by a double aquifer system. Typically the area is underlain by 10 to 20 m of undifferentiated Pleistocene sand, 30 to 50 m of Pliocene-Miocene clayey strata, and 450 m of cavernous Eocene limestone and dolomite (Barraclaugh, 1962; Lichtler and others, 1968). The cover is thinnest around the Wekiva swamp (part of the river lowlands), on the central-north side of the area. Numerous springs discharge around the margin of the swamp and the limestone may be exposed in the vents. The cover is thickest in the southeastern part of Orange County, where it exceeds 90 m.

The Pleistocene sand forms an unconfined, surficial aquifer. The water table is typically less than 5 m below ground surface. The Pliocene-Miocene clayey strata form a confining unit above the cavernous limestone. Dolines have perforated the clayey strata at many places. The Eocene limestone and dolomite forms the Floridian Aquifer which is the principle source of potable water for the area. The potentiometric surface of the Floridian Aquifer is usually 6 to 9 m below the elevation of the water table. The slope of the potentiometric surface is generally east or northeast at gradients of 0.13 to 0.95 m/km.

New Doline Characteristics

All of the new dolines in the Orlando area are cover-collapse or, less commonly, cover-subsidence dolines. During the 26 year period from 1961 to 1986, inclusive, 144 newly formed dolines were reported in the Orlando area. The mean diameter and depth of the new dolines was 9.9 m and 4.7 m, respectively. The median diameter and depth was 5.8 m and 3.4 m, respectively. Histograms of new doline dimensions show a distinctly log-normal distribution, with smaller dolines being more common. The largest and most destructive recent doline was the Winter Part Sinkhole which collapsed in May, 1981. It was 91 m in diameter, 30 m deep and caused $4.5 million of damage to roads, homes, commercial buildings, and other property. Recent records, which tend to be more complete, show that approximately 11 new dolines per year develop in the Orlando area.

The areal density of new doline collapse was contoured using a weighted-moving-average technique. Densities ranged from 0 to 0.46 dolines/km^2, for a 25 year period from 1961 to 1985, inlusive (Figure 5). Frequencies range from 0 to 0.018 dolines/km^2/yr. The estimated frequencies are obviously minima, because not all new dolines were reported.

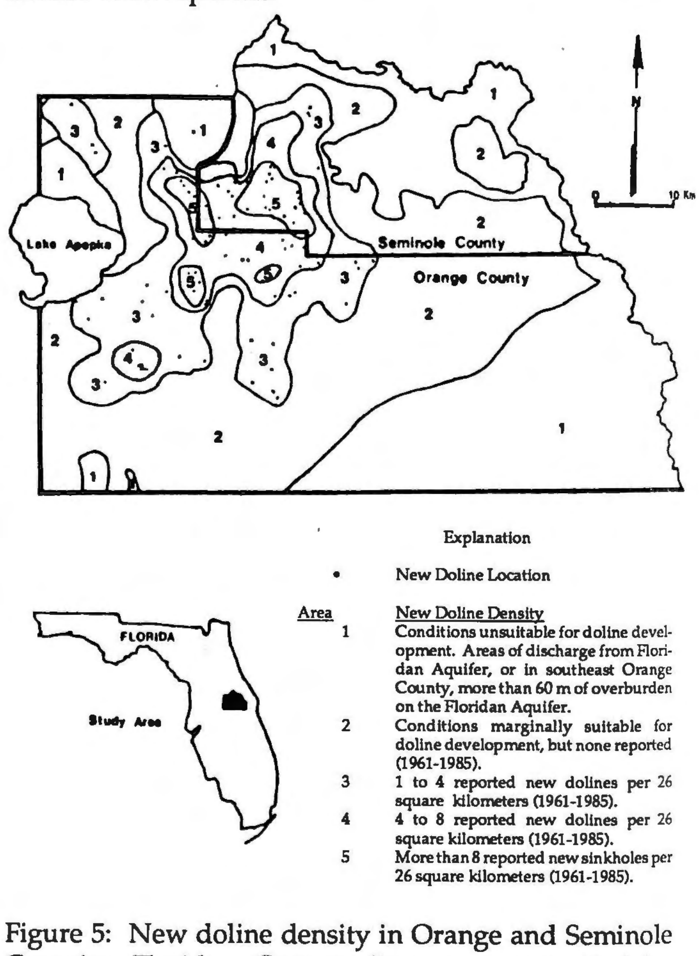

Figure 5: New doline density in Orange and Seminole Counties, Florida. Contour lines are constrained by physiographic regions, and, in southeast Orange County, by cover thickness. At least 144 dolines developed over a 26 year period. The density diveded by 26 years is equal to doline frequency in terms of the minimum number of new dolines per unit area per unit time.

Recharge

Approximately 85% of all new dolines formed in areas of high recharge (>25 cm/yr), even though such areas covered only 31% of the study area. Recharge areas were mapped by Lichtler and others (1968) and Tibbals (1975). Six percent of the dolines occur in areas of moderate recharge (8-25 cm/yr) which cover 7% of the area. Only 9% of the new dolines occur in poor recharge areas (<8 cm/yr) which cover 62% of the area. The high recharge areas are generally ridges in the central or western part of the study area (Figure 6). The downward flow of infiltrating water (i.e., recharge), through breaks in the confining layer, erodes the overburden sediment and transports it downward into karstic openings in the limestone. Thus, areas of high recharge are more prone to doline collapse.

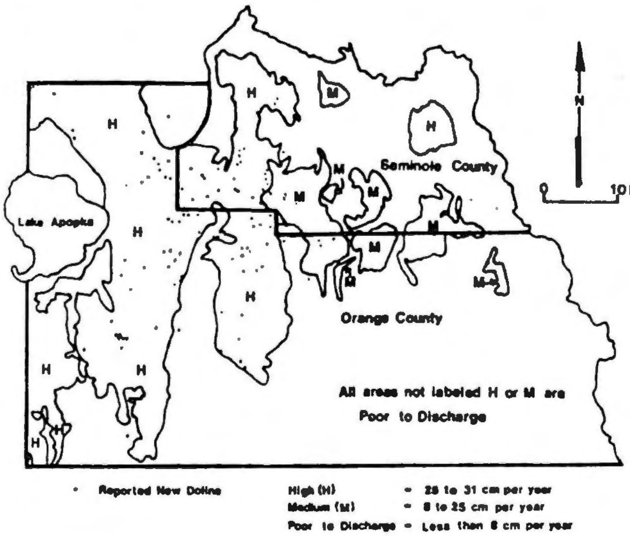

Figure 6: New dolines occur dominately in elevated sandy, high recharge areas in Orange and Seminole Counties, Florida. The city of Orlando is located in north-central Orange County in the high recharge area.

Overburden Thickness

In the Orlando area, new dolines have occurred at sites where overburden thickness ranged from 1 to 63 m, with a mean of 37 m. The frequency distribution of overburden thickness was compared between high recharge areas which had experienced doline collapse and similar areas which had not. Square cells, 3.2 km x 3.2 km, were used for comparison. New dolines form more frequently in cells where overburden thickness is 27 to 47 m. They are less common in areas of both thicker and thinner cover. In the study area, thin overburden corresponds with areas of poor recharge or even discharge. Thus, there is little downward flow of water to initiate doline collapse. Areas of thicker cover occur downdip to the east. It is apparent throughout the Floridian Peninsula that doline collapse rarely affects the surface in areas of thick cover (>60 m).

Photo Linears

Most previous studies, which have noted a coincidence between dolines and photo linears, have based their conclusions on the distribution of large, ancient dolines visible on topographic maps. Significant data on the locations of recent collapses has rarely been examined, and even more rarely statistically evaluated. The common paradigm is that dolines develop along fractures (joints and faults) and that photo linears are expressions of fractures; therefore, dolines develop along photo linears.

Using a map of photo linears interpreted from Landsat images by the Florida Department of Transportation, the relationship between photo linear density in areas where dolines had recently collapsed and similar areas where none had developed was statistically evaluated. The relationship to photo linear intersections was similarly tested. The density of both high altitude photo linears and high altitude photo linear intersections did not show a statistically significant relationship to areas of doline collapse at the chi-square confidence level of 10%.

A low altitude map was then created from 1:24,000 scale aerial photographs. Again, statistical analyses for photo linear intersections and photo linear density based on 3.2 km x 3.2 km cells, showed no statistically significant relationship to areas of doline collapse. While dolines undoubtedly develop along fractures, not all fractures are evident as photo linears in areas of thick cover. Therefore, the density of photo linears or photo linear intersections is not a valid predator of high sinkhole risk areas.

Potentiometric Levels

Numerous authors have identified groundwater pumpage and lowered potentiometric surfaces as triggers for doline collapse. In Orlando, the greatest proportion of dolines (28%) collapse in the month of May, which coincides with the lowest annual potentiometric levels in the Floridian Aquifer.

The amount of decline required to induce doline development in the Orlando area was investigated by comparing the water level frequency in selected reference wells to the number of new dolines that collapsed during the time the potentiometric surface was at various levels. Typical results from Well OR47, located in an area of frequent doline collapse, are shown in Figure 7. If doline collapse was unrelated to the potentiometric surface level, then the number of dolines occurring at any given level would be proportional to the percent of time the potentiometric surface remained at that level. However,

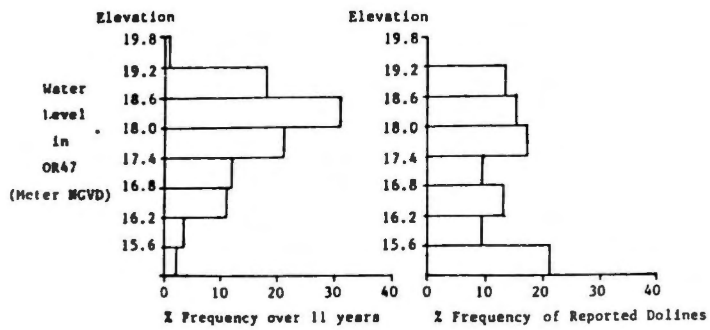

Figure 7: Comparison of water levels in OR47 and frequency of reported noew dolines.

more dolines than expected begin to occur when the level in Well OR47 drops to 16.8 m, a decline of 1.5 m below the mode. At an elevation of 14.1 m, or 3.2 m below the mode, ten times more dolines occur than would be expected during the brief time the potentiometric surface stands at this elevation. That is, 23% of the new dolines occurred during the 2.1% of the time when the water level in OR47 was lowest.

Managing consumptive groundwater use to avoid excessive localized drawdowns in the high recharge areas with appropriate cover thickness would minimize doline development induced by man.

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Water Quality Impacts in Coldwater Cave Related to Agricultural Land Uses

Betty J. Wheeler, E. Calvin Alexander, Jr.
George N. Huppert, Russell S. Adams, Jr.

Introduction

Coldwater Cave, in Winneshiek County, Iowa, is located in a fluvio-karst basin where a well-defined karst topography is expressed at the surface. The cave is an active vadose stream system with a main stream passage. The cave stream resurges at Cold Water Spring. Over 16 km of passages have been surveyed to date. The cave is developed in the Dunleith Formation of the Galena Group. The Galena Group is composed of the Dunleith, the Wise Lake, and the Dubque Formations, all of Ordovician age. These units, which are at the surface or are thinly drift-covered in Winneshiek County, are mostly interbedded limestones and dolomites. Together they form the Galena aquifer, which is the primary domestic and agricultural water source for many people in this region. All formations of the Galena Group are highly jointed. Solutional widening of these joints have provided the impetus for karst development (Hallberg, *et al.*, 1983).

The Coldwater Cave groundwater basin underlies about 30 square miles (78 km^2) of largely arable land in Winneshiek County, Iowa and Fillmore County, Minnesota. This groundwater basin underlies the Pine Creek and the Cold Water Creek surface watersheds. The surface streams are tributaries of the Upper Iowa River, which defines the regional base level and southern boundary of the surface watersheds and the groundwater basin.

The soils in the basin are generally developed on loess and scattered patches of till. This region has been farmed for more than 130 years. Farms are typically 260 acres (150 ha). The major crops, grown under a system of large-scale mechanization, are corn, soybeans, and oats, with about one-fourth of the land in permanent pasture. Small feedlots are scattered throughout the basin. Government incentive programs and crop subsidies, as well as market prices, have been among the forces that influence farming practices.

In the early 1970s the State of Iowa leased the cave site in order to study the feasibility of developing it as a state park. As part of that effort, water chemistry tests were done on the cave waters (Koch and Case, 1974). After two years the State of Iowa allowed the lease to expire, an control reverted to the landowners. The owners will now allow access to the cave by qualified scientists.

Six years of nearly continuous record of the stream level in Cold Water cave exists. Since 1984, this record includes continuous rainfall data (Bounk, 1987). Mike Bounk, of the Iowa Geological Survey Bureau, has generously made these records available for use in evaluation of fluctuatons of chemistry with discharge and in monitoring storm-driven water chemistry changes. A Minnesota Department of Natural Resources State Climatology Office rain station is located in Harmonyhh, Minnesota, 9 km north of the cave within the upper portion of the groundwater basin. Monthly precipitation records from the Haromny rain gauge go back to 1948 an provide an excellent record of the long-term wet/dry cycles within the basin. Daily rainfall records from Harmony extend back to 1973 and can be compared with the rainfall data collected at the cave entrance, to evaluate intrabasinal rainfall variability.

Research to Date

The inorganic chemistry of the water in Coldwater Cave, Winneshick County, Iowa was monitored monthly for 25 months in 1985-1987 to determine the water quality in the cave. Water samples from various upstream tributaries within the cave were collected twice in 1986 and five times in 1987. The chemical data show that the cave waters contain 4.5 to 7.4 ppm of nitrate-nitrogen, but that the tributaries to the main stream have distinct and fluctuating concentrations. The nitrate levels fluctuate in response to storm events, and may be responding to influences such as seasonal changes, wet and dry cycles, and changes in agricultural practices. All of the drinking water in this watershed comes from private domestic wells. The U. S. Department of Health Drinking Water Standard for nitate-nitrogen is established at 10 ppm. The presence in the region of isolated individual wells with nitrate-nitrogen contents of less than 0.1 ppm indicates that the natural level of nitrates in this area is very low. Thus, it is apparent that some man-induced influences have increased the nitrate concentrations to near the drinking water standard.

Eight of the monthly samples were analyzed for a suite of agricultural chemicals. Seven of these samples contained atrazine, a common agricultural herbicide, at the sub-part per billion level. Although the current U. S. EPA drinking water standard of 3 parts per billion (ppb) was not exceeded in any sample, the detectable presence of atrazine indicates that herbicides are reaching the groundwater system. A link between land use an water quality is obviously suggested.

Three quantitative dye traces were conducted in 1986 to define the main sources of water flowing into the upstream end of the cave. Samples were collected at the base of the entrance shaft and at Cold Water Spring, which is the resurgence from the cave. These traces showed that portions of Deer creek, Cold Water Creek, and Pine Creek sink and then contribute water to the water to Coldwater Cave. Travel times in these three traces were less than 8 hours to the sampling station in the cave, and from input points up to 3 km from the cave. A fourth trace in 1987 from a more downstream point on Pine Creek demonstrated that water sinks in that creek and resurges in the downstream end of the cave. Travel time to Cold Water Spring in that trace was about 13 hours. Such direct connections to the cave stream indicate that pollution of the surface steams an have a detrimental effect on the water quality and ecology of this important cave.

Research to Complete

Current research is investigating what, if any, effects on water quality have been caused by modern agricultural land use practices in this karst basin. The hypothesis being tested is that there is a direct relationship between agricultural land use practices and water quality. The following activities are currently underway.

(1) A detailed land use survey was developed and will be sent to all farm operators in the basin asking about land use practices since the mid-1960s. County agricultural and soil conservation experts were interviewed about regional land use practices and problems, and that socio-economic framework in which participation in government assistance programs occurs.

(2) Water samples of the cave water and the two creeks were collected simultaneously for 6 months in 1987. Similar concurrent sampling will be repeated this year during one or two storm events.

(3) The cave water in the main stream an in drips will be sampled during one or two storm events this year to document how such events drive water quality changes in the cave. Background samples of seven drips were collected during the winter to use for comparison.

Partial funding for the 1985-1986 research was received from the Sigma Xi Research Society. The 1985-1986 research was done in conjuntion with similar groundwater studies in the two adjoining basins to the north, which were funded by a grant from the Legislative Commission on Minnesota Resources.

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Relations of the Fluvial System to Karstification: A Progress Report

Jerry R. Miller

Introduction

Geomorphologists once envisioned the arrangement of karst features as chaotic. Recently, however, morphometric investigations have identified statistical relations between the components of karst landscapes (Williams, 1966; 1971; White and White, 1979; 1983). Although complex, these reactions are far from chaotic (Baker, 1973) and tend to suggest that karst landscapes evolve in an orderly fashion which is highly dependent upon the interaction of both surface and subsurface drainage systems. Nonetheless, little is known of the response of fluvial systems to karstification and vice versa. For example, channel form (planimetric configuration, channel pattern, cross-sectional shape,, and gradient) is hypothetically adjusted to sediment type (size and load) and the hydraulic regime of a watershed. Changes in either sediment type or hydrology, initiated by climatic, tectonic, or anthropogentic land-use alterations, will require a change in channel form in order to attain a new equilibrium state (Knighton, 1984; Ritter, 1986). Such morphologic channel response, associated with changes in hydraulic regime and/or sediment type which result from bedrock dissolution, is at best poorly understood. Additionally, few studies have addressed the influence of fluvial system morphology, including basin shape and relief, drainage network characteristics, and channel form, on the magnitude and rates of karstification, and consequently, the formation of karst landforms.

Current Study

In June, 1987, a two-year study was initiated in the fluviokarst of the Crawford Upland, a south-central Indiana, with financial support from the Cave Research Foundation, to examine the interaction of surface and subsurface drainage systems. Primary objectives of this study are to: (1) identify changes in hydraulic regime and sediment type associated with the erosion of clastic cap rocks from a watershed and the progressive exposure of underlying carbonates, (2) create a model (or models) which explains the adjustments of fluvial systems to karstification, (3) determine the influence of drainage basin morphometry and channel form on bedrock dissolution and subsurface stream capture, and (4) better define the interaction of surface and subsurface drainage systems as well as the evolution of fluviokarst.

Data Collection

Since initiation of the study in June, 1987, research has concentrated on the selection of basins for investigation, basin instrumentation, and the collection of morphometric drainage net data. Twelve basins located on the Crawford Upland near Leavenworth, Indiana were selected for study: four are predominantly developed in a clastic terrain, four in a mixed carbonate/clastic terrain, and four in a carbonate-dominated terrain. In order to identify quantitative differences in hydraulic regime and sediment type associated with differing areal quantities of exposed carbonates, basins have been instrumented upstream of defined sinks, downstream of perennial springs and at basin outlets. Instruments, emplaced at a total of 28 sites, include crest stage recorders, continuous suspended sediment traps and rising stage sediment traps. Additionally, 12 of the 28 sites contain bedload traps and 6 sites are instrumented with continuous water-stage recorders. Data is presently and will continue to be collected through June, 1989. In addition to the above data, information pertaining to subsurface flow routes and storage, sediment size in the channel perimeter, and channel form is being collected from the 12 study basins.

