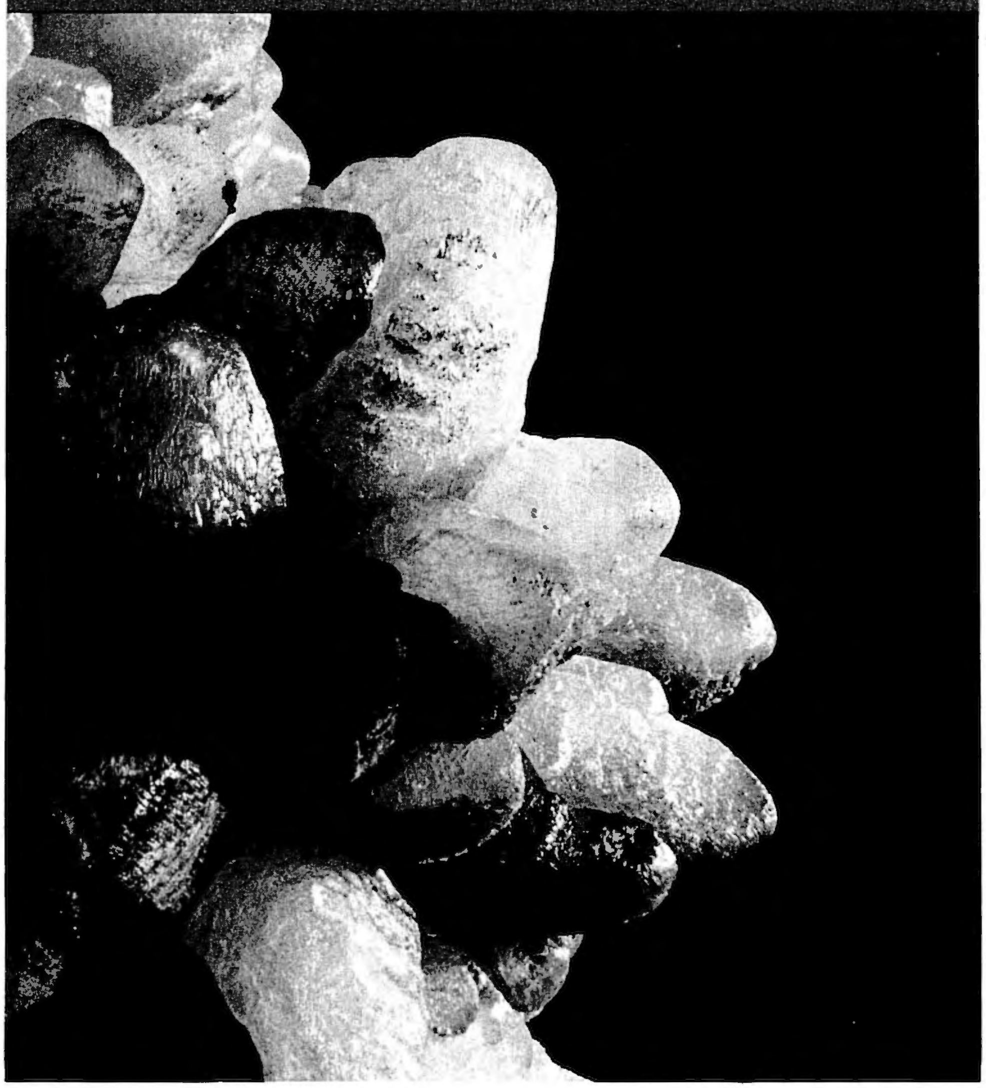
CAVE RESEARCH FOUNDATION 1984

Annual Report



CAVE RESEARCH FOUNDATION

Cave Research Foundation
1984
Annual Report

Cave Research Foundation
4916 Butterworth Place, N.W.
Washington, DC 20016
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 and karst wilderness features, and to assist in the interpretation of caves through education.

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Cover: Calcite crystals forming a wall coating in Jewel Cave, South Dakota. The long dimension of the photograph is approximately 25 cm. The crystal faces have been partially redissolved by condensing moisture. (Photo by Arthur N. Palmer)

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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 Also, many of the processes that formed the cave passages we travel are no longer active in these areas.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 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.

Acknowledgements

Many of the projects outlined in this Report have been conducted within the boundaries of public lands. The support and encouragement of the Superintendents and staffs at Mammoth Cave National Park, Carlsbad Caverns National Park, Guadalupe Mountains National Park, Sequoia-Kings Canyon National Park, Grand Canyon National Park, Lincoln National Forest, Buffalo National River and Ozark-St. Francis National Forests have greatly contributed to the success of these projects. Their assistance is greatly appreciated.