Relations of Drainage Net Morphology to Stream Sinks: Preliminary Results

Thirty sub-basins of the Beaver Creek watershed, located in the Crawford Upland approximately 20 km southwest of Bedford and 75 km northwest of Leavenworth, Indiana, were selected for morphometric analysis. All selected streams originate in Pennsylvanian-age clastics and traverse Mississippian-age carbonates in their downstream reaches. Rivers in 15 of the selected sub-basins sink near the clasti-carbonate contact, but rivers in the other 15 sub-basins are surficially integrated with the regional baselevel: Beaver Creek. The distribution of sinking and integrated systems is not systematic; rather they are spatially intermixed throughout the region of fluviokarst. Three morphologic parameters were measured for the 30 sub-basins from USGS 7.5' topographic maps (Table 1).

Discriminant analysis, using Statistical Analysis System (SAS), determined that integrated and sinking stream systems could be differentiated at a 90% confidence interval using the three above morphometric parameters. This limited data set suggests that the more variable, but generally higher drainage densities, stream frequencies, and first order channel frequencies are associated with sinking streams. This promotes channelized runoff and subsurface stream capture. Presumable, the increase in channelized runoff increases the rate of carbonate dissolution beneath master channels and controls the location of incipient karst.

Field reconnaissance suggests that variations in drainage net morphology may correspond to differences in shale distribution within the clastic cap rocks. The variable distribution of sandstone and shale in this region of the Crawford Upland has been noted by Gray and others (1960).

Table 1. Summary of basin morphometric parameters for 15 integrated and 15 sinking streams tributary to Beaver Creek on the Crawford Upland, south-central Indiana.

Integrated Basins					Karst Basins				
Basin No.	Area	DD	Fs	F1	Basin No.	Area	DD	Fs	F1
1	1.27	7.1	33.0	26.0	1	1.55	6.1	32.2	25.2
2	1.13	7.3	32.8	26.6	2	0.43	5.8	27.9	20.9
3	2.2	6.6	33.6	26.4	3	0.35	6.6	25.7	22.9
4	2.64	6.2	30.3	23.1	4	1.34	7.1	39.6	29.1
5	4.48	5.0	24.1	18.1	5	1.75	7.0	36.6	28.6
6	0.81	7.3	38.1	30.9	6	0.82	7.5	37.7	29.3
7	0.96	5.8	27.0	20.8	7	0.82	7.5	37.7	29.3
8	2.51	6.2	25.5	16.8	8	3.07	5.3	25.1	18.2
9	3.33	5.6	22.3	16.8	9	1.90	8.1	45.7	33.2
10	1.24	8.0	29.8	24.2	10	1.90	8.4	56.0	41.1
11	1.70	6.5	32.3	24.1	11	1.41	6.4	35.4	24.1
12	1.11	6.2	31.4	23.4	12	1.94	7.3	38.1	28.9
13	3.08	6.3	31.2	23.1	13	1.14	7.2	35.1	28.1
14	0.93	7.3	32.3	26.9	14	0.56	5.9	32.3	25.0
15	3.27	6.5	35.8	26.3	15	0.37	8.6	54.3	43.2

Drainage Area - km^2
Drainage Density (DD) - km/km^2
Stream Frequuency (Fs) - $\#/km^2$
First Order Stream Frequency (F1) - $\#/km^2$

These relations, coupled with additional geologic and morphometric parameters, are being examined in greater detail in these and other basins of the Crawford Upland including the 12 basins instrumented to obtain sedimentologic and hydrologic data previously described.

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Some Notes About Cueva del Indio, Huila, Colombia

Eliseo Amado González and Ludis del Rosario Morales Alvarez

Parque Nacional Natural Cueva de los Guácharos is located in the Department of Huila, Colombia, at 1° 22′ north latitude, 76°00′ west longitude (Figure 8). The park was established to preserve the caves, primary forest and fauna. The caves in the park include Cueva del Indio, Cueva de los Cuadros, Cueva del Murciélago, Cueva del Hoyo, and Cueva de los Guácharos. Tom Miller[1,2] provided descriptions and compass-and-pace maps of some of these caves. The park is named after the later cave, where the bird *Steatornis caripensis* Humbolt, commonly called a guácharo or oilbird, roosts. The area surrounding the caves is characterized by an annual mean atmospheric precipitation of 2618 mm, relative humidity of 89.3%, and temperature of 16.8° C. Notable plants of the park's dense forest are *Bomarea caldasia* H.B.K., *Cyathea quindiuensis* Karsten (tree fern), and *Quercus humboltii* H.B.K. (white oak). The park serves as a refuge for *Tremarctos ornatus* Cuvier (bald-faced bear), *Dusicyon thous apollinaris* Tate (fox), five species of primates, and 14 species of bats. Over 270 species of birds are reported from the park.

In 1983, we began studying ecological relationships of the spider *Heterophrynus cervinus* Pocock (Amblypygi), as well as its allometric and morphological patterns, in Cueva del Indio.[3,4,5] Our present research focuses on this cave.

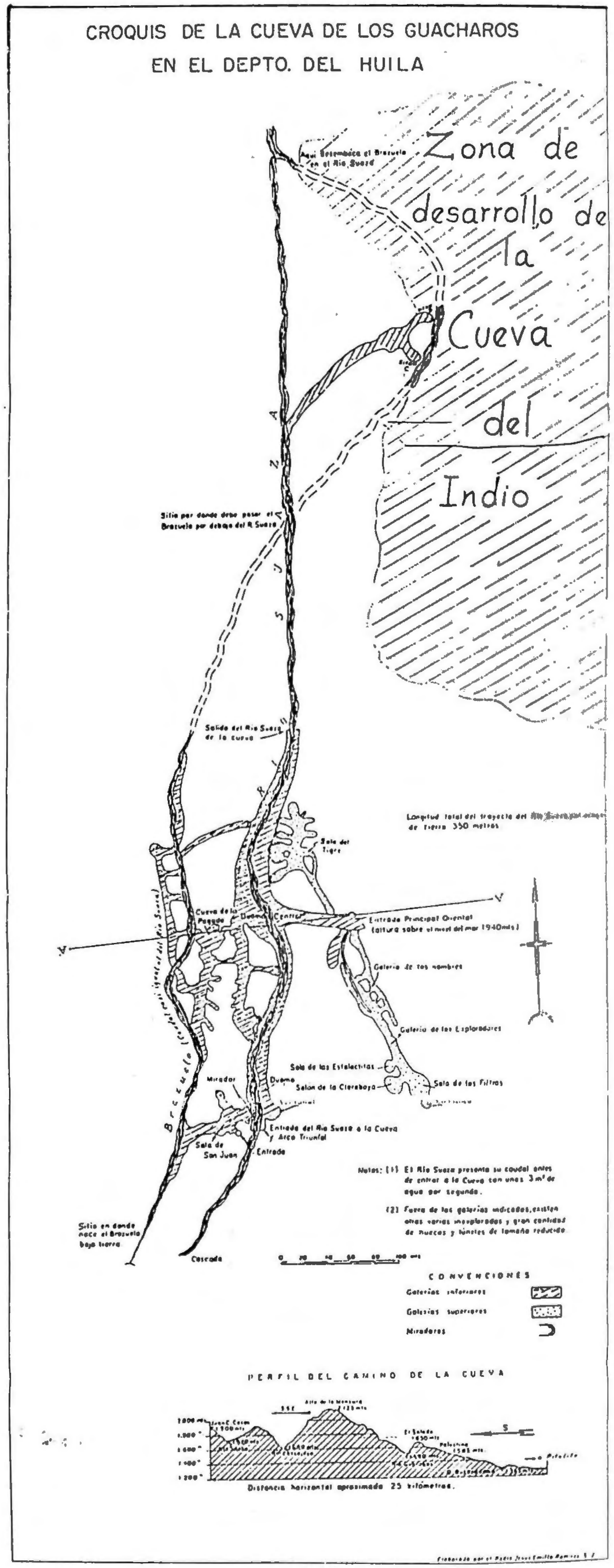

Figure 8: Sketch of Cueva de Los Guacharos located in the Department of Huila, Colombia.

Cueva del Indio is located on a synclinal valley and to the west of the Rio Suaza at an altitude of 1,760 meters above sea level (Figure 9). It is formed in a calcareous rock (70% carbonate, 30% silicate) with fossils of marine shells from the lower Cenomian and upper Albian (approximately 100 million years ago). These fossils more closely resemble those from the Washita (Texas) Formation than others from the eastern Colombian Andes.[6]

Cueva del Indio has 11 passages branching from the principal corridor, which is 760 meters long. It has a surveyed length of 3508 meters with a maximum change in elevation of 150 meters and has seven entrances and two springs with discharges of greater than 1 cubic meter per minute. The cave contains a variety of passageways ranging from large canyons (30 m. wide by 30 m. high) to crawlways (0.5 m.wide by 0.3 m. high). Anastomses, gours, and crystal pools occur at various locations. Speleothems have diverse forms such as stalactites, stalagmites, columns, curtains, shawls, and helictittes.

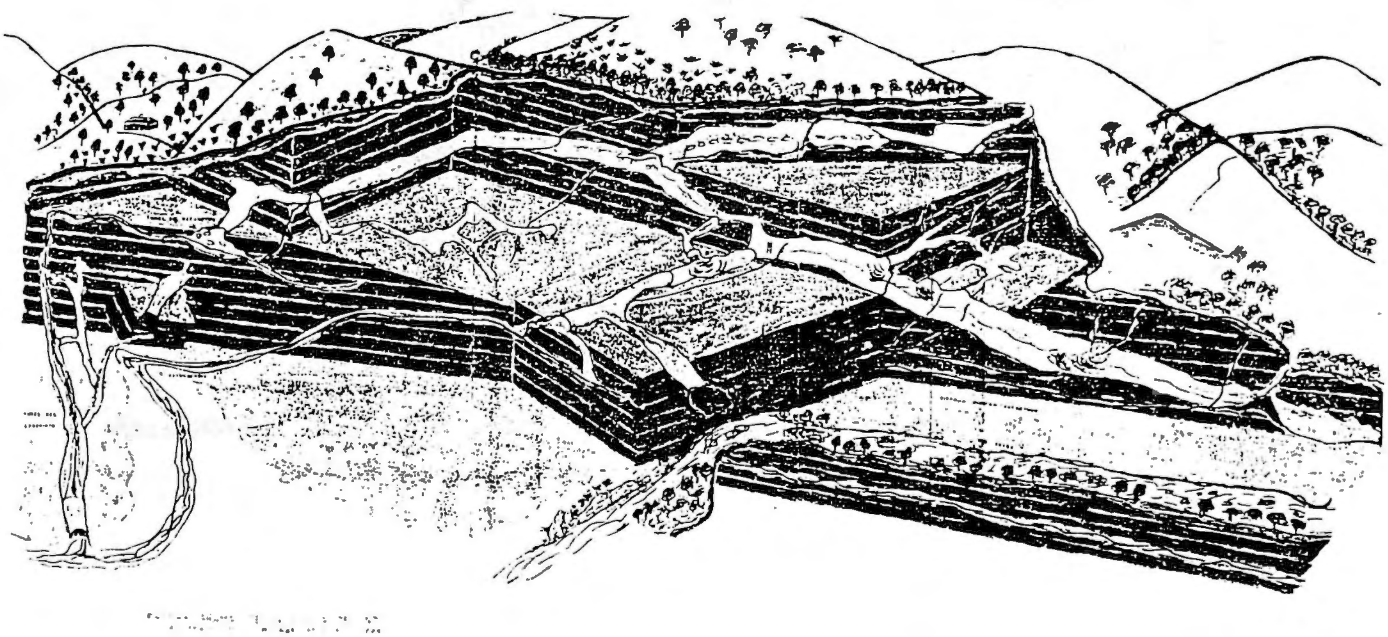

Figure 9: Stereographic view of Cueva del Indio showing topographical and geological characteristics.

The floor of the cave is covered with breakdown throughout the principal passages, gypsum crystals, alluviums, and colluviums coming from the surface with a high organic matter content. Alluviums are composed of 12.5% gravel, 35.5% sand, and 51% clay and silt in Túnel del Apagón and composed of 12% sand and 88% clay and silt in the principal passage at the entrance of Túnel del Decámetro . Glauconitic sands (iron and potassium silicate) are on the floor of the principal passage and slatey, clayey sands are on the floor of Túnel de las Pizarras.

Few streams can be followed within the cave because they quickly disappear into deep sumps. By using fluorescein and rhodamine dyes, we found that two distinct hydrologic systems exist in the present Cuevo del Indio. One is first encountered in Túnel de las Borugas (Figure 10), where vadose streams disappear into small sumps. This water appears at a sump in Túnel del Decametro and then in Túnel de los Laberintos before emerging at the surface as a spring. A second hydrologic system begins in Cueva de los Guácharos, where the Rio Suaza flows through the cave. A secondary stream, flowing at a lower level in this cave, disappears at a sump and then reappears at two sumps in Túnel de las Bóvedas in Cueva del Indio. Finally, this water appears at a separate resurgence near the principal entrance. Water from the two springs join and then flows into the Rio Suaza.

We hope to continue with a further study of the speleogenesis of Cueva del Indio and the influence of Rio Suaza on the formation of the entire system of caves in the park.

We thank the many people have helped with field work in Cueva del Indio and, in particlular, park ranger Guillermo Medina. We sincerely appreciate the help of Dr. Edward Lisowski for teaching us a lot of things about speleology and Mr. Ronald Wilson for his kindness,

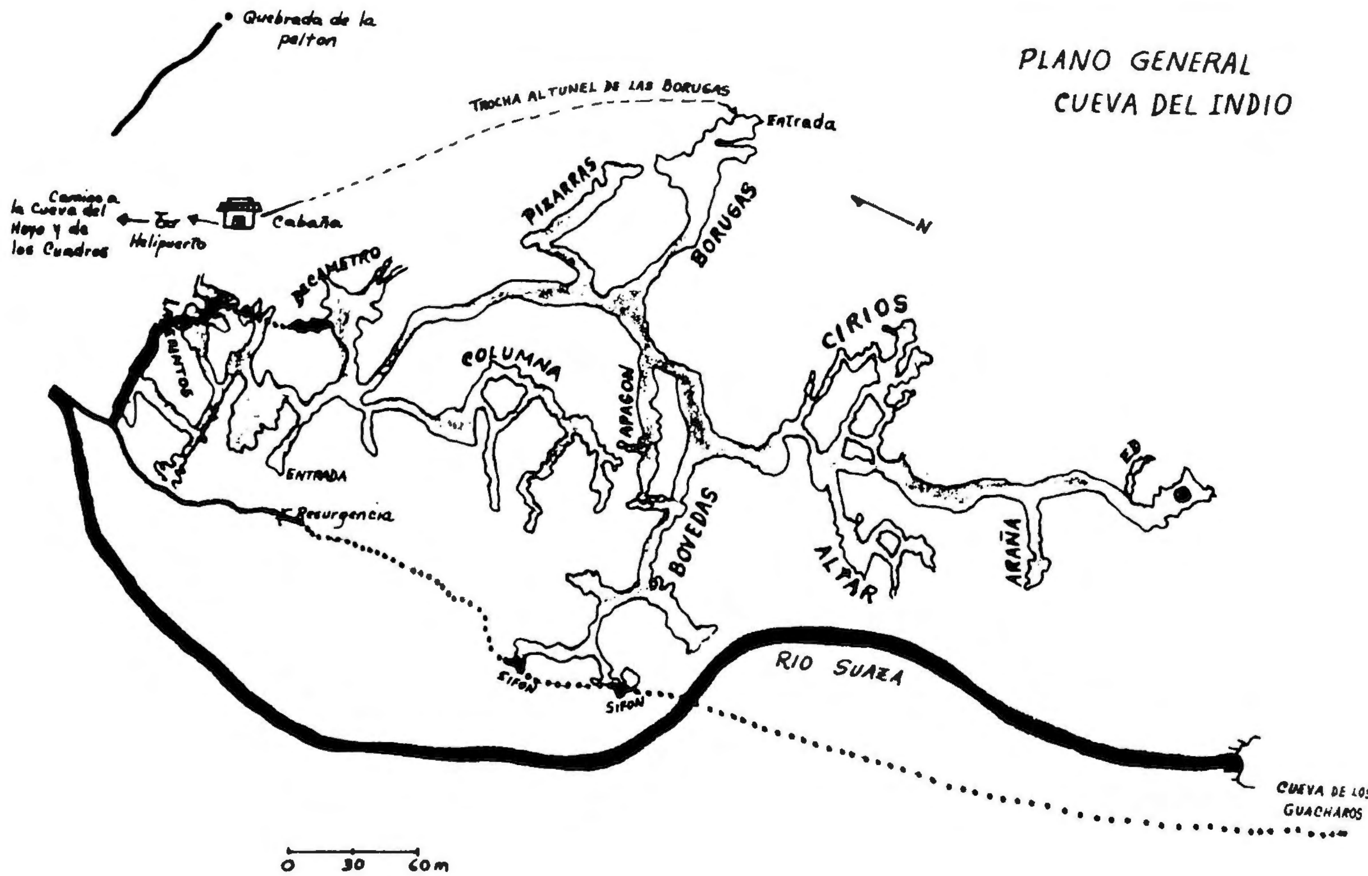

Figure 10: Plan view of Cueva del Indio, Huila, Colombia

advice, and bibliographic data. We also thank Professor Ernest Guhl for his constant interest in our research and for comments on our manuscripts. Brother Daniel González, Museo de la Salle, helped with the flora determinations and provided encouragement. This work was supported by a grant from Fondo para la Protección del Medio Ambiente Jose Celestino Mutis Fen Colombia.

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Geochemical Evolution of a Conduit Cave Stream: Laurel Creek, Monroe County, West Virginia

Christopher G. Groves

Laurel Creek, in Monroe County, West Virginia, drains an area of about 50 km^2 on rock of the Mississippian Mauch Chunk Formation (predominantly shales and sandstones) and the subjacent Greenbrier Group (predominantly limestones). Upon reaching the Greenbrier, the creek flows for about three kilometers upon a bed of quartz alluvium, sinks into the Laurel Creek Cave-Cross

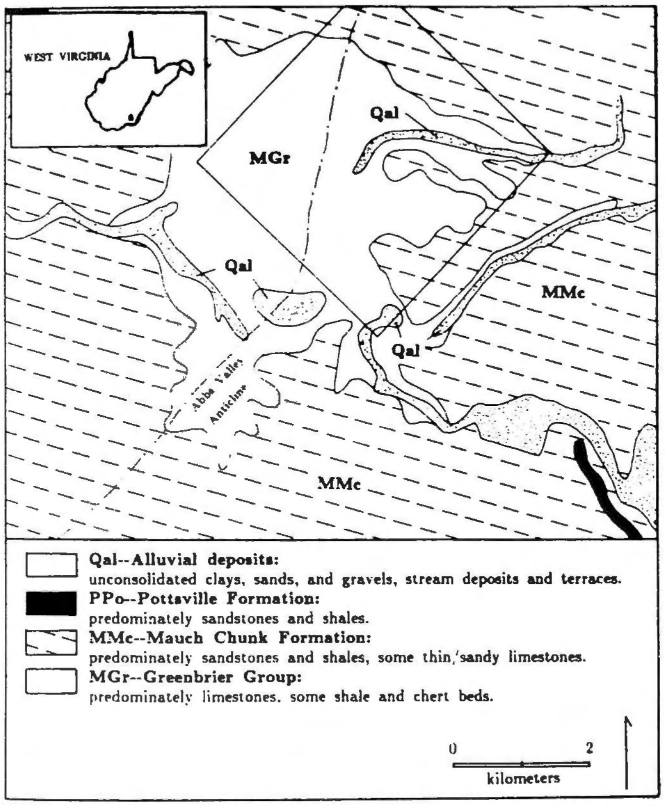

Figure 11: Geology in the vicinity of the study area, after Reger (1926).

Road Cave Drainage System, then resurges after about two kilometers of subsurface flow (Figures 11 and 12). The purpose of this investigation is to study the geochemical changes that occur within Laurel Creek as it flows from the caprock onto the limestones and through the cave system. Specifically, the object of the study are:

1. to determine the point at which Laurel Creek becomes saturated with respect to calcite,
2. to determine the rate of calcite solution as Laurel Creek flows through the cave system, and
3. to determine the rate of enlargement of the cave system.

A mass-balance approach was used in this study in order to gain an understanding of the types and rates of the weathering reactions occurring as Laurel Creek flows off of the caprock and through the cave system. Samples were collected from five locations along Laurel Creek on April 11 and 12, 1987 at locations shown in Figure 12. Samples were taken from the creek 1) at a covered bridge just above the Mauch Chunk/Greenbrier contact, about three kilometers upstream from Laurel Creek Cave, 2) just upstream from the entrance to Laurel Creek Cave, 3) within Laurel Creek Cave, about 250 meters from the

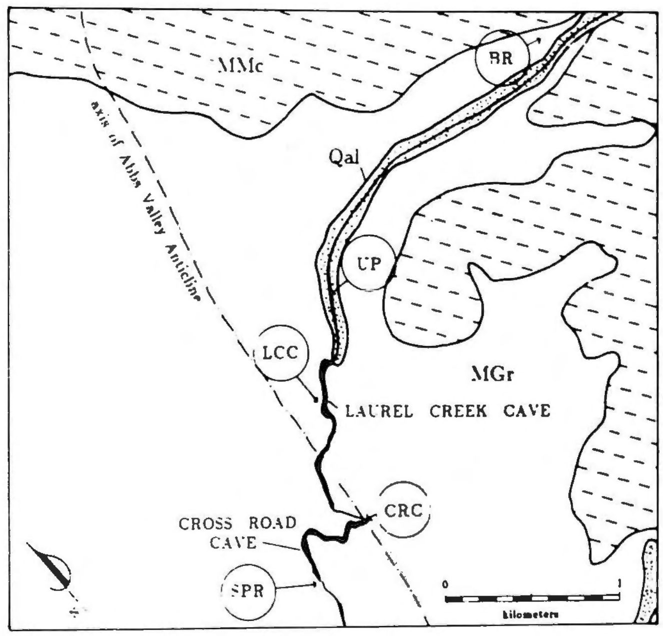

Figure 12: Detailed geology of the study area, showing sample locations. sampling opints are: Br – bridge, UP – upstream from the entrance to Laurel Creek Cave, LCC – Laurel Creek Cave, CRC – Cross Road Cave and SPR – spring below Cross Road Cave. Only high discharge cave stream passages shown.

entrance, 4) within Cross Road Cave, just below the upstream entrance and 5) at the spring below the point where the stream leaves Cross Road Cave.

As as each of the stations, three samples were collected in acid-rinsed, 250 ml bottles: one for alkalinity measurements (preserved with chloroform), and one each for anion and cation analysis. Temperature, conductivity and pH were measured in the field at the time of sample collection. Discharge was measured at the spring with a current meter at the beginning and the end of the sampling period because the creek stage was dropping slowly during the collection period in response to a snow and rain storm (approximately 1.5 inches liquid precipitation) that had occurred during the previous week. A dye trace to measure time-of-travel through the system was conducted using fluorescein dye to provide information for rate calculations. At the bridge and spring, three complete sets of samples were collected for replicate analysis.

Upon return to the lab, all samples were refrigerated. The samples were filtered through a 0.45 µm filter, then acidified with concentrated HNO_3. Alkalinity (bicarbonate) titrations were performed within 36 hours of returning to the lab. Concentrations of calcium, magnesium, sodium and potassium ions were determined on the undiluted, acidified samples using atomic absorption/atomic emission spectrophotometry. NO_3, Silica and SO_4^{2-} were determined by colorimetry.

In order to determine the point at which the stream becomes saturated with calcite, raw data from the analyses were input into the geochemical speciation model WATEQF (Plummer, *et. al.*, 1976). This computer program calculates formation of ion pairs and complexes and activities of all species in solution using thermodynamic calculations. With this information the program is able to calculate the saturation state of the water with respect to solid mineral phases. The saturation index for calcite ($S.I._{calcite}$) is given by:

$$S.I._{calcite} = \log [IAP(T)/K(T)] \qquad (1)$$

where IAP(T) is the ion activity product and K(T) the equilibrium solubility product (at the sample temperature) for the reaction:

$$CaCO_3(s) \rightleftharpoons Ca_2+ + CO_3^{2-} \qquad (2)$$

The value of $S.I._{calcite}$ determines whether the solution is undersaturated (S.I. < 0), supersaturated (S.I. > 0) or in equilibrium (S.I. = 0) with respect to calcite.

Results of analyses are shown in Table 2 and Figures 13 and 14. at a discharge of 1.01 m^3/s, Laurel Creek behaves as follows:

1) Between the Mauch Chunk/Greenbrier contact and the spring, Laurel Creek experiences an increase in pH, conductivity, alkalinity and concentrations of Ca^{++}, Na^{++}, SO_4^{2-}, and NO_3.SiO_2 concentration decreases, and the concentrations of Na^{++} and K^{+}, as well as the mole ratio of Ca^{++}/Mg^{++}, remain relatively constant.

2) Laurel Creek remains undersaturated with respect to calcite throughout the entire section studied.

3) Calcite is dissolved in the Laurel Creek-Cross Road Cave System at a rate of 4.12 mg $l^{-1}hr^{-1}$.

4) The cave system is being enlarged at a rate of 0.41 m^3/day.

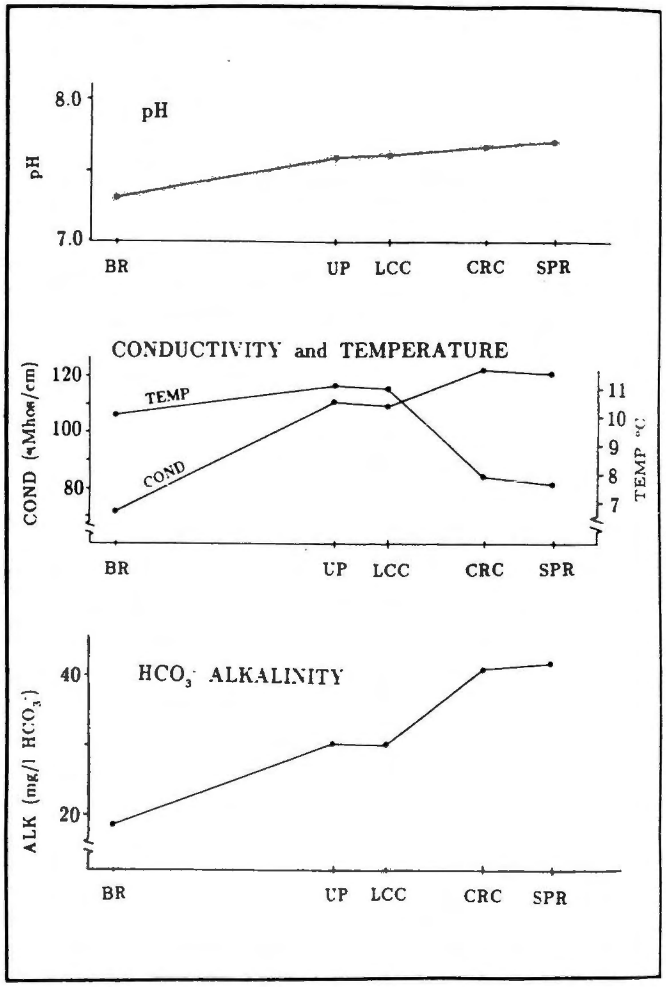

Figure 13: pH, conductivity, temperature and alkalinity. X-axis shows sampling locations.

References

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Table 2: Analysis of data collected at five locations

	BR(s.d.)	UP	LCC	CRC	SPR(s.d.)
Date	4/11	4/11	4/11	4/12	4/12
pH	7.31	7.66	7.61	7.68	7.71
Temp °C	10.2	11.2	11.1	7.8	7.6
conductivity (μMhos/cm @ 25°C)	62	100	97	122	129
Ca^{++} (mg/l)	8.41*(.24)	12.43	12.22	16.04	17.52*(.19)
Mg^{++} (mg/l)	1.23*(.02)	1.71	1.70	2.18	2.22*(.58)
Na^{+} (mg/l)	1.43*(.15)	1.45	1.60	1.70	1.72*(.03)
K^{+} (mg/l)	0.80*(.07)	0.77	0.82	0.83	0.77*(.03)
SiO_2 (mg/l)	4.4*(1.4)	3.7	4.0	ND	2.2*(.17)
SO_4^{2-} (mg/l)	8.0*(.57)	8.0	8.4	7.9	10.0*(.61)
HCO_3^- (mg/l)	18.3*(.58)	30	30	41	43.7*(1.53)
NO_2^- (mg/l)	1.1	1.4	1.3	2.1	1.0

BR - Bridge
LCC - Laurel Creek Cave
UP - Upstream from Laurel Creek Cave entrance
CRC - Cross Road Cave
SPR - Spring

* mean value based on three replicate samples; means are accompanied by standard deviations.

ND - not determined

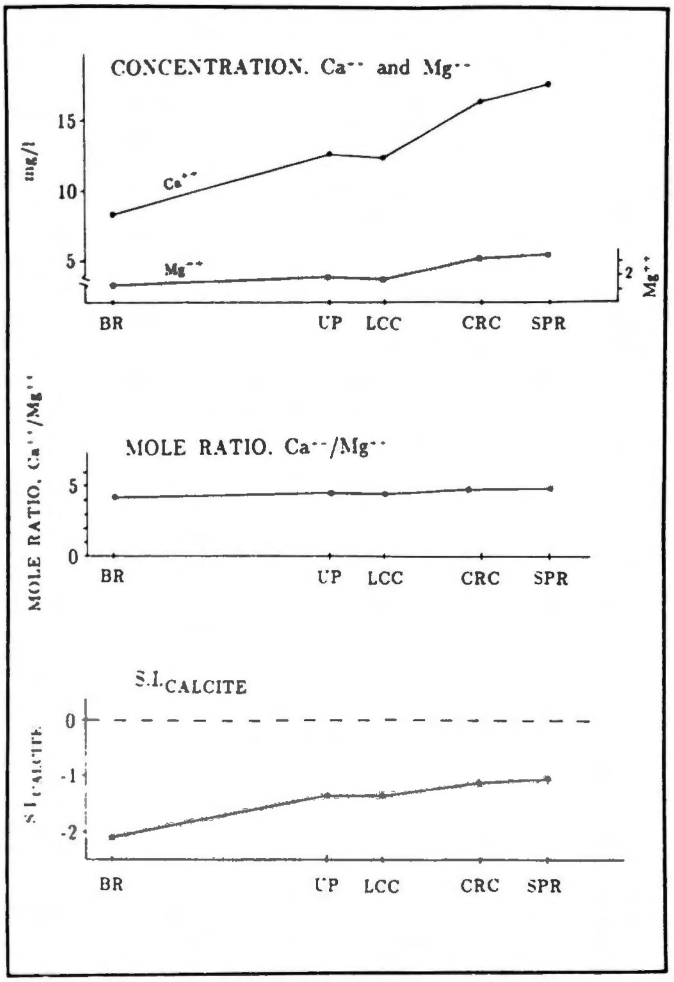

Figure 14: Ca^{++} and Mg^{++} concentrations, mole ratio Ca^{++}/Mg^{++}, and $S.I._{calcite}$.

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Acknowledgements

Appreciation is expressed to the following individuals for generously providing assistance to this project: Deana Groves, Tim Bowen, James Galloway, John Harper, Janet Herman, Alan Howard, Bill Jones, Fred Kohlberg and Craig Smith.

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

John C. Tinsley

Introduction

The objective of this study is to estimate rates of hill-slope erosion and sediment yield to sinkholes within the climax white fir forest that characterizes much of the Redwood Canyon karst area in Kings Canyon National Park. Volumes of eroded sediment are estimated on the basis of the sedimentology and stratigraphy of respective sinkholes which function as sediment traps. The karst contains about 60 sinkholes, half of which intermittently trap sediment eroded from hill-slopes under coniferous forest vegetation. The sinkhole sediments are composed chiefly of gravel, sand, silt and clay derived from the granitic and metamorphic rocks into which the canyon is cut, and from alluvial deposits along Redwood Creek and its tributaries. Of special significance to this study is the presence of a volcanic ash layer that forms a marker bed for these stratigraphic studies.

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. The powdery tephra, identified by its distinctive trace element chemistry as a product of the Deadman Dome vent, 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 no all of the deposits of sediment and ash directly to the cave below, for these sinkholes preserve little if any record of the ash. Alternatively, a sinkhole floored with sand and silty sediment is permeable; seepage of water through the sediment-plug effectively traps air- and water-borne sediment, including tephra, within the sinkhole. The trapped sediment is accreted vertically to that sinkhole's sedimentary record. Deposits of non-tephra-bearing sediment continue to wash into sinkholes and bury the tephra deposits.

Geologists prize deposits of tephra, especially those formed by airfall processes, because they are isochronous, or the same age everywhere that they occur. Such deposits have been erupted, transported, and deposited within a very short span of geologic time, and enable geologists to establish age equivalence among deposits that occur in widely separated localities. In the context of Redwood Canyon and its karst, this tephra deposit is a 700 year old marker bed or datum that enables geologists to estimate the rate of erosion of adjacent upland areas under conditions of a coniferous forest cover, a modern climate and varying slope angles and exposures. 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

The tephra deposit is used as a marker bed and time delimiter. In each sinkholes, an array of 15 to 30 homes are excavated using a hand-powered soil auger and the respective thicknesses of tephra and post-tephra sediment are measured in each hole. From the suite of measured thicknesses of sediment, the respective volumes of tephra and post-tephra and post-tephra sediment are estimated using isopach mapping techniques. The quotient of the tephra volume (or post-tephra sediment volume) divided by the area of the drainage basin draining into the sinkhole yields an estimate of the vertical thickness of tephra or post-tephra sediment eroded into the sinkhole from the drainage basin, provided the sinkhole has been behaving itself properly and functioned as a sediment trap and has not leaked appreciable sediment to the cave system. Comparing as many sinkhole and drainage basings 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. The estimated erosion rates would be applicable to the coniferous forest ecosystem under conditions of present climate which prevailed during the past 700 years.

There are about 60 sinkholes known in the Redwood Canyon karst; about 1/3 of these will be suitable for this study. Some of the sinkholes contain abundant deposits of granite boulders and cobbles; these are unyielding opponents to the soil auger as well as unsuitable media for efficiently trapping fine-grained particles of tephra and clastic sediment. Other sinkholes have open conduits which serve as principal inputs of water and sediment to the Lilburn Cave system The open conduits commonly observed in some of these sinkholes, while not passable to the caver, are not capable of trapping tephra or most post-tephra sediments. Consequently, were we to estimate erosion rates within these drainage basins, we would incur a biased rate that was too low. Only by comparing results from a number of well-plugged sinkholes can we obtain estimates of sediment yield for further analysis.

Results

Twenty-two sinkholes have been examined and ten sinkholes have been augered as of 12/31/87. Hillslopes of less than 10% tend to retain at least part of the mantle of volcanic ash, which then becomes mixed with the soil owing to biological and physical processes. Slopes steeper than about 10% generally shed their ash mantle readily into the sinkholes and are more efficient contributors of sediment, especially coarse sediment, than their more gently-sloping neighbors. The tephra blanket apparently ranged in thickness from 1 to 5 cm thick in the Redwood Canyon area. Erosion rates of the soil mantle measured in this way range from 0.5 -1.5 cm/yr.

During the 1988 field season, we plan to conclude the field study of these sinkholes. During 1987, a large number of rather small, shallow sinkholes having small drainage basins were studied to determine the minimum size of drainage basin required to generate an unambiguous volume of sediment to bury the tephra layer. We have discovered that the tephra layer typically is rather poorly preserved where gentle slopes and small drainage basins cause sedimentation rates to be low. Under these conditions, burrowing organisms tend to homogenize the stratification within the uppermost strata of the sinkhole and, where the base of the tephra is not clearly identifiable, unseemly degrees of uncertainty creep into the analysis. These refinements are enabling us to identify thresholds of slope and drainage basin size below which the estimates of soil erosion rates and tephra thickness become unreliable using this technique.

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ECOLOGY PROGRAMS

Community Structure of the Arthropods of Carlsbad Cavern

Diana E. Northup, William S. Ziegler and Kenneth L. Ingham

1. Introduction

Censusing of macro-arthropods using pitfall traps in Bat Cave, Sand Passage and Left Hand Tunnel of Carlsbad Cavern, continued during January through October 1987. The three study sites and methods used were described previously (Northup and Kuper 1986). Data and specimens from these monthly census trips were used for studies of (1) macro-arthropod species diversity, (2) rhaphidophorid reproductive patterns, (3) rhaphidophorid age class patterns, (4) rhaphidophorid sex ratios and (5) rhaphidophorid diet. An intensive period of study from mid-May to mid-June, 1987, provided additonal information on activity rhythm patterns of macro-arthropods in sand passage and on rhaphidophorid emergence to the surface from the rear of Bat Cave. Summaries of the findings of these studies are included below. More detail is provided in Northup (1988).