The editor wishes to thank all of the contributors to this Report with a particular note of thanks to John Tinsley, Tom Poulson and Richard Watson for their interest and suggestions. Special thanks also to Arthur Palmer, Roger Brucker and Pete Lindsley for responding to a request with some outstanding photographs.

Other acknowledgements appear at the end of some reports.

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Highlights of 1984

1984 has been a very good year, George Orwell's predictions not withstanding. Maybe he did not have the Cave Research Foundation in mind when he wrote his book. We are unique as a *volunteer research* organization. I believe our strength and success lies in this unusual marriage of multi-talented and highly professional people and their contribution of time and resources to the venture we call CRF.

Several events head the list of notable achievements during the year. Bill Mann, a member of the Foundation who has become a highly respected computer expert, has, through a generous donation, helped launch a new phase in CRF's cartography program. Patty Jo Watson, a mainstay of the Foundation's archaeological efforts, donated her author's fee on an article she wrote for the *World Book* to aid in future archaeological research. Another important event was the publication of *Grand Kentucky Junction*, a collection of six explorers' stories of the connection of the Flint Ridge Cave System to Mammoth Cave. It is a beautifully bound volume printed on acid-free paper. Through the efforts of Roger McClure, CRF's Treasurer, the Foundation now also has an 8-page, illustrated informational brochure highlighting the many facets of the Cave Research Foundation.

The Foundation has negotiated several new agreements with federal land managers. Heading the list is a national agreement with the Bureau of Land Management. CRF and the National Speleological Society jointly signed a memorandum of understanding with the BLM that recognizes contributions to the protection and management of caves on BLM lands. (Figure 1). This agreement allows CRF to develop specific cooperative management agreements with the BLM for individual cave areas in the West. A second agreement was negotiated with the National Park Service at Buffalo National River, Arkansas to produce a highly accurate map of Fitton Cave. The Foundation also renegotiated use permits with Mammoth Cave and Carlsbad Caverns National Parks. Preparations are in the final stage for a new national agreement with the National Park Service. Discussions with the Park Service over the last 18 months have developed a greater understanding of mutual goals and objectives which will be reflected in this new agreement.

Discussions were held with NPS Administrators in Washington, DC concerning cave resource interpretation. CRF Chief Scientist Tom Poulson visited the NPS Harpers Ferry, VA Center to talk with interpretation and exhibit planners concerning plans for improvements to the interpretive exhibits at the Carlsbad Caverns and Mammoth Cave visitor's centers. A number of suggestions have been incorporated into the planning process.

Roger Brucker participated in the Cave Management Symposium, an annual event that CRF helped initiate ten years ago. The steering committee decided that it was time to evaluate the purpose of the symposia and establish some goals and objectives for future meetings.

The 46th meeting of the Board of Directors of the Cave Research Foundation was held in St. Louis, MO, November 2-3, 1984. For several years, the Board of Directors has been concerned about the need to produce maps of the Mammoth Cave area for internal use, as well as for other researchers, the Park Service and for general publication. The Board has set a goal of producing quadrangle maps of publishable quality to cover the entire Mammoth Cave area. As a first step toward reaching this goal, CRF awarded a grant to Richard Zopf, the chief cartographer for the central Kentucky area, to develop the mechanism for accelerating the production of maps of the Mammoth Cave area and to establish cartographic standards, procedures and techniques to accomplish this goal. Reports to

Figure 1: From left to right: Bureau of Land Management Director, Robert Burford; Assistant Secretary of the Interior, Garrey Carruthers; Cave Research Foundation President, Sarah G. Bishop; and National Speleological Society President, Paul Stevens signing a Memorandum of Understanding on June 11, 1984. This event took place at the offices of the Department of Interior in Washington, DC. (Photo courtesy of the Department of Interior)

the Board of Directors and the CRF cartography community on this project will be emphasized during the 1985 Annual Meeting.

Superintendent Dunmire of Carlsbad Cavern/Guadalupe Mountains National Parks and Jim Wiggins, Management Assistant at Mammoth Cave National Park discussed goals for their parks and how CRF could help achieve those goals. Wesley Henry from the Washington Office of the Bureau of Land Management encouraged cooperative projects between the Foundation and his agency.

The Cave Research Foundation awards membership to individuals who have made and who will continue to make substantial contributions to the Foundation, or who have made particularly noteworthy contributions to the world of speleology. The following individuals were elected members of the Foundation in November: Thomas Alfred, Paul Blore and Kathleen Lavoie.