2. Species Diversity

Hill's N_2 values (Hill 1973) of species diversity (alpha-diversity) were calculated from data collected for all three locations between December 1984 and October 1987. All observations in which species could be told apart were included in the analysis. Consequently, a large number of rhaphidophorid subjuveniles were not included as it is impossible to visually differentiate species at that size. Overall, Left Hand Tunnel N_2 values were closer to one, while Sand Passage and Bat Cave had higher values, indicating relatively more even proportions of each species than in Left Hand Tunnel.

Community coefficients (beta-diversity) were calculated for all three locations. Left Hand Tunnel and Sand Passage showed a 100% overlap due to equivalent species rhichness (4 species) and composition. These two sites differed in relative abundaces of the four species present. Bat Cave, which as a much greater species richness (13 different species were captured in the pitfall traps) than the other two sites, had a community coefficient of 35.3% with each of the other two sites. This community coefficient was over-estimated due to the lack of division of the mites into their several separate species.

3. Rhaphidophorid Reproductive Patterns

3.1 Seasonality and Egg Number and Size Differences Between Species

One hundred and twenty-four cavernicolous rhaphidophorids gathered from November 1986 through October 1987 from Sand Passage, Bat Cave and Left Hand Tunnel were dissected to provide data on the number of eggs per rhaphidophorid and average size of eggs in each of the two rhaphidophorid species. Plotting of number of eggs in each rhaphidophorid dissected, by capture date showed no seasonal trend to egg presence. Of significance was the finding that *C. longipes* showed significantly larger and few eggs than *C. carlsbadensis*. Differences in egg number between species were tested with a Kruskal-Wallis non-parametric ANOVA due to unequal variances; differences in egg size between species were tested with a t-test.

3.2 Field Observations of Mating

Mating has been observed in both species in various areas of Carlsbad Cavern. *C. Longipes* have been observed mating in the Main Corridor in June and *C. carlsbadensis* have been seen mating in the Big Room in early January and in Left Hand Tunnel in late November. In November, 1985, various *C. carlsbadensis* males and females were placed in a tank in Left Hand Tunnel and mating behavior was observed. The males often thouch the females with their antennae as a preliminary to copulation. After this exchange, males turn around and waggle their posteriors at the female. If she is receptive she will turn around, and presumably by feeling with his cerci, the males fuse to the females after turning their abdomen over 180°. The matings observed lasted approximately 3-5 minutes. No male-male aggression was observed among the males prior to the matings.

4. Rhaphidophorid Age Class Frequencies Over Time

4.1 Adult Population Fluctuations

Adult *C. longipes* numbers remained low in Bat Cave and their appearance in traps was sporadic. during the study period their numbers have declined in this site. The number of *C. Carlsbadensis* adults increased in the late fall and early winter months. A substantial surge in the number of *C. carlsbadensis* adults occurred in the winter in 1985-86, which was not seen in the previous or following winter. A similar surge in number was not seen in Sand Passage, and Left Hand Tunnel was not censused during that period.

Number of *C. longipes* adults increased during spring and summer months in Sand Passage. *C. carlsbadensis* were almost always seen in lower numbers that *C. longipes* in Sand Passage and their numbers increased in winter. In Left Hand Tunnel, adult *C. carlsbadensis* numbers peaked in early winter, but remained high most of the year. *C. longipes* numbers remained consistently low except for a period in early 1985.

4.2 Non-Adult Rhaphidophorid Populations Fluctuations

Analysis of the subjuvenile frequency data showed different patterns of population peaks among the three areas. Numbers of subjuveniles peaked in winter in Left Hand Tunnel and Bat Cave; Sand Passage, on the other hand, showed peak numbers in spring and summer, with lows in winter. These trends are consistent with the peaks seen in the adult rhaphidophorid data for the dominant species in each of these areas. In Sand Passage, this also correlates with the rhadine beetle frequencies which peak in early summer and dip somewhat in winter. The number of rhadine beetles in Bat Cave peaked somewhat in previous winters, were low in the summer of 1986, and peaked in the summer 1987. Thus, the Bat Cave rhadine beetle data does not correlate as well with the subjevenile data as does the Sand Passage data.

Prior to separating juveniles into subjeveniles and juveniles, the data showed a pattern of juvenile population peaks similar to that described above for subjuveiles. Analysis of the non-adult data that post-dates the division of juvenile data into subjuvenile and juvenile data showed that numbers of juveniles remained constantly low in Sand Passage, in contrast to the high number of subjuveniles in this area. A similar pattern for subadults in Sand Passage was seen. Left Hand Tunnel showed a pattern of peak numbers of juveniles and subadults in summer months with more modest numbers in the winter. A similar situaion existed in Bat Cave where subadults peaked in summer and dipped in winter. Juveniles, however, showed winter and summer peaks during 1986-87 in Bat Cave.

5. Sex Ratios

Sex ratios, for each species in each location, were calculated using the formula:

$$\text{Sex Ratio} = \frac{m-f}{2(m+f)} + \frac{1}{2}$$

where m is the number of males and f is the number of females. The formula maps the domain of 0 to ∞ to the range of 0 to 1. Check dates which included less than a total of 5 individuals (male and/or female) were not included in the analysis. The results varied considerably throughout the cave. Overall, *C. carlsbadensis* sex ratios were skewed towards males in Bat Cave and towards females in Sand Passage and Left Hand Tunnel, and skewed towards males in Sand Passage. Sex ratio differences were tested with a chi-square test; none of the sex ratio patterns were significant and some sampling error was observed in the data.

6. Feeding

6.1 Gut Contents Analysis

The gut contents of the 124 rhaphidophorids dissected for the reproductive study were examined to determine the nature of the rhaphidophorid diet. Food items in the guts of Bat Cave rhaphidophorids consisted of various arthropod parts, including moth scales, some veined wings, legs covered with black spines, larval hairs, rhaphidophorid parts and non-rhaphidophorid eggs. There was no evidence that rhaphidophorids were eating guano in Bat Cave. Sand Passage rhaphidophorid guts were generally empty or contained rhaphidophorid adult or juvenile parts. Left Hand Tunnel guts included unidentifiable material that looked like applesauce, zrhaphidophorid parts, and in two rhaphidophorids, moth scales. No plant material was identified in any of the guts from any of the sites.

Overall, gut contents were predominantly animal in nature, indicating that the rhaphidophorids in Carlsbad Cavern are mainly carnivorous. The degree to which these rhaphidophorids are cannibalistic is still in question. Most of the rhaphidophorids used in the study were captured in pitfall traps which may encourage cannibalism; however, one of the free captures had clear evidence of rhaphidophorid remains. Becuase the remains included a mandible, it is unlikely that the rhaphidophorid was merely eating its own exuviae.

6.2 Field Observations of Feeding

C. carlsbadensis have been observed carrying guano moths in their mouths on two occasions in Bat Cave. In the same area they have also been observed eating on the carcasses of a ring tail cat and several bats. Rangers have reported rhaphidophorids feeding on bat carcasses in the Queen's Chamber and on human feces left near or on visitor trails. Any food dropped by park visitors attracts rhaphidophorids to feed upon it. Rhaphidophorids are often seen feeding side-by-side with rhadine beetles.

7. Activity Rhythms

Activity rhythm of cavernicoles was studied during three separate 24-hour periods in Sand Passage, which was chosen due to its continual total darkness and remoteness from human influence. The only species that appear to vary in a pronounced manner are the non-adult rhaphidophorids which dip at either 2:00 a.m. (in two of the studies) or 6:00 a.m. (in one of the studies). The other species and the adult rhaphidophorids do not show clear patterns of activity.

8. Surface Investigations and Within Cave Migrations

Traps palced around the second entrance which drops into the back end of Bat Cave have captured both C. longipes and C. carlsbadensis. To date, the traps have been set only in May and June of 1987, and seasonality of this surface migration has not been investigated. Within the cave considerable rhaphidophorid migration occurred. Rhaphidophorids marked in Sand Passage have been noted by Rangers above Bat Cave in the Main Corridor and in the Queen's Chamber. A rhaphidophorid marked in Left Hand Tunnel was noted near Crystal Springs Dome which is a considerable distance into the Bit Room.

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Dynamics of a Cave Predator-Prey System: Coevolution or Not?

David M. Griffith

The dynamics of a carabid beetle preying on eggs of a Rhaphidophorine "cricket" are being studied in Mamoth Cave National Park. The main natural experiments are different spatial scales of abiotic & biotic heterogeneity within and between cave sites. These patterns suggeste hypotheses which are being tested by field and lab experiements. The site with highest beetle density is least variable with R.H. > 85% and 13-14° C year around. Yet predation rate, based on exclosure rings, varies from 0-99% over seasons and spatially with substrate moisture of 6.2-4.0 pF. This may not be consistent or intense enough selecton for coevolution. But direct measures of individual predation success an cricket egg-laying rates, along with population estimates, give a 33% predation rate overall. Also, my behavioral experiments show that beetles use specialized behavior to locate eggs and suggest that cricket egg-laying patterns allow some avoidance of predation. Bimonthly samples will show if beetle and cricket fecundities are correlated in the ways expected from a coevolutionary scenario.

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Selection and Regressive Evolution in a Cave Population of the Amphipod *Gammarus minus*

Ross T. Jones

The role of selection in regressive evolution in cave animals has been controversial since the time of Darwin and before (Kane and Richardson 1985). There is a long standing controversy between those who view energy economy as critical to the evolution of reduced eyes (Sket, 1985) and those who view eye and pigment degeneration as a consequence of selectively neutral, structurally reducing mutations (Wilkens, 1985). To my knowledge, there have been no previous attempts to directly measure selection on any morphological character for any cave organism.

My study organism is the crustacean amphipod *Gammarus minus*. In my study area of southeastern West Virginia *G. minus* is found in surface and cave streams. Surface individuals have a large eye containing about 40 facets and relatively small antennae. Individuals from cave populations have smaller eyes containing about 5 facets and much longer antennae.

Presently, I am concentrating on testing the hypothesis that the reduction in eye size and increase in antennae size of the cave populations relative to the spring populations is due to selection. To do this it is necessary to determine if these sensory structures have any effect on the fitness of an individual.

Mate finding ability is an especially appropriate fitness component to use to estimate selection on sensory structures. Evidence for both distance-active (Borowsky, 1985) and contact (Hartnoll and Smith, 1980) sex pheromones have been found in amphipods. Presumptive chemoreceptors necessary for the detection of pheromones occur on the antennae in amphipods. Hartnoll and Smith (1980) showed that pair-formation was reduced by 75 percent when both the first and second antennae were removed. While chemoreceptors occur on other parts of the body, antennae are of obvious importance in finding and recognizing mates.

Once individuals have sorted themselves into mating pairs a long (between one and two weeks) period of amplexus occurs in which the larger male carries the female continuously on his ventral surface. The female is released briefly to molt before insemination occurs. This long period of amplexus allows for the easy identification of copulating pairs in the field.

To measure selection on the sensory structures I am using the method of Lande and Arnold (1983). With this method the correlation between fitness (mate finding ability) and the characters is determined with the use of simple linear and multiple regression.

Table 3 provides data from a study of selection, on some antennal and eye characters, which is due to differential mate finding ability. Two large samples of sexually mature individuals were made, one in the winter of 1986 and one in the winter of 1987. These samples contained both amplexing and non-amplexing individuals with amplexing individuals making about 30 percent of both samples. To take into account the effects of body size on the sensory structures each eye and antennal character was regressed on a body size measurement (head length) and the resulting residuals were used. I have also found that size is highly correlated in age in *G. minus* therefore differential mating success caused by age differences can also be accounted for.

S′ is the selection differential of each character and represents the change in the mean of the residuals of each character between the mating population and the population as a whole. These are calculated from the simple linear regression of fitness on each standardized character (mean=0 and variance=1). B′, is the partial regression coefficient of the multiple regression of fitness on all measured characters. This represents the amount of correlation between the character and fitness, holding all other characters constant, and takes into account phenotypic correlation. Positive values for the selection parameters indicate that mate finding ability increases with an increase in the size of the character while negative values indicate that mate finding ability increases with a reduction in the size of the character.

The amount of variation in mate finding ability (R2) is 24 percent and 29 percent in males during the two years and only 8 percent and 16 percent for females. Except for females in 1986 there was a significant multiple regression.

No significant selection was found on the antennal characters for either males or females in 1986. However, significant selection differentials and partial regression coefficients were found for peduncle length in 1987. In addition the 1987 male sample indicated a significant selection differential for antennal flagellar number. Since the partial regression was not significant, this is probably an indirect effect of selection on the correlated peduncle character.

More unexpected was the finding that there was a significant partial regression coefficient, as well as overall selection on ommatidia number for both males and females (see Table 3). For all samples, selection was acting to reduce ommatidia number.

To my knowledge these data represents the first direct evidence that increased non-visual sensory structures in a cave animal is truly the result of selection. More importantly, this is evidence that for at least one cave animal the regressive evolution of eyes is due to selection and not to neutral mutations.

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Table 3: Estimates of directional selection for *Gammarus minus* in Organ Cave in the winters of 1986 and 1987. S′ is the Selection differential and B′ is the partial regression coefficient (see text).

Males

	Winter 1986 n = 97		Winter 1987 n = 95	
Character	s'	B'	s'	B'
Peduncle length	.014	.172	.042[1]	.449[1]
Antennae segment number	.011	.112	.039[2]	.164
Eye facet number	–.270[2]	–.323[1]	–.212[3]	–.271[1]
		R^2 = .24		R^2 = .29

Females

	Winter 1986 n = 97		Winter 1987 n = 95	
Character	s'	B'	s'	B'
Peduncle length	–.014	–.112	.0331	.4012
Antennae segment number	.012	.080	.008	.015
Eye facet number	–.1373	–.2413	–.1392	–.3422
		R2 = .08		R2 = .16

1 Significant at the .01 level
2 Significant at the .05 level
3 Marginally significant at the .1 level

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Aquatic Communities in the Cathedral Domes Section of the Mammoth Cave

Julian J. Lewis

After a three year pause from working in Mammoth Cave National Park, I have resumed studies concerning the aquatic invertebrates found in various habitats in Mammoth Cave. Past work concentrated on evaluating the distribution and life history of the two species of troglobitic isopods found in the subterranean waters of the park (Lewis, 1981a; 1981b; 1982; 1983; Lewis and Lewis, 1980; 1983).

The emphasis of work started in 1987 is to look at aquatic communities in Mammoth Cave. Very little is known about the composition of communities in the cave. Most of what is known consists of records of individual species from various locations. The way in which these species assemble into communities is largely unknown. Thus, merely identifying all the species present in a given location goes beyond what has already been done for most aquatic locations in Mammoth Cave.

Community diversity increases in as one progresses from the aquatic habitats of the upper levels towards the lower levels of the cave. Communities in upper level shaft drains (e.g., Shaler's Brook, Gratz Avenue) frequently consist of only two or three species. Typically the majority of the population will consist of the isopod *Caecidotea stygia*, with an occasional flatworm *Sphalloplana* sp. and amphipod *Stygobromus* sp. to be encountered. In mid-level streams the crayfish *Orconectes pellucidus* starts to be predictably encountered, along with the isopod *Caecidotea bicrenata* whitei, flatworm *Sphalloplana* sp. and amphipods *Stygobromus* and *Crangonyx*. At base-level communities are relatively complex, the possibilities including the two species of troglobitic fish, *Amblyopsis spelaea* and *Typhylicthys subterraneous* , crayfish *Orconectes pellucidus*, shrimp *Palaemonias ganteri*, snail *Antroselates spiralis*, along with isopod *Caecidotea bicrenata* whitei, amphipods *Stygobromus* spp., and flatworms *Sphalloplana* spp.

In the one group that has been carefully studied (isopods) in Mammoth cave there is a predictable vertical distribution pattern. The distribution of the other two common groups of small invertebrates (flatworms and amphipods) within the cave system is very poorly known.

Two species of flatworms are known from the Mammoth Cave System, *Sphalloplana percoeca* and *Sphalloplana buchanani*. According to Kenk (1977), it is possible to identify these two species from external morphology (Figure 15). Examination of the head reveals that *S. percoeca* has prominent auricles, knob-like structures that extend from either side of the head. In *S. buchanani* the auricles are absent. For identification, I have taken living worms from the cave streams and placed them in glass screw-cap culture tubes. The worms crawl along the length of the tube extended in manner that makes it possible to identify the species by placing the vial in front of a light and scrutinizing the shape of the head. Thus, it is possible to identify these flatworms alive, in the cave, then return them to their habitat.

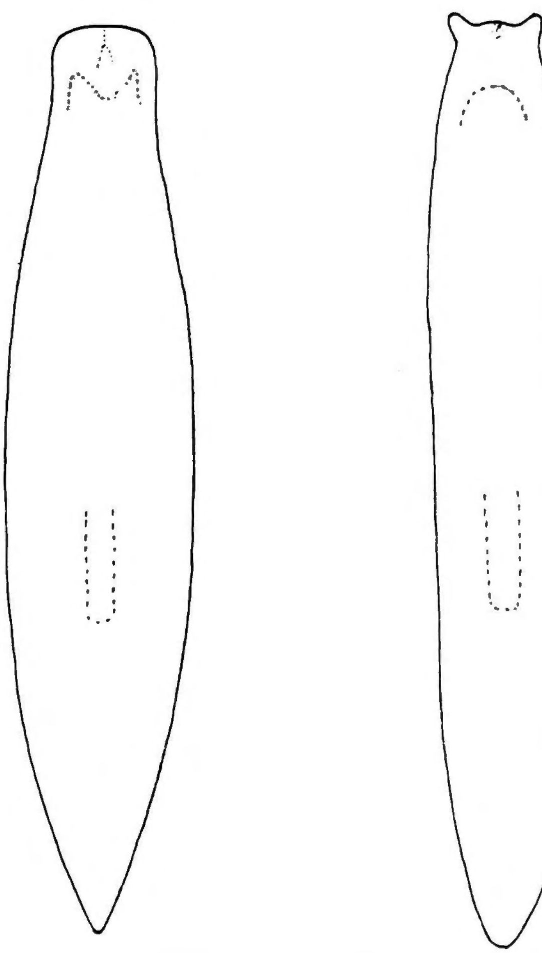

Figure 15: Identification of Mammoth Cave flatworms, taken from Kenk (1977): (a) *Sphalloplana buchanani* and (b) *Sphalloplana percoeca*.

Three species of amphipods are known from Mammoth Cave: *Stygobromus exilis, Stygobromus vitreus* and *Crangonyx packardi*. It is relatively simple to tell *Crangonyx packardi* from the *Stygobromus* spp. by its considerably greater size. However, it is unlikely to be possible to discern the two tiny species of *Stygobromus*, or immature *Crangonyx* from one another without the use of a microscope.

Field study

My present objective is to discover the way in which the species discussed above assemble into communities at different levels in Mammoth Cave. I have chosen the Cathedral Domes section of the cave to work in due to several factors: (1) This area is relatively accessible, the trip from the Carmichael Entrance consisting of n easy mile and a half of walking height passage, (2) it is possible to gain access to streams at a variety of elevations above base-level in this section of the cave. Unlike many other dome waterfalls, the stream passage above Cathedral Domes is accessible to study. Although below Cathedral Domes the stream falls into a shaft with an unenterable drain, other similar low level streams are apparently accessible nearby in the vicinity of Florence Williams Dome, (3) Cathedral Domes is sufficiently populated to allow study. In contrast, some shaft drain streams (e.g., Lucy's Dome) are virtually uninhabited.

To date I have found the following animals in the Cathedral Domes stream: (1) Both species of flatworms are present, but the number examined so far is much too small to draw any conclusions as to which, if either species is predominant; (2) All three species of amphipods are present, with *Crangonyx packardi* the predominant invertebrate in the stream. *Stygobromus* spp. make up a lesser constituent of the fauna; (3) The only isopod present is *Caecidotea* stygia.

This community is interesting on several counts. This is the only place in Mammoth Cave where I have found *Crangonyx packardi*. The presence of this amphipod at Cathedral Domes is probably due to the large amounts of organic matter present in the stream from the collapsed staircase. From a morphological standpoint this species is not as highly adapted to the cave environment as the Stygobromus species, retaining small eyes in some populations. In other habitats in Mammoth Cave there may simply not be enough food present to sustain this relatively primitive troglobites.

Cathedral Domes is also interesting as the site of the syntopic occurrence of *Stygobromus* and *Sphalloplana*. The troglobitic two isopod species in Mammoth Cave, in contrast, rarely occur together in the same habitat. It appears that in the instances where both species are found together it is a case of upper level *Caecidotea stygia* washing into an established population of *Caecidotea bicrenata* whitei. The incidence of syntopy in *Stygobromus* remains to be seen. However, I have found both species of *Sphalloplana* in Cathedral Domes and Shaler's Brook, and Kenk (1977) reports both from the breakdown stream in Rafinesque Hall.

To study the aquatic community in Cathedral Domes I have started conducting a periodic census of a 30 foot section (Figure 16). This section consists of at the point where it leaves the plunge pool beneath the waterfall, to where it flows into an unenterable hole in the wall of the passage. The habitat consists primarily of shallow mud-bottomed stream, littered with gravel and pieces of rotting wood. The wood's origin was the staircase constructed during the time that an entrance was present above Cathedral Domes allowing access by commercial tours. The entrance was closed and in time the staircase collapsed and now lies in the pool beneath the waterfall.

To census the invertebrates, a tape measure is stretched the length of the stream. Starting from the downstream end, all animals present in each 2 1/2 foot section of the stream are identified and an approximate size estimate made. All moveable objects (stones and pieces of wood) are turned and examined for animals clinging to the undersides. Other hiding places are prodded with a small brush to flush out any small animals that might be hiding within. Thus, an attempt is made to count, identify and measure all animals present in this section of stream. Results of a typical census are given in Table 4.

The work for the future consists of several things. The census in Cathedral Domes will be continued. It is hoped that additional census areas can be established in the passage above Cathedral Domes and in another stream at a lower level. Particular attention will be given to looking at microhabitat utilization by the amphipod and flatworm species to see if there is some discernible pattern to their distribution.

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Figure 16: The stream census area in Cathedral Domes, Mammoth Cave. The tape extending the length of the stream is used to locate the part of the stream where each invertebrate is found (*photo by Carla Lochner and Jerry Lewis*).

Table 4: Results of an invertebrate census in Cathedral Domes, 11/27/87.

Stream Section (in feet)	*Crangonyx packardi*	*Stygobromus spp.*	*Caecidotea stygia*	*Sphalloplana percoeca*
0-2.5	0	0	0	1
2.5-5.0	0	0	0	0
5.0-7.5	2	1	0	0
7.5-10.0	3	0	0	0
10.0-12.5	6	4	0	0
12.5-15.0	3	3	0	0
15.0-17.5	0	0	1	0
17.5-20.0	0	0	1	0
20.0-22.5	1	0	0	0
22.5-25.0	2	0	0	0
25.0-27.5	3	0	0	0
27.5-30.0	2	1	0	0
TOTAL	**22**	**9**	**2**	**1**

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Bioenergetics of cave crickets (*Hadenoecus Subterraneus*) and camel crickets (*Ceuthophilus Stygius*)

Kathleen H. Lavoie, Eugene H. Studier,
William D. Wares III, and Julie A. M. Linn

Trogloxenes are animals which are commonly found in caves but which must leave the cave to feed. Trogloxenes, such as bats and cave crickets, appear to provide the major, and certainly the most dependable, source of fixed carbon input into temperate cave ecosystems. Many of the caves found in MCNP have extensive populations of cave crickets and lesser populations of camel crickets which probably offer the major source of nutrient input into these caves in the absence of large bat populations.

Crickets input food in the form of guano, carcasses, and eggs. Estimates of the quantitative importance of crickets to energy flow in cave ecosystems are hindered by a lack of reports concerning the energy economics of both species. This on-going research project is involved in determining energy economics, population dynamics and interactions, and aspects of the basis biology of both species.

Phase 1 was reported on in a series of three publications (see citations below). To summarize, our results support the widely-accepted idea that cave crickets (*Hadenoecus subterraneus*) are more cave-adapted than camel crickets (*Ceuthophilus stygius*), and are more restricted in when they can leave the cave to feed. Female cave crickets losst weight at a rate which would make them crop-empty every 11.5 days. To avoid using up body energy reserves, they would need to leave the cave to feed at least every 11.5 days. Females were able to fill their crops up to 101% of the crop-empty live weight. Male cave crickets lost weight at a slower rate, but they were not able to consume as much food as the females (up to 72% of their body weight). Males should leave the cave to feed at least every 9.9 days.

Camel crickets lost wates over the five days of the study, which we interpret as a rapid phase due to crop-emptying, followed by a slower rate of weight loss when fat reserves are being utilized. Using the more rapid rate, female camel crickets should forage at least every 3.0 days and males every 2.3 days. Full camel crickets are only able to consume 39% (females) or 34% (males) of their body weight in food. Since camel crickets have very little flexibility in how often they should feed to maintain their fat reserves, they must be able to leave the cave more frequently and under a wider range of environmental conditions that cave crickets, which is generally assumed to be the case. Cave crickets are through to leave the cave only when surface weather is very humid, dark, and not too hot or cold. Since cave crickets do not need to forage as often as camel crickets, they have more flexibility to wait for a night when environmental conditions are more favorable.

We also determined that there is a predictable relationship between Hind Femur Length and Crop-free Live Weight in both species. The relationship differed by sex in the camel circkets and was the same for both sexes with the cave crickets. This relationship allows us to weigh and measure the hind femur length of a cricket, and determine its crop contents without having to sacrifice the cricket.

Low metabolic rate is also assumed to be a general characteristic of cave-adapted animals. The metabolic rates for *Hadenoecus* cave crickets were one-half that expected for surface insects of similar mass. Metabolic rates of *Ceuthophilus* camel crickets were greater than *Hadenoecus*, but still less than metabolic rates of surface insects of similar size. Since the metabolic rate for cave crickets is lower than camel crickets, we can support the idea that cave crickets are more cave-adapted than camel crickets.

Contributions of guano from each species to the energy base in the cave is affected by caloric value of wastes, amount of wastes produced, and frequency of feeding, suggesting that *Ceuthophilus* may be a more important source of fixed carbon compared to *Hadenoecus*. However, *Ceuthophilus* show seasonal size differences since they apparently reproduce and grow over a one-year cycle compared to the broader size distribution found in *Hadenoecus* all year long. These seasonal differences in size may off-set some of the nutritional input differences over the course of a year, with cave crickets becoming more important in winter and spring. Distribution of the two species within a cave is also different, with camel crickets typically found close to entrances and cave crickets more widely distributed. Energy inputs from cave cricket guano, though low, are more predictable in time and space, and are probably more important to the specialized troglobitic animals deep within a cave than camel cricket guano.

We are still gathering data for Phase 2 of the project, dealing with seasonal differences in bioenergetics, foraging, and population dynamics.

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Characteristics of Copulating Pairs and Annual Cycle of Gonad Maturation in Cave Crickets, *Hadenoecus subterraneus*

Eugene H. Studier, Kathleen H. Lavoie, Dennise R. Nevin, and Kelly L. McMillin

Many aspects of the reproductive biology of cave crickets have been investigated. Reports concerned with mating, oviposition, eggs and nymphs are available (see Barr, 1967; Hubbell & Norton, 1978). In association with ongoing extensive studies of nutrition in cave crickets (see Studier, *et al.*, 1986), we have collected adult individuals for dissection, which also provides data on the annual cycle gonadal development. Additionally, copulating pairs of cave crickets collected in Spring and Summer have been dissected for comparison with other adult individuals.

Crickets used in this study were collected at different times of the year (mostly monthly) from Floyd Collins Crystal Cave, White Cave, Great Onyx Cave, Frozen Niagra and Austin Entrances to Mammoth Cave and Sophys Avenue of Mammoth Cave - all located within Mammoth Cave National Park. Additional collections were made from Walnut Hill Cave, located about 2 miles by road from Park City, Kentucky. All crickets were killed by freezing within 1 hour of capture and held frozen until dissection. Upon thawing, hind femur length (HFL) to the nearest 0.1 mm was determined, sex recorded, and total wet weight was determined (to 0.1 mg). Crickets were then dissected and wet crop contents and wet weights of mature gonads as well as number of mature ova were determined. These specimens were then dried to constant weight at 50-60° C and dry weights were recorded.

The percentage of adult crickets with mature gonads is shown in Figure 17. Most adult male cave crickets contain developed spermatophores at all times throughout the year with minimum frequency occurring in late summer (50% in September). Essentially all adult males contain spermatophores from October through May. In adult females, mature ova were present in all monthly samples except July. Peak frequency of gravid females in late Winter (88.2% in Jan., 79.2% in Feb.) coincided with peak frequency of spermatophores in males. Based upon these gonadal cycles, cave crickets appear to be capable of reproduction in all months with the possible exception of July. These data correspond nicely to the annual total number of crickets in copula, copulation frequency, and appearance of cave cricket nymphs reported by Hubbell and Norton (1978). When present, there are invariably 2 spermatophores in males (in 157 cases). The number of ova present in gravid females is extremely variable, ranging from 1 to 30. Seasonal averages, however, are quite consistent. In Spring (May), 8 gravid females averaged 6.1 ova/individual; Summer (August), 14 averaged 6.0 ova/female; Fall (November), 6 averaged 7.3 ova/female; and, in Winter (February), 27 averaged 10.6 ova/female. The Winter sample average is markedly raised by 8 gravid females from Sophys Avenue of Mammoth Cave at 18.11 ova/female (range=9-30). Sophys Avenue crickets were not collected in other seasons. Excluding those crickets, the Winter average for 19 gravid females from other caves is 7.4 ova/cricket. The annual average of mature ova in gravid females (n=47) is 6.8 ova/female, excluding the Sophys Avenue Winter crickets, and 8.4 ova/female (n=55), including those females. The remarkably high number of mature ova in gravid Sophys Avenue females suggests excellent nutrition availability at that site leading to very high reproductive rates and deserves further study.

Cave crickets appear to mature when their HFL reaches or exceeds 20.0 mm. Of 157 males containing spermatophores, 6 (3.8%) had HFLs less than 20.0 mm (minimum = 18.9 mm). Of 199 females containing mature ova, only 1 (0.5%) with HFL less than 20.0 mm contained mature ova. Fourteen pairs of copulating crickets were collected in Spring and Summer 1986. The number of mature ova was 6.1 ova/female (S.E.=1.3; range=1-16) which agrees nicely with the values of 6.0 and 6.1 ova/female found in non-copulating gravid females in those seasons. HFLs in these copulating pairs (females=21.7 + 0.6 mm and males=21.6 + 0.2 mm) are not different. The single mature female with a HFL less than 20.0 mm was one of the copulating crickets and had a HFL of 15.5 mm.

Remaining data on copulating pairs are given in Table 5. Total wet weight and carcass wet weight of copulating females is grater than that of males (t=2.95; 26 d.f., P<0.001; and t=3.55; 26 d.f.; p<0.01; respectively. Carcass dry weight of females is also greater than in males (t-2.33; 26 d.f.; P<0.05). We have independently determined the relationship of carcass and crop wet and dry weights to HFLs in cave crickets by season. Details of those analyses are reported elsewhere; however, in both Spring and Summer, all large females are heavier than males of similar HFL. These differences in copulating crickets, therefore, correspond to expected differences of other crickets of similar size. In terms of absolute weights, seasonal equations predict carcass wet weights of 0.4012=0.4070 gm for females of HFL=21.7 and 0.3391-0.3484 gm for males of HFL=21.6. Comparison of these values with those for copulating crickets (Table 1) indicate that copulating crickets have absolute carcass

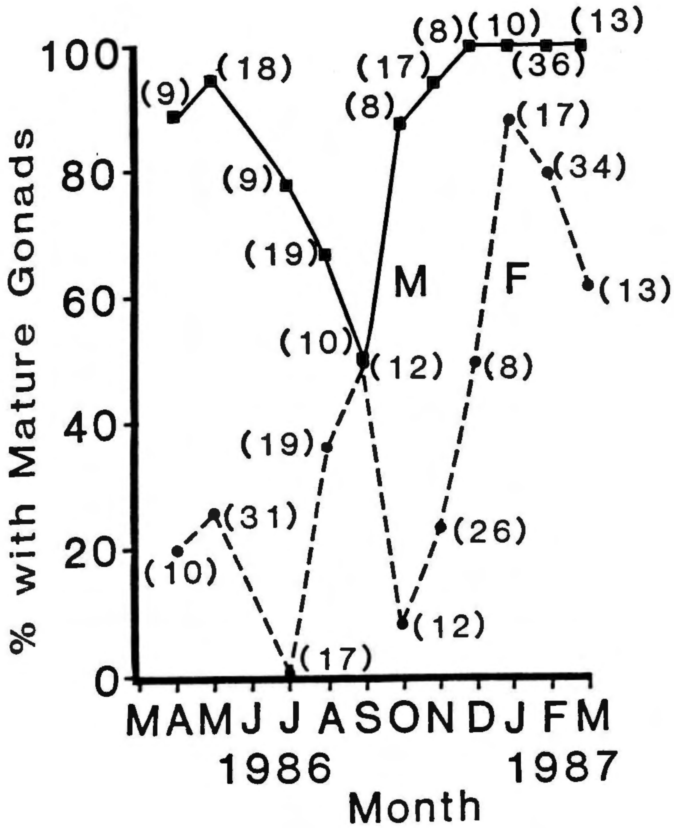

Figure 17: Percentage of adult cave-crickets, Hadenoecus subterraneus, containing mature gonads (April 1986-March 1987). Numbers in parentheses represent total individuals examined each month.

weights somewhat higher than expected. Carcass dry weights, however, fall within expected ranges for females (0.1016-0.1259 gm) and males 0.0856-0.1047 gm). Expected crop wet weights for females (0.0999-0.2311 gm) and males (0.0919-0.2690 gm), as well as dry weights (0.0235-0.0594 for females and 0.0221-0.0691 gm for males), are markedly higher than values found in copulating crickets. The relatively empty crops found in both sexes of copulating crickets imply an abnormally long hiatus since their immediately previous feeding bout (Studier, *et al.*, 1986). Lack of full crops in copulating cave crickets may allow increased skeletal flexibility needed in body orientation and bending required for copulation. Alternatively, full crops may impair copulation by stearic hindrance.

Acknowledgements

We thank CRF for providing access to their field facilities in MCNP. 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 5: Wet and dry weights of carcasses, crops, gonads, and total weight of copulating cave crickets (n = 14). Numbers in parentheses are standard errors of the means.

	Total	Carcass	Crop	Gonads
	Wet Weight (gm)			
Females	0.5192 (0.0199)	0.4266 (0.0154)	0.0616 (0.0177)	0.0309 (0.0067)
Males	0.4280 (0.02377)	0.3502 (0.0150)	0.0551 (0.0161)	0.0226 (0.0011)
	Dry Weight (gm)			
Females	0.1320 (0.0057)	0.1187 (0.0036)	0.0100 (0.0031)	0.0102 (0.0029)
Males	0.1197 (0.0071)	0.1001 (0.0050)	0.0141 (0.0057)	0.0056 (0.0002)

Seasonal individual size distributions and mortality of populations of cave crickets, *Hadenoecus subterraneus*

Eugene H. Studier, Kathleen H. Lavoie, Dennise R. Nevin, and Kelly L. McMillin

Many aspects of population biology are predicated on the ability to estimate absolute population numbers. Cave crickets, *Hadenoecus subterraneus*, exist in very large numbers in many roosting caves. Additionally, the relatively small size of individual cave crickets coupled to the marked irregularities which provide many hiding places characteristic of cave roosts, make direct population counts extremely difficult and of limited reliability. Only one such attempt has been made only for large crickets (Hubbell & Norton, 1978). Collection of large numbers of cave crickets in their roosting caves, however, is a relatively simple matter, which we have utilized to gain some insight into the population biology of cave crickets.

Populations were studied in four caves - Floyd Collin's Crystal Cave (C), Frozen Niagra Entrance to Mammoth Cave (FN), and White Cave (W), all in Mammoth Cave National Park, and Walnut Hill Cave (WH) located 2 miles by road from Park City, Kentucky. Data were collected for four seasons - Spring (28 April-3 May 1986), Summer (26-27 July 1986), Fall (20-24 October 1986), and Winter (24-27 January 1987). Measurements were taken in FN after sunset (8-12 p.m.) and during daylight hours in all other caves. Cave crickets were collected by hand, sexed when large enough, and hind femur lengths (HFL) determined with dividers and recorded to the nearest 0.1 mm. With the exception of about 80 individuals from WH in each season which were used in other studies, crickets were released at their capture site after measurements were taken. Considerable care was taken in searching for and collecting crickets to ensure appropriate representation of smaller crickets which are more readily overlooked and roost in smaller crevices and fewer open spaces than larger crickets.

The major criticism of this study centers around potential bias in collecting crickets which represent the true size distribution of individuals within the population. Many ideas regarding avoidance of this potential bias were discussed. If one measures easily collected individuals, counts would be heavily biased in favor of large crickets. Seasonal movements of crickets within caves prevent useful counting of all crickets within a defined area. The method used here, however, was consistently applied in all four study caves in all four seasons. Thus, any size bias was consistent and season to season differences probably reflect real changes. Although bias may exist for size distribution, there should be no bias in regard to gender and male-female ratios should reflect absolute differences within populations or seasons.