It is a pleasure to report on this great variety of projects and other activities that the Foundation has been involved in this year. They are numerous and exciting and the new year is expected to bring more of the same.

Sarah G. Bishop
President, Cave Research Foundation

Figure 2: An amazing display of stalactites can be seen in the area of the Bell Cord Room, located at the end of the Left Hand Tunnell in Carlsbad Caverns. Many of these stalactites and "soda straws" (tubular stalactites) are 3-4 feet (91-122 cm) in length. The Bell Cord Room is believed to be formed in the upper portion of the massive member of the Capitan limestone; however, speleothems so heavily coat the walls, ceiling and floor that very little bedrock is exposed, thus making locating the area stratigraphically difficult. (Photo by R. Pete Lindsley)

CARTOGRAPHIC PROGRAM

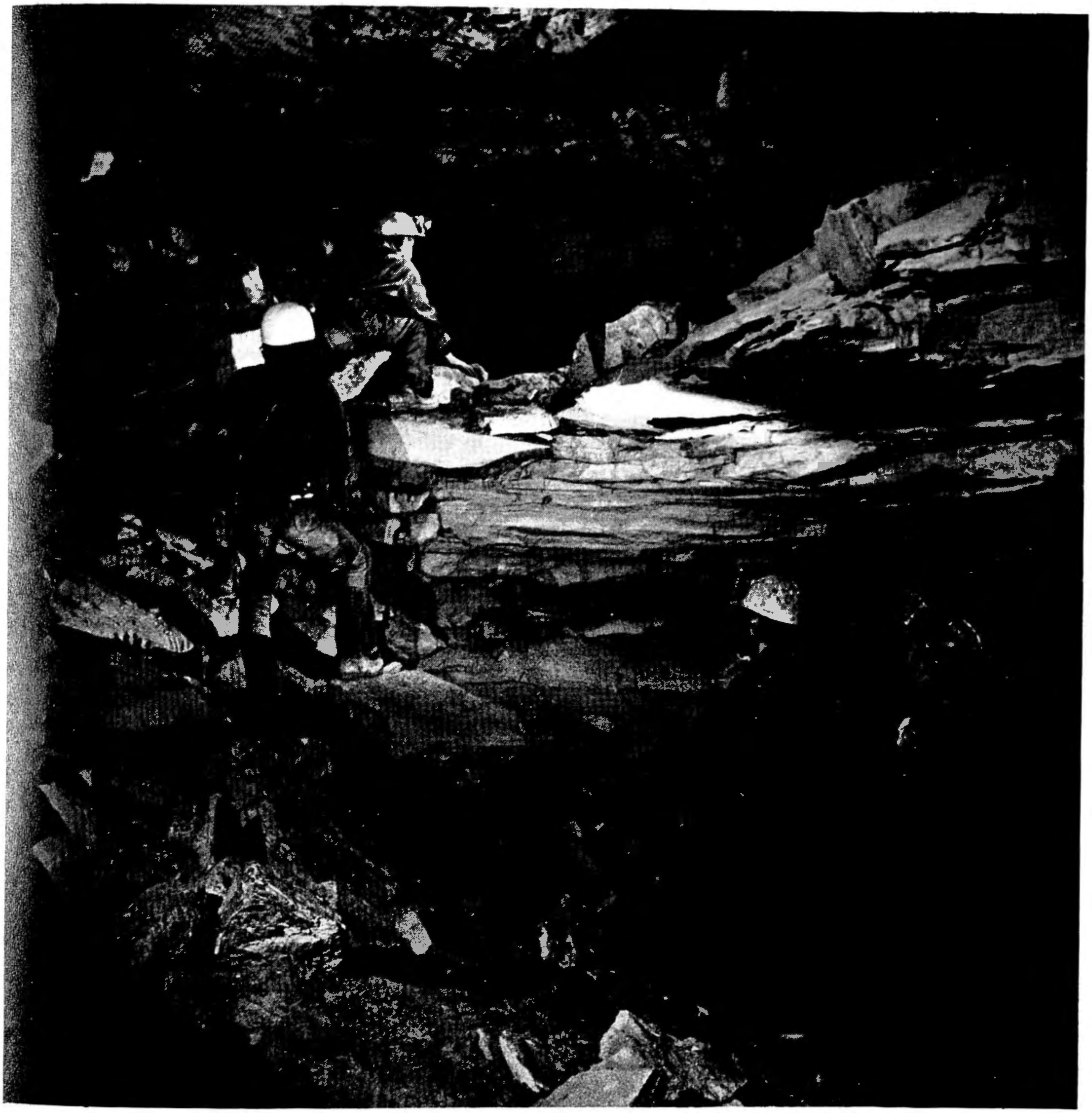

Figure 3: A survey team works its way into the Flint-Mammoth Cave System. The cavers are seen negotiating a breakdown pile which has partially blocked the passage. Breakdown consists of rock fragments (ranging in size from chips to huge blocks) that have fallen from the ceiling and walls, accumulating slowly into sometimes massive piles. The mechanism that causes breakdown varies: solution along joints and partings that hold the rock together; the wedging effect of minerals growing in fractures, and collapse when broad expanses of ceiling are left unsupported by receding waters are some examples. (Photo by Roger Brucker)

Operations Manager's Report: CRF Pacific

John W. Tinsley

The efforts and achievements of the Cave Research Foundation have emphasized the continuing study and exploration of Lilburn Cave and the Redwood Canyon karst area, located within the Grant Grove section of Sequoia and Kings Canyon National Parks. Six expeditions were scheduled in pursuit of ongoing research activities. Of these, one was devoted to cave rescue exercises involving Foundation and National Park Service personnel. Two "unscheduled" expeditions were conducted to repair the water level recorded at Big Spring (Stan Ulfeldt) and to retrieve charcoal "bugs" following the Memorial Day Expedition's fluorescein dye traces. A total of 35 CRF JV's participated in 1984 and an average of 18 persons attended each expedition.

Peter Bosted reports that the 1984 survey totals amount to 7500 feet (2285 m) added to the Lilburn Cave Map (scale: 1" = 20'). Total passages surveyed, re-surveyed, and/or resketched exceeds 26,000 ft (7921 m). An interim map is being prepared for transmittal to the National Park Service during early 1985.