For purpose of analysis, cave crickets were grouped by 1 mm increments in HFL, e.g., 15.0-15.9 mm = 15 mm HFL, etc., and analyzed by gender only in individuals of HFL > 14.9 mm. Given good light and adequate time, crickets can be sexed down to about 9 mm HFL. Under field conditions, we feel there is potential for error in sexing crickets with HFLs < 15 mm.

Analysis of size distribution data is not yet complete. Within a given season there appear to be no differences (with one exception to be discussed later) between caves. Data for all four caves have been summed for each season and will be presented in several related figures.

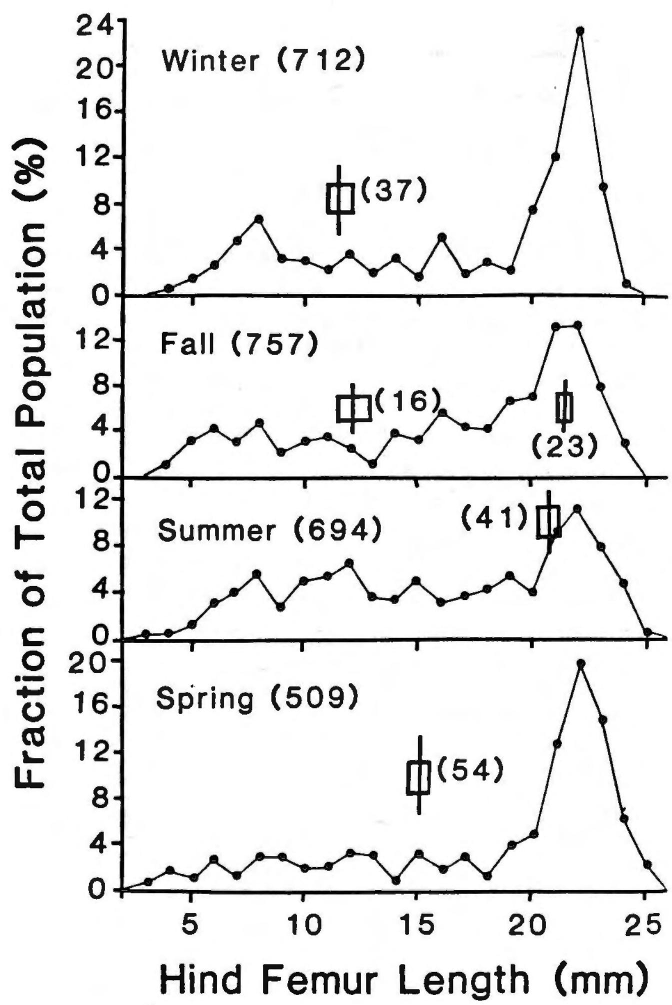

Figure 18: Size distributions of total collected cave crickets, Hadenoecus subterraneus, by season. Sample sizes in parantheses. Distribution of camel crickets, Ceuthophilus stygius, are represented by boxes where the bar is mean HFL and width presents 95% confidence intervals.

The distribution of crickets collected classified by HFL for all caves in all seasons is depicted in Figure 18. Inspection of Figure 18 shows no marked differences in individual size distributions between caves within any season and that crickets of all sizes are present in all seasons. Surprisingly, or disappointingly, there are no traceable peaks within the smaller sized crickets which would indicate a seasonal period of intense reproduction within the populations and allow estimation of growth rates. This seems strange in view of reported marked seasonal differences in reproductive effort in this species (Barr, 1976; Kane *et al.*, 1975; Hubbell and Norton, 1978). Perhaps reproductive effort shows stronger seasonality in "deep cave" sites as opposed to entrance sites.

Data for camel crickets (*Ceuthophilus stygius*) are also presented in Figure 18 as discrete boxes, where the vertical line is the mean HFL of crickets measured and the width shows 95% confidence intervals. Camel crickets exist in discrete size categories by season, reflecting their yearly life cycle.

In all seasons, adult cave crickets (HFL > 19.9 mm, see Studier *et al.*, this issue) comprise the greatest fraction of each population. Figure 19 shows total crickets summed for all four caves for each season. The preponderance of adults could be due to a regular pulse of reproduction with that group reaching adult size at the same time and/or the probability that developing crickets pass through early instars regularly but remain in adult form much longer than in any sub-adult stage. Since adult crickets can live at least 17 months (W. Wares, personal communication) vs the 7 to 11 months reported by Hubbell and Norton (1978), the second explanation and probably both explanations contribute to the preponderance of adults in each season.

The fraction of the total population represented by adults varies in a cyclic seasonal pattern reaching maximum representation in winter (52.0%), minimum representation in summer (37.9%) and intermediate levels in spring (50.9%) and fall (42.9%). The decrease in adult percentage of population indicates a marked mortality among adult crickets, especially in the spring to summer period, followed by a maturation of sub-adults in the summer through winter period.

The same data are shown as age pyramids separated by sex in Figure 20. When tested by chi-square with Yates correction for continuity, total crickets by gender among sub-adults (15.0-19.9 mm; 263 females: 231 males) show a sex ratio not different from 1:1 ($x2=2.0$; 1 d.f.; $P>0.1$). Similarly tested, adult crickets by gender (713 females: 509 males) show a sex ratio which is significantly different from unity ($x2=34.0$; 1 d.f.; $P<0.005$). Lack of a sexual bias among sub-adults and the preponderance of females among adult crickets implies a differential mortality

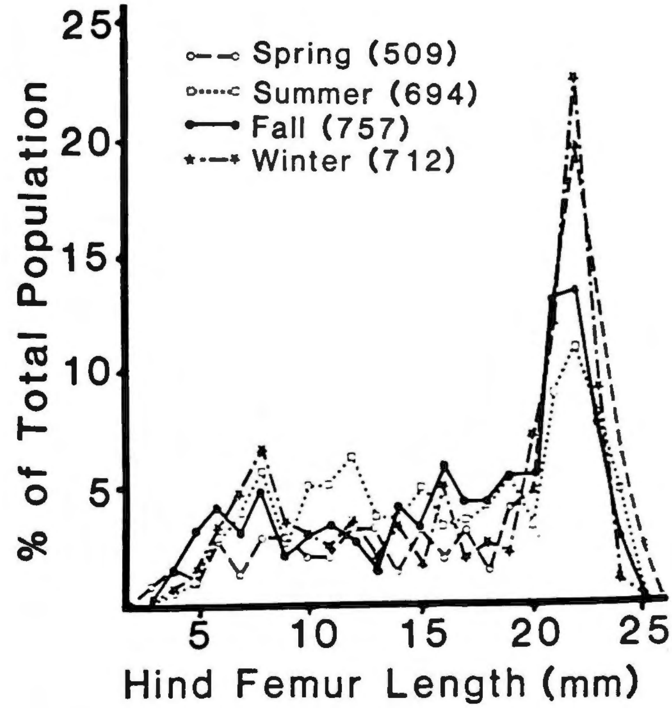

Figure 19: The fraction of total collected cave crickets of each size by season. Sample sizes are in parentheses.

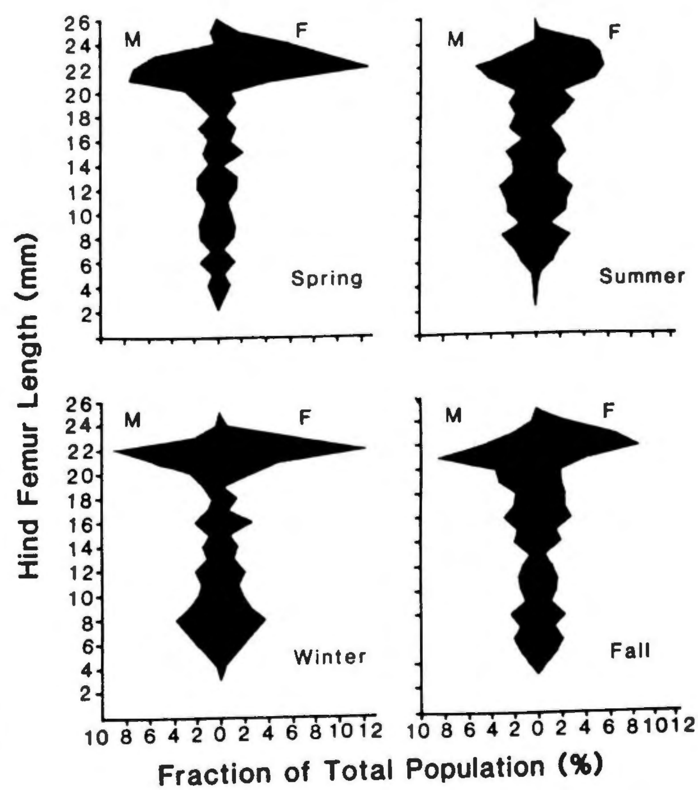

Figure 20: Age pyramids by HFL for male and female cave crickets collected in each season. Crickets below 15 mm HFL were not differentiated by sex. Individuals with HFL ≥ 20 mm are adults.

among adult crickets with greater death rates among adult male crickets. We have determined that male crickets must leave the caves to feed more frequently than females, which may result in greater predation on male crickets outside the security of the cave (Studier, *et al.*, 1986).

Although only general impressions were noted, we agree that total populations were largest in the winter season and smallest in the summer season. These observations agree with Hubbell & Norton's (1978) data on adult crickets. These changes in total population sizes may be real, or may be the result of fewer suitable roosts available during the harsh winter months, resulting in preferential localization of crickets in caves which are easily accessible to scientists. One final observation is pertinent regarding total populations. With one exception, we estimate that counts in all caves in all seasons represented no more than 10% of total populations. The exception, the winter count in Crystal, represents all crickets found in the cave census area (total count = 78 crickets). The drastic population crash in this cave in winter is directly attributable to a marked decrease in the relative humidity in that cave at that time due to a large influx of very cold air. Crickets were unable to maintain water balance in the relatively dry air (66% RH), rapidly dessicated, and died. Specifics of that process will be reported elsewhere. Interestingly, the Crystal population was nearly back to normal by April-May 1987.

We recently field tested the potential usefulness of some mark-recapture methods for estimating total adult populations and anticipate doing these studies over the next year.

Acknowledgements

We would like to thank CRF for access to field facilities in MCNP. This research was done as a part of Research Science Project MACA-N-103 with the cooperation of the National Park Service. We thank the many willing students and friends who helped collect data over the year of this study. Special thanks go to Ernie and Annie Szuch for aid in field work and to Dr. Tom Poulson for useful discussions.

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Biology of cave crickets (*Hadenoecus subterraneus*), and camel crickets (*Ceuthophilus stygius*) (Insecta; Orthoptera): parasitism by hairworms (Nematomorpha)

Eugene H. Studier, Kathleen H. Lavoie, and Clay M. Chandler

Abstract

Gordiid hairworms identified as *Chordodes morgani* were collected from a rivulet in Floyd Collins' Crystal Cave, KY, and the hemocoel of camel crickets, *Ceuthophilus stygius* and cave crickets, *Hadenoecus subterraneus*. These collections extend the range for *C. morgani* to include Kentucky and add two new host species for this parasite. Infection rates for adult camel crickets were 16.9% for females and 2.9% for males. Adult cave crickets showed low infection rates of 0.8% and 0.9% for males and females, respectively. Based on average hairworm biomass, growth was slow during the summer while hosts were sexually immature and then became very rapid as host crickets matured. Repression of ova development was seen in parasitized female camel crickets (34.0 ova/female vs. 2.2 ova/parasitized female).

Research

The occurrence of internal helminths (unidentified gordiid hairworms) in the camel cricket, *Ceuthophilus stygius* and cave cricket *Hadenoecus subterraneus*, was very briefly mentioned in Hubbell (1936) and in Hubbell and Norton (1978), respectively. Hubbell (1936) also indicated fly larvae of *Oedematocera flaveola* Coquillet as frequent parasites of camel crickets.

From March 1986 through July 1987, nearly monthly collections of cave and camel crickets were made in several caves in or near Mammoth Cave National Park, Kentucky (Walnut Hill, Great Onyx, White, and Floyd Collins' Crystal Caves as well as the Frozen Niagara and Austin Entrances to and Sophys and Marion Avenues of Mammoth Cave). In association with ongoing studies of the biology of these crickets (e.g., Studier *et al.*, 1986, 1987a) collected individuals were dissected for several purposes including examination for macroscopic internal parasites.

Juvenile horsehair worms were found in some crickets of both species in the May through December samples. Additionally, 2 adult hairworms were collected on the floor of the entrance to Floyd Collins' Crystal Cave from a temporary rivulet created by heavy epigean rain in late July, 1987. These adult hairworms and one adult from cricket hemoceal were identified as *Chordodes morgani*. A second juvenile worm from cricket hemocoel was tentatively identified as *C. morgani*. These collections extend the range for *C. morgani* (Chandler, 1985) to include Kentucky and add 2 species for this parasite. The voucher specimens are deposited in the U. S. National Parasite Collection, accession numbers.

Although details of reproductive and population biology will be presented elsewhere, cave crickets (*Hadenoecus subterraneus*) reproduce throughout the year and adult life span exceeds one year. Individuals of all age classes are, therefore, present in all seasons. Only 2 hairworm juveniles were found in adult cave crickets: one in a male (of 106 examined = 0.9%) and one in a female (of 130 = 0.8%) both collected on 9 December 1986 from Floyd Collins' Crystal Cave. Of 153 juvenile cave crickets examined (49 in May, 50 in August and 54 in November), none was parasitized by hairworms.

Camel crickets (*Ceuthophilus stygius*) complete their life cycle in one year and reproduce only in the fall, so adults were found only in the July through October collections. Of 70 males examined, 2 (2.9%) harbored hairworms while 11 of 65 (16.9%) females were parasitized, thus females are hosts more frequently than males. Parasitized individuals came from caves, representing where collection efforts were made in any given month. The 3 May and 4 October crickets came from Great Onyx Cave; 24 October, one each from Frozen Niagara and Austin Entrances, and 4 from Great Onyx Cave.

O'Brien and Etges (1981) reported that camel crickets collected about 100 miles NE of Mammoth Cave National Park function as common intermediate hosts for the roundworm *Pterygodermatites coloradensis* but they make no mention of the occurrence of hairworms in the animals they examined. In addition to the horsehair worms, we collected one unidentified fly larva from a *Ceuthophilus*. No voucher specimens of either parasite are available.

Including all age hosts, camel crickets (9.6%) are much more heavily parasitized than cave crickets (0.5%). The higher incidence of hairworms in camel crickets may relate to their need to drink water to maintain water balance whereas cave crickets do not (Studier *et al.*, 1987b). Of parasitized male camel crickets, one contained one hairworm while the other harbored 2. Of 11 parasitized females, 7 contained one, 3 contained 2, and one contained 3 juvenile hairworms. Hairworm parasite load in individual camel crickets (1.46) is somewhat higher than in cave crickets (1.00).

Some indication of growth rate of the hairworms can be determined by following changes in average worm biomass with time. Among camel crickets, average hairworm biomass was 46.3 mg in 2 parasitized individuals on 3 May 1986, 67.4 mg in 5 individuals on 4 October 1986, and 168.8 mg in 6 individuals on 24 October 1986. Based on these limited data, hairworms grow very slowly during the summer while the host camel crickets are subadults and young adults, and grow very rapidly when host crickets rapidly develop gonads and become sexually active.

Energy which would be devoted to ova growth appears to be diverted to parasite nutrition in adult camel crickets. Seven non-parasitized female camel crickets collected in October 1986 contained an average of 34.0 ova while 9 parasitized females collected at the same time contained an average of 2.2 ova. In fact, 7 parasitized females contained no ova at all. A similar phenomenon has been reported for Mormon crickets parasitized by hairworms (Thorne, 1940).

Acknowledgements

We thank the many students and colleagues who participated in the field work and the Cave Research Foundation for the use of their field facilities. This work was done under MACA-N-103 with the cooperation of NPS personnel at Mammoth Cave National Park. Funding was provided by a University of Michigan Faculty Development Grant to EHS.

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Aspects of Population Structure in Cave Crickets, *Hadenoecus subterraneus*

Studier, E. H., K. H. Lavoie, D. Nevin and K. McMillin

Abstract†

We determined individual size (hind femur length) by sex for cave cricket populations by season at four caves in or near Mammoth Cave National Park, KY. There were no marked differences in individual size distributions between caves within any season. Crickets of all sizes were present in all seasons. Adult crickets comprise the greatest fraction of each population in every season. There are no traceable peaks within the smaller sized crickets indicating no marked seasonal differences in reproductive effort in cave crickets. The fraction of adults in measured populations varies in a cyclic seasonal pattern reaching a peak in winter (52%) and a minimum in summer (38%). The changes in adult percentage of the population may reflect seasonal differences in emigration and immigration but more likely results from a marked mortality among adult crickets in the Winter to Summer period and maturation of sub-adult in the Summer to Winter period. For all crickets counted, there is no gender prevalence among sub-adult crickets while the sex ratio of adults shows significantly more females than males. Our data, therefore, indicate greater mortality rates among adult males than females. Although only general impressions were noted, we agree that total populations were largest in the Winter sample and smallest in the Summer. An apparent population crash occurred in Crystal Cave in the Winter of 1987 due to an influx of cold air which lowered relative humidity in the entrance and normal roosting sites.

† Paper presented at the N.S.S. Convention, July, 1987.

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Aspects of Reproductive Biology in Cave Crickets, *Hadenoecus subterraneus*

Studier, E. H., K. H. Lavoie, D. Nevin and K. McMillin

Abstract††

Monthly collection, dissection and fresh and dry weighings of adult as well as copulating pairs of individuals provide useful data on several aspects of the reproductive biology of cave crickets, Hadenoecus subterraneus, in Mammoth Cave National Park, KY. Minimum spermatophore frequency (50%) in adult males occurred in September with essentially all mature males having spermatophores from October through May. Mature ova reached peak frequency in January and February and minimal frequency in July. With the possible exception of July, mature crickets appear to be capable of reproduction in all months with peak frequency occurring in January and February. While males invariably had two spermato-

phores, the number of ova present in gravid females varies from 1 to 30. With the exception of one sample, numbers of mature ova in gravid females were seasonally consistent at 6.0 to 7.4 ova per cricket. The exception was a sample of 8 females collected in the Winter from Sophy's Avenue of Mammoth Cave which averaged 18.1 ova per cricket. Cave crickets of both sexes are sexually mature when their hind femur length ≥ 20 mm. Compared to non-copulating gravid adults, females contain the same number of mature ova (6.1 ova per female), both sexes have somewhat higher wet carcass weights and markedly lower crop contents.

†† Paper presented to the N.S.S. Convention, July, 1987.

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Jumping Parameters in Cave Crickets, Hadenoecus subterraneus

L. Mason, E. H. Studier and K. H. Lavoie

Abstract†

Cave crickets of all sizes and both genders were studied primarily in Sophy's and Marion Avenues of Mammoth Cave National Park in May and July of 1987. Cave crickets were collected from cave walls and ceilings, brought immediately to the nearby testing area (a wide, smooth part of the cave floor) and encouraged to jump successively to exhaustion. Parameters measured included primary compass direction taken by the crickets, number of hops, time to exhaustion, total distance covered and individual hop distances. Among adult crickets, there were no gender related differences in any measured parameter nor was there a primary compass direction taken. For adults, number of hops, time to exhaustion, total distance hopped and individual hop distances averaged (range) 8.0 (3-15), 11.2 sec (6.8-17.8), 334 cm (156-688) and 43.0 cm (22.3-71.7), respectively. There was no relation between individual hop distances with successive hops (total range = 9-116 cm). Upon exhaustion, hind legs of most crickets became rigidly extended. Using their front four legs, exhausted crickets walked to a hiding place. Hind legs could not be voluntarily flexed by the crickets for many minutes after hopping to exhaustion. These data indicate that muscle fibers used in jumping may be exclusively fast twitch (white) muscle cells.

† Presented to the N.S.S. Convention, July, 1987.

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Microbial involvement in food digestion by cave crickets, *Hadenoecus subterraneus*

Lavoie, K. H., E. H. Studier and C. Kennedy

Abstract†††

Although data are still tentative, digestive enzymes found in the crops of cave crickets are produced by microbes found in the crops. These microbes include a predominant group of Gram positive bacteria and a yeast found in all crops of all crickets examined at all times of the year. We are using electrophoretic techniques to compare crop enzymes with enzymes produced by pure cultures of these microbes. Information on the histology of the cricket digestive tract will also be presented, which indicate no secretory structures associated with the crop to provide cricket-produced enzymes.

††† Paper presented at the N.S.S. Convention, July, 1987.

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Possible food storage strategies used by the cave rat, *Neotoma floridana*

Lavoie, K. H., L. Sawyer King and L. Simonuvic

Abstract†

Cave rats (*Neotoma floridana*) inhabit the entrance areas of most caves in Kentucky and Indiana. These rats generally store nuts, grains and other food in the caves. The high humidity and relatively warm cave temperatures provide ideal conditions for the growth of food-spoilage microbes, including the fungi which produce mycotoxins. It has been observed that cave rats almost universally have cedar in their nests and middens. We thought that the volatile compounds in cedar might provide a natural fungicide which would reduce food spoilage of stored material in caves. A laboratory study showed no significant difference in the plate counts of fungi and bacteria on corn and sunflower seeds placed directly on cave mud with or without cedar. Placement of foods on the cedar instead of directly on the mud did reduce the growth of microbes on both corn and sunflower seeds, and also reduced the rate of germination of

stored food. Ungerminated seeds would provide richer sources of nutrients for cave rats than germinated seeds. Cedar may be used by cave rats to preserve both the nutritional quality of stored foods and to reduce their spoilage.

[†] Paper published in *The NSS Bulletin Journal of Caves and Karst Studies*, Vol. 47 No. 1, October, 1985.

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Water budgets of cave crickets, Hadenoecus subterraneus and camel crickets, Ceuthophilus stygius

E. H. Studier, W. D. Wares II, K. H. Lavoie and J. A. M. Linn

Abstract[††]

1. Studies of cave and camel crickets from cave entrances in Mammoth Cave National Park have produced estimates of total water budgets and component contributions to water balance.

2. Weight specific (mg/g crop-free live weight/hr) total water loss (3.200 vs 2/220) and water gaoined in food (2.393 vs 1.902) are greater in cave than in camel crickets, repectively.

3. Weight specific evaporative water loss in both humid, still air (2.269 vs 1.325) and dry, moving air (15.28 vs 9.85) is greater in cave than in camel crickets, respectively.

[††] Paper published in *Comp Biochem. Physiol*, Vol. 86A, No. 2, pp 295-300, 1987.

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ARCHAEOLOGY AND ANTHROPOLOGY PROGRAMS

In Memorium - Tribute to Louise Robbins

Patty Jo Watson

A shadow was cast over this year by the loss of Louise Robbins, for more than 20 years a devoted and much-valued participant in CRF archaeological work in Kentucky and Tennessee. After a long and valiant battle with cancer, Louise died on June 6, 1987. She was one of the earliest members of the CRF Archaeological Project, beginning her work with us in the late 1960s by a careful analysis of the Salts Cave mummy "Little Al" (Robbins 1971). She spent hundreds of hours both above ground and below with CRF Archaeological Project personnel in support of a wide variety of investigations, while herself contributing curatorial and chronological studies on the Mammoth Cave mummy ("Lost John"), documenting and interpreting the 4500 year old human footprints in Jaguar Cave, Tennessee, and recovery and description of human remains from Blue Spring Hollow shelter in Mammoth Cave National Park as well as from the Carlston Annis and Bowles shell mounds. All of this activity was important and central to our endeavors, but my own memories of working with Louise center on the summer of 1974 when we were attempting to devise a flotation-water separation system for mass-processing sediments from the Carlston Annis shell mound. In spite of many discouraging setbacks, Louise's cheerful suggestions, the inventive techniques and mechanical skills she applied to our primitive waterworks system, and her willingness to work hard and virtually nonstop — without complaint — for 12 to 14 hours at a stretch were crucial factors in our ultimate success. None of us who did fieldwork with Louise in the caves, rockshelters, and shell mounds of Kentucky and Tennessee will forget her. As she was for so many years, so she still is in our memories: a strong; buoyantly enthusiastic, and knowledgeable friend and colleague.

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Cave Research Foundation Archelogical Project - 1987

Patty Jo Watson

Field Trips, Conferences, and Presentations

In May, 1987, P. J. Watson participated in the CRF 30th Anniversary Symposium at Mammoth Cave National Park by summarizing the major results of the CRF Archaeological Project and joining the discussion among Mammoth Cave and other NPS officials and CRF personnel about future problems and prospects.

During June, three fieldtrips took place. Bruce McMillan, Director of the Illinois State Museum, led a lively group of Museum personnel – archaeologists, biologists, and geologists — to the Park where they were met by CRF Archaeological Project members P.J. Watson, M.C. Kennedy, and R. Wilson. With the cooperation of superintendent Pridemore and the Mammoth Cave staff, we guided them through an evening tour of the Main Cave in Mammoth (Historic Entrance to Violet City); then on the following day took them to the Big Bend of Green River and the Carlston Annis shell mound in Butler County where we have been carrying out research complementary to the cave archaeology since 1972. This last part of the tip was made especially memorable by a lavish buffet dinner prepared and served by Mr. and Mrs. Waldemar Annis, who own the bottomland where the shell mound is located. Consequently, the Illinois scientists were favorably impressed not only by the research, but also by the friendliness and hospitality of the people with whom we work.

The second June field trip was made into the upper level, Black Chamber area off Wright's Rotunda in Mammoth Cave. CRF - JV geologist Sam Frushour led while Patrick Munson, Ken Tankersley, Mary Kennedy, and Pat Watson made observations on selenite and other gypsum mining activities to advance the investigations referred to in the 1986 Annual Report (p. 33).

The third trip was made by Ron Wilson, Mary Kennedy, and Pat Watson to Jaguar Cave, Tennessee, to obtain a few measurements for the final detailed map and report on the archaeology of that cave. We plan to submit the report to the Journal of Field Archeology in the near future.

In August, Chris Hensley-Martin an Mary Kennedy represented the CRF Archaeological Project at a conference held in Mammoth Cave National Park by NPS archaeologist Guy Prentice. Prentice is carrying out a three-year reconnaissance survey and excavation program on the surface archeology of the Park as part of a major effort to create a comprehensive inventory of cultural-historic remains within the Park boundaries. CRF archaeologists are cooperating closely with Prentice, as are the Kentucky Heritage Council personnel who oversee archaeological research throughout the state.

In November, P. J. Watson presented a lecture and discussion at the Institute of Archeology, University of London. The topic was Mammoth Cave archeology and the light it throws upon the origins and development of plant domestication.

Reference

Robbins, Louise M., 1971, An Early Woodland Mummy from Kentucky, *American Antiquity*

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Archaeological Investigations at the Floyd Collins Birthplace, Edmonson, County, Kentucky

Philip J. DiBlasi

Abstract

In October 1987, a domestic water line was placed across a portion of the William Floyd Collins Birthplace/ Crystal Cave Complex located in Edmonson County, Kentucky. Prior to excavation, plat maps were examined to determine the potential this action would have in disturbing structures associated with the life of Floyd Collins. The water line was excavated mechanically using a "Ditch Witch" that produced a transverse profile of the site. Though no features were encountered, these methods produced a small but significant assemblage. Subsequent analysis of this highly fragmented material culture indicated the presence of the structure where William Floyd Collins may have been born and spent the first 20 years of his life. Additionally, this study has served to: (1) further assess the applicability of artifact patterning studies and mean date determinations to rural domestic sites; (2) demonstrate the utility of applying readily available information on commonplace artifact forms to date structural elements of standing structures; and (3) permit a glimpse of the material possessions and lifeways of a struggling farm family in turn-of-the century Kentucky.

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The Mechanics, Utility and Status Report of the Small Cave Resource Inventory at Mammoth Cave National Park

Philip J. DiBlasi

Abstract

The Small Cave Resource Inventory (MACA-N-98), describes caves and karst features in a uniform manner employing a standardized "check-off" form. Two forms are used: one for the entrance (including the twilight zone and immediate environs) and an interior form. Data recorded includes: locational, physical, geological, bio-

logical and cultural information. The form has been structured in a way which makes it useable in most commercially available data bases for storage and retrieval.

Over 200 caves and karst features are recorded in Mammoth Cave National Park and with the assistance of the Cave Research Foundation approximately 10 percent have been surveyed and inventoried. Maps and inventories are made available for resource managers and researchers as they are produced. It is expected that the results will eventually be published in a folio format.

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Preliminary Results of Investigation at Bering Sinkhole: A Karst Feature Burial Vault

Leland C. Bement

Bering Sinkhole (41KR241) is located in northern Kerr County, in the central portion of the Edwards Plateau, a limestone karst area of central Texas (Figure 1). Common geological features in this region include caves, caverns and sinks, which, in the former, were often used by prehistoric man as habitation sites and, in the latter, as burial localities (Turpin and Bement 1985:23). Site 41KR241 is a solution cavity which has been exposed on the surface, forming a sinkhole. The solution cavity formed along a north-south trending fault line which was expanded by water erosion. The surface opening is 2 meters east/west by 4 meters north/south and is located at the south end of the fault line (Figure 21). Sediments, washed into the opening from the surrounding hillslope, have 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 cavity could be quite large. In addition, surface runoff is channelled into the opening but no standing water has been observed in the chamber even after hard downpours of over 1/2 inch.

Interest in this hole by the landowner led to the removal of 2 meters of sediments from a 1.5 by 3 meter portion at the southern end with the aid of a track hoe. During the course of this mechanical excavation, rodent, wolf, bear and human skeletal remains were removed. Professional archaeologists were contacted to evaluate the find, and materials were distributed for analysis. Initial findings revealed that a minimum of six human skeletons had been removed. Charcoal collected by Dr. Joel Gunn, The University of Texas at San Antonio, rendered an uncorrected age of 1085 +/- 60 years before present (Pitt-0073). When calibrated using Stuiver and Riemer (1986) one sigma ranges from AD 890 to AD 995, date at least one usage of the hole to the Late Prehistoric Period.

In an effort to determine the possible limits of the cavern and the potential for additional human burials and paleontological specimens, a testing program was conducted by Dr. Solveig Turpin, Dr. Herb Eling and Leland Bement of the Texas Archaeological Research Lab, UT Austin, between October 16 and 23, 1987. Test procedures included the cleaning and documentation of the track hoe excavation, downward and lateral extension of the pit, and the removal of special samples for further analysis.

Test excavations immediately uncovered additional human and rodent skeletal remains in the alcove deposits along the east side of the shaft (Figure 21). The density of human skeletal remains slowed the progress of the excavation with a total area removed at 2.8 square meters to an average depth of 30 centimeters. All excavated deposits were water screened through window mesh hardware cloth.

Preliminary results of the testing program show the human materials recovered represent almost every anatomical element, thus indicating the good preservation of the deposits. A minimum number of individuals has been set at seven based on the repetition of single elements, five right calcanei; dentition and post crafial elements of a juvenile; and the burned and scorched remains of a probable cremation.

Cultural materials associated with the skeletons include eight tubular bone beads, a deer antler billet, and a badly burned projectile point. The projectile point was contained in a concentration of charcoal and burned bone from the cremation. Unfortunately, the extensive burning of this specimen has rendered typological classification impossible, although its size is that of a dart point rather than an arrowpoint. In addition, a Frio dart point was recovered from one of the track hoe bucket dumps. This point indicates a Late Archaic utilization of the sink.

Formal analysis of the sinkhole remains is currently underway. The seven individuals recovered during the test excavation and other six removed previously (assuming the latter are not a subset of the former) bring the total number of interments to 13; the only burial popula-

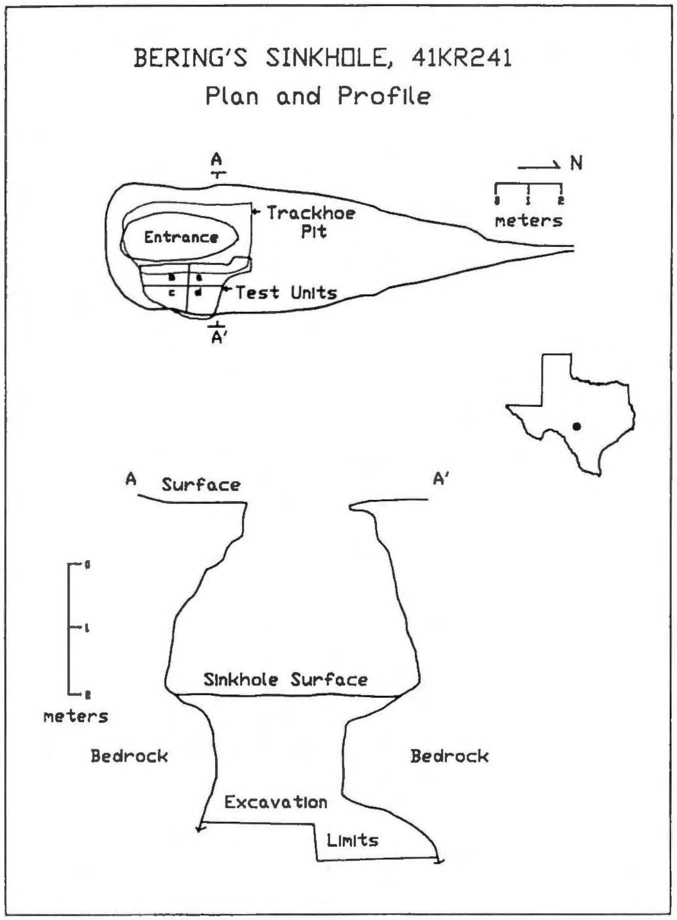

Figure 21: Location, plan and profile of Bering Sinkhole.

tion known from Kerr County. Such burial populations provide invaluable information on the diet, health, and social composition of prehistoric groups on the Edwards Plateau, and add a new site type to the cultural inventory of the area—broadening our understanding of prehistoric cultural adaptations in this major karst region of Texas.

Acknowledgements

Funds provided by the Karst Research Fellowship were used to defray expenses incurred during fieldwork and in the initial analysis of recovered materials. Lodging accommodations as well as water and electricity were graciously provided by the landowner, Mr. Augie Bering. Excavation materials and analysis lab were provided by the Texas Archaeological Research Lab, The University of Texas at Austin.

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CRF Fellowship and Grant Support

Each year, the Foundation may award up to $7500 as a Fellowship or as one or more grants for research in karst-related fields. The truly exceptional proposal may receive a Karst Research Fellowship (limit $3500); meritorious proposals may receive one or more karst research grants, in amounts less than $2000, awarded to qualified students in graduate programs in the natural or social sciences. Applications 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 the methodology. A detailed announcement of the competition is mailed in early Autumn, and the deadline for receipt of the proposal, supporting documents and letters of reference is January 31. Awards are announced by April 15. Send inquiries to:

Dr. John C. Tinsley
U.S. Geological Survey
345 Middlefield Road, Mail Stop 975
Menlo Park, CA 94025

In 1987, thirteen proposals were received and one Fellowship and six Grants were awarded:

1. A CRF Karst Fellowship ($2000) awarded to Mr. Bailey D. Kessing, Department of Zoology, University of Hawaii, Honolulu, HA 96822, for his proposal entitled "The evolutionary history of the cave spider Lycosa howarthi: a mitochondrial DNA analysis".

2. A CRF Karst Research Grant ($500) awarded to Mr. Leland C. Bement, Texas Archeological Research Laboratory, 10100 Burnet Road, BRC 5, Austin, TX 78758-3120, for his proposal entitled "An archeological investigation of a vertical shaft sinkhole in Val Verde County, Texas".

3. A CRF Karst Research Grant ($1000) awarded to Mr. David M. Griffith, Department of Biology, University of Illinois at Chicago, Chicago, IL 60680, for his proposal entitled "The dynamics of a terrestrial cave predator-prey system: abiotic and biotic interactions".

4. A CRF Karst Research Grant ($1000) awarded to Mr. Ross Jones, Department of Ecology and Evolutionary Biology, Northwestern University, Evanston, IL 60201, for his proposal entitled "A neuroanatomical study of regressive evolution of the amphipod Gammarus minus"

5. A CRF Karst Research Grant ($1000) awarded to Mr. Jerry R. Miller, Department of Geology, Southern Illinois University, Carbondale, IL 62901, for his proposal entitled "Channel form adjustment in response to karstification in south-central Indiana: a study of process linkage".

6. A CRF Karst Research Grant ($1000) awarded to Mr. James Webster, Department of Geography and Geology, Western Kentucky University, Bowling Green, KY 42101, for his proposal entitled "The association between radon levels in the caves and residential environments of Bowling Green, Kentucky".

7. A CRF Karst Research Grant ($1000) awarded to Ms. Betty Wheeler, Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455 for her proposal entitled "Water quality of Coldwater Cave, Winneshiek County, Iowa".

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

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INTERPRETATION AND EDUCATION PROGRAM

Figure 22: Scott House (left) peers through 3D glasses at a three-dimensional line map of the Lilburn Cave system as Stan Ulfeldt explains the various cave levels and their relationship to the surface of Redwood Canyon.

Education Program

Cave Management Plan at Ozark National Scenic Riverways

Scott House

The Ozark National Scenic Riverways has begun work on a comprehensive cave management plan for the 250+ caves within the Riverways boundaries. Issues include: recreational caving, research, biota preservation, archaeological and paleontological resources, etc. The ONSR also has some of the largest springs in the United States: five springs each flow over 25 million gallons per day (the largest, Big Spring, flows an average of 276 m gpd), another ten each flow over 1 m gpd.

Management steps are planned to protect the integrity of the karst and biotic resources of the area. One important feature of the plan is that each cave will have an individual cave management prescription written for it. There will be no wholesale categorization of caves into management types. An additional feature is that an advisory team will work with the Park Service in the writing and revising of these prescriptions. Consultants presently working with the park on the plan are: Alan Everson of the University of Missouri, Tom Aley of the Ozark Underground Laboratory, and Scott House of Cave Research Foundation.

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Cave Wilderness

Sarah G. Bishop

During 1987 interest in cave wilderness in national parks reawakened after well over a decade of silence. William P. Mott, Jr., the Director of the National Park Service, asked Sarah Bishop, a CRF Director, to make a presentation to him and some of his staff about the concept.

The cave wilderness concept was first described by the NSS in 1967 in the form of a wilderness proposal for Mammoth Cave National Park. At first the NPS rejected it as incompatible with the Wilderness Act, but in 1975 the Department of the Interior, which includes the NPS, accepted cave wilderness as a legal interpretation of the Act, but chose not to make any designations at that time.

Mr. Mott seemed very interested in where cave wilderness could be designated in the national parks. Dr. Bishop pointed out that Mammoth Cave was an ideal candidate being that it is the longest cave in the world and a World Heritage site. Also, whereas some of the surface of the park might not qualify as wilderness, cave passages underneath could still be truly wild. Mr. Mott was impressed with the advantages of designating at least part of the Mammoth Cave System as wilderness and asked the park staff to look into the possibilities. Cave wilderness is now included in speeches Mr. Mott presents around the country.

A second expression of interest in cave wilderness came from Carlsbad Cavern National Park. Lechuguilla Cave had finally been opened up in the park and the survey teams were discovering a fabulous wonderland. Richard Smith, the park superintendent, wrote a letter to the caving community via *The NSS News* asking for comments on and support of cave wilderness designation for Lechuguilla. The NSS asked Sarah Bishop to chair a Cave Wilderness Subcommittee, which she agreed to do, making it a joint effort with CRF. As the year came to a close, interest in and support for cave wilderness at Lechuguilla started building within the caving and conservation communities. At the fourth World Wilderness Congress the attendees passed a resolution calling for caves throughout the world to be evaluated for possible wilderness designation. The issue was certainly revived. Surely action will be forth coming.

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News and Notes from Washington, DC

Sarah G. Bishop

March, 1987 - National Parks and Conservation Association Conference on Americans Outdoors.

NPCA's conference focussed on the recommendations from the President's Commission on Americans Outdoors. Points of interest to CRF are the role of volunteers, partnerships between public and non-profit organization, and access to and conservation of federal lands. Sarah Bishop participated in the conference and encouraged increased public involvement with federal land managers in accomplishing their major goals and objectives.

July, 1987 - National Park Service Workshop on Park Friends Groups.

Sarah Bishop represented CRF at the workshop which attracted over 100 NPS managers who were interested in starting friends groups. A primary concern of the attendees was how to get money to do projects that were beyond the reach of their budgets. They felt this should be a major function of a friends group. Bishop promoted the recruitment of volunteers with professional level expertise to do this type of project in cooperation with park personnel. Emphasis was placed on the benefits of building a park constituency based on contributions of time and energy to important park projects. Several superintendents expressed interest in volunteer projects. Work is being done to assist in the recruitment of capable volunteers.

Take Pride in America Awards

The Cave Research Foundation was a semi-finalist in the national Take Pride in America competition. Also, both the National Park Service and the State of New Mexico recognized the Foundation with Take Pride in America awards. The awards were in recognization of more than 4500 hours of work donated by CRF to Carlsbad Cavern and Guadalupe Mountains National Parks for cave research, exploration, mapping, and restoration and for helping with the interpretation of these efforts for park visitors.

The Federal Cave Resources Protection Act

A bill was introduced in the U. S. House of Representatives promoting the protection of caves on federal lands. The Cave Research Foundation encouraged the passage of this bill. (Note: the bill passed the House in March, 1988 and is under consideration in the Senate). ∞

Preliminary Results of an Investigation of Radon Levels in the Homes and Caves of Bowling Green, Warren County, Kentucky

James W. Webster

Introduction

Radon (^{222}Rn) is a naturally-occurring radioactive gas that is a product of the radioactive decay of uranium which is widely distributed in rocks and soils. The decay of radon results in the formation of several radioactive ions which when inhaled can attach to lung tissue. Decay of these ions releases alpha particles which can destroy, damage or mutate lung tissue.

Outdoor radon levels are thought to present no significant health hazard because of the diluting effects of the atmosphere. Indoors, radon can accumulate to hazardous levels. It has been estimated that as many of 20,000 lung cancer deaths per year in the United States may be associated with radon (EPA, 1986). Radon gets into homes from soil and rock by seepage through openings in floors and walls. Radon in groundwater can be released into homes from private or municipal wells.

Identification of Problem and Purpose of Research

Bowling Green, Kentucky is a city of approximately 50,000 people located approximately thirty miles from Mammoth Cave National Park. The city has had a history of problems which are associated with the karst landscape upon which the city is built. Of particular concern has been the problem of chemical fumes rising from contaminated caves beneath the city and collecting in buildings on the surface. Research has shown that in many cases, buildings with a history of fume problems have some type of a direct connection with the cave system beneath the city (Crawford, 1985).

Studies have shown that caves can have radon levels that are many times those of outdoor air. Grab samples by Webster and Crawford indicate that, at times, some Bowling Green caves have developed concentrations of radon daughters in excess of 5 working levels (1000 pCi/1 of radon gas assuming 50% equilibrium). Past problems with toxic fumes form contaminated caves entering homes has raised the question as to whether high levels of radon gas may be coming into homes as well.

The purpose of the study is to investigate the hypothesis that high levels of radon are coming into some homes from caves. The research method involves first establishing a working mean residential radon level for the city of Bowling Green and then comparing that value with the average radon concentration in buildings which are believed to have a direct connection with the cave system because of their history of fume problems.

Preliminary Data and Discussion

A total of one hundred homes have been tested as of November, 1987 using activated charcoal canisters. Residential radon levels averaged 10.4 pCi/1 and ranged from less than 1 pCi/1 to greater than 130 pCi/1. Fifty-seven percent of the Bowling Green homes tested were at or above the 4 pCi/1 value which has been adopted by the EPA as the residential warning level. The average for basements and first floors tested was 22.8 and 5.7 pCi/1 respectively. The average radon level for 12 buildings (not included in the general survey) with a history of fume problems tested thus far is 44 pCi/1 (Figure 23).

The statewide survey of residential radon levels in Kentucky, sponsored by the EPA, included 879 homes in 117 counties. The average value obtained by the state of Kentucky was 21.8 pCi/1 with 17% of the homes tested being at or above the 4 pCi/1 level. State wide, 83% of the homes tested were below the 4 pCi/1 level compared with 44% for Bowling Green (Figure 24). Sixteen percent of the homes tested statewide and 41% of the Bowling Green homes tested fell into the 4 to 20 pCi/1 range.

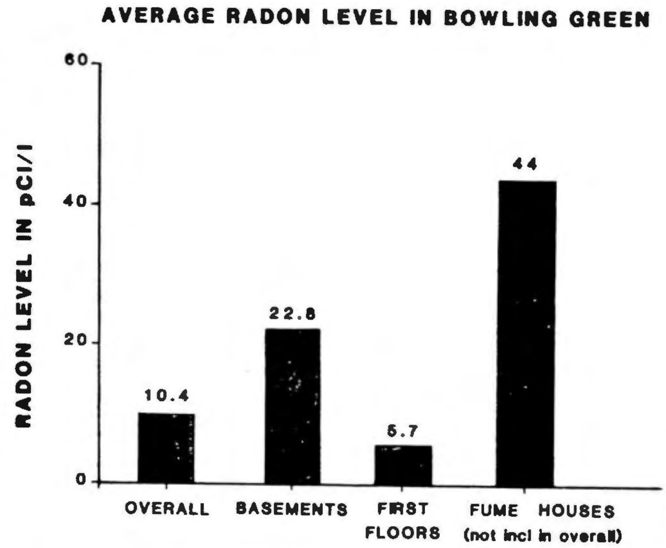

Figure 23: Average radon level for 12 buildings with a history of fume problems.

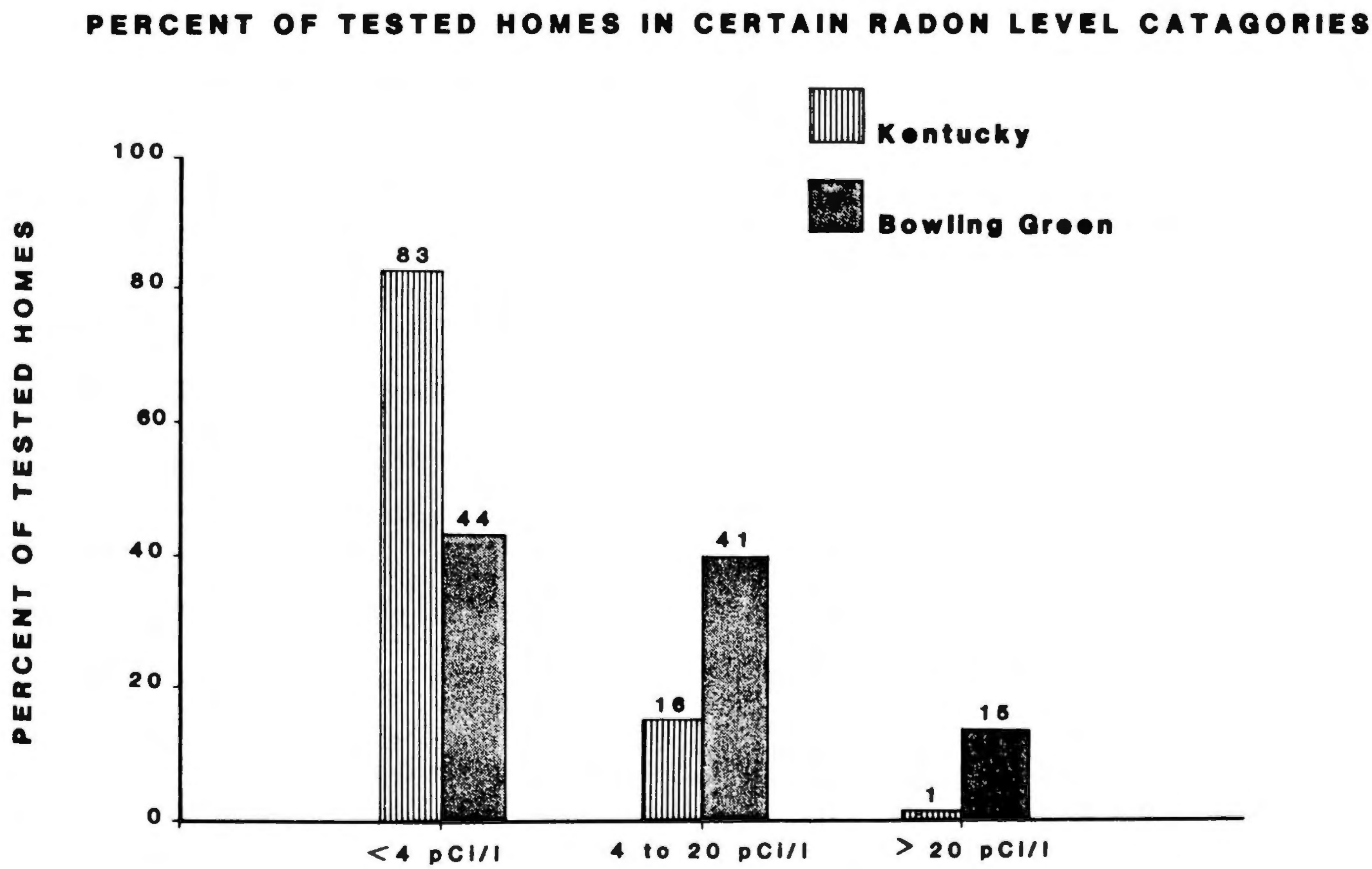

Figure 24: Comparison of homes tested for radon levels in Bowling Green and the state of Kentucky.

Statewide less than 1% of the homes tested were greater than 20 pCi/1 while 15% of the Bowling Green homes tested were above 20 pCi/1.

Twenty-five Warren County homes were included in the state survey. Fifteen of the 25 (60%) tested above the 4 pCi/1 level. Three of the six highest values recorded in the state were in Warren County.

Conclusions

Preliminary screenings indicate that residential radon may be a significant source of indoor air pollution for many Bowling Green residents. These findings seem to e supported by data collected by the state of Kentucky as part of a federally sponsored survey. The first step in dealing with the problem of indoor radon contamination is to identify those homes which have levels in excess of the recommended standards. If radon problem areas can be found in karst areas and delineated, then monitoring programs, remedial action and planning for radon mitigation in future developments can be carried out in a way that will benefit the public.

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Mammoth Cave Narrative Description Program

Mick Sutton

The Narrative Description Program, MACA N-124, was established in June 1987. The long-term goal of the program is to provide a comprehensive description, in more or less uniform format, of the hundreds of passages, rooms, shafts, etc., that make up Mammoth Cave. As a corollary to the passage descriptions, a gazetteer is being written, which gives basic information on all the place names that are in use or have been used in the Mammoth Cave System. A large part of the effort over the six months since the program was established has gone into setting up procedures and guidelines.

Gazetteer

The gazetteer is being developed primarily under the direction of Susan Hagan. Each entry gives the location of the feature and, where known, derivation of the name and other pertinent information. An example showing the general format is given below. The amount of information on each place name varies considerably. Often nothing is known beyond the fact that a name appears on a map; other entries contain a considerable amount of interesting historical background. At present, the gazetteer contains 234 entries for Mammóth Cave and 250 entries for Flint Ridge. This is nowhere near the final total, which we estimate will be in the range of 700-1000 entries. The gazetteer is constantly being expanded and updated as more information is analyzed. In conjunction with the gazetteer, a bibliography of source material is being assembled.

Passage Descriptions

Experimentation with format and cross-reference systems has led to what promises to be a workable approach. Passage descriptions are filed alphabetically; cross reference to the gazetteer gives the location of the passage and the name(s) of the 1:600 map(s) where it is portrayed. Each passage is described in the normal direction of inbound travel, where this is obvious; otherwise the direction is arbitrary. Short side passages and cutarounds are described with the main passage in the order in which they occur. Un-named passages are labelled with the named passage with which they are associated together with the appropriate CRF survey letter, e.g., "Woodbury L-Survey"; "Morison P-Loop". These too are described in the order in which they occur along the main (named) passage.

Morrison Avenue an its associated passages on the south flank of Mammoth Cave Ridge were chosen to develop and example of the form. These passages form a relatively long (3/4 mile) isolated group, and display a wide variety of long and short side passages and cutaround loops. They have considerable historical interest. An excerpt from the Morrison Avenue description (below), gives an idea of the style and the level of detail for which we are aiming. A preliminary description of Woodbury Pass (1800 ft long) has also been prepared. The western end of Kentucky Avenue, from Forks of the Cave to Morrison Avenue (about 1700 ft), has been described. In total, the described passages amount to 1.4 miles, or about half of one percent of Mammoth Cave. In addition, a description of the New Entrance, together with a stratigraphic column, is being developed under the direction of Rick Olson, and research on historic signatures is being conducted by Philip DiBlasi.

The main effort for now will focus on description of the passages of the Half Day and Frozen Niagara tours of eastern Mammoth Cave. The Kentucky Avenue and New Entrance descriptions will be completed, and descriptions of Sandstone, Cleaveland, and Boone Avenues, Roses Pass, and Jeanne's Avenue will be developed. In addition to this work, data is being collected opportunistically during certain survey trips. The ability to do this will expand as more people are trained in the style and techniques. Procedures for publishing the descriptions along with the appropriate maps will be formulated.

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Publications and Presentations

Published Articles and Papers

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Cave Books

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

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

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

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

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

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

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

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THE CAVE RESEARCH FOUNDATION

Figure 25: The Cave Research Foundation was honored in April, 1987 with the presentation by NPS Director William P. Mott of a "Take Pride in America Award". Accepting the award for the Foundation is Sarah Bishop, a CRF Director.

CRF's Thirtieth Anniversary Celebration

Sarah G. Bishop

On May 23, 1987, more than 50 members of the Cave Research Foundation and the National Park Service gathered at Mammoth Cave National Park to toast the longevity and successes of the Foundation. A symposium was convened to capture the highlights of CRF programs in exploration, cartography, research and management advice to the Park Service. The celebratory dinner that followed brought together old friends and new and capped a very happy day.

Dr. Eugene Hester, the newly appointed NPS Associate Director for Natural Resources, opened the symposium with remarks about the long term contributions of the Foundation to the management of several cave parks. He talked about how CRF's work fit within current NPS research objectives and praised the Foundation as being an innovating force within the Park Service.

Throughout the rest of the morning, current and former premier explorers and cartographers told of discovery and revelation. Their stories wove together over time (30 years) and distance (California to New Mexico to Kentucky) to form a picture of how we find and describe caves. Each presenter also had a vision for CRF's future.

In the afternoon, researchers told of the long-term development of ideas and of the growth of respect and enthusiasm for karst research within the scientific establishment. Geologists, biologists and archaeologists shared the spotlight and noted the milestones they had reached while working with the Foundation. They too had view on where future CRF research should be directed.

At the end of the afternoon several NPS managers commented on the proceedings and suggested future directions for CRF. Dominic Dottavio, the new Chief Scientist for the Southeast Region, praised the clarity of the CRF mission - research, conservation, education - and challenged us to balance them and tie them together strongly. He stated that the CRF partnership with the NPS was a good model and that the Park Service should encourage its dissemination throughout the system.

The evening's banquet brought everyone together in a renewal of friendship and high spirited conversation. The festive even came to a close as excepts from letters of congratulations from a dozen Park Service people with whom we worked over the years were read to the appreciative crowd.

CRF Management Structure 1987

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R. Pete Lindsley, Secretary
Sarah G. Bishop
R. Scott House
Tim Schafstall

Roger E. McClure, Treasurer
Bill Wilson
Rich Wolfert
Richard B. Zopf

John C. Tinsley

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Conservation Committee Chairman	Sarah G. Bishop
Publications Committee Chair	Roger McClure
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Chief Surveyor	David Hoffman
Project Cartographers	Gary R. Schaecher
	Robert L. Taylor
	John P. Brooks
	Jack Regal

Operating Committees

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

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

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

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

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

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

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