John Tinsley continues his studies of erosion rates in the Redwood Canyon karst. A volcanic ash deposit erupted 700 years ago from the Inyo Craters area of eastern California has formed a useful marker bed in sinkholes of Redwood Canyon. Sediment yields estimated from the volume of post-tephra sediment preserved in sinkholes indicates that the surface of the mantled karst is being lowered at a rate of 1 to 2 cm every 1000 years.

Jack Hess and Mike Spiess continue studies of the stable isotope geochemistry and hydrology of the Redwood Canyon karst. Indications are that the water sources within the canyon are isotopically similar and uniform. Seasonal variations in temperature and in electrical conductivity of cave waters indicate that the tributary streams afford well-mixed water and longer residence times compared to the main stream of Lilburn Cave. The karst terrain situated north of the present limits of Lilburn Cave is the locus of the greatest amount of dissolution of marble within this karst.

Luther Perry reports a positive result of dye-tests linking Pebble Pile Creek to the principal Lilburn Cave resurgence at Big Spring. The transit time is loosely bracketed at present, ranging from more than 3 days to less than 3 weeks. Pebble Pile Creek is the last major tributary to be conclusively linked to Big Spring.

A reconnaissance investigation of arthropods from Redwood Canyon caves was conducted by Thomas S. Briggs, Vincent F. Lee, and Darrell Ubick of the California Academy of Sciences, San Francisco, CA. Finds include specimens of *Macrovelia hornii* from Cedar and Lilburn Caves (previously unreported from caves) and an undetermined linyphiid spider which appears to be troglobitic. The remaining specimens include representatives of troglophile, trogloxene, and epigean populations.

Continued vigorous progress is anticipated in most of the preceeding disciplines during 1985, especially in the fields of sedimentology, hydrology and cartography. We anticipate cooperative efforts with the National Park Service as the karst resource management plan takes shape and deepening involvement in the interpretive program at Crystal Cave, the show cave operated by the National Park Service in Sequoia National Park.

Lilburn Cave Cartography—1984

Peter Bosted

The survey, re-survey and re-sketching of this complex cave progressed steadily during 1984 with 30 JV's participating. The February, April and July expeditions each fielded three survey teams, the May expedition mustered five trips; the August expedition, six; and the October expedition, two. A total of 7842 ft (2389 m) of passage was surveyed, using 536 survey stations. Of this, about 950 feet (289 m) was passage not previously surveyed. Areas of the cave receiving the most attention were the Jefferson Memorial/Blue Passage complex, the Clay Palace area, the Attic and the Hex Room. This project now counts more than 26,000 ft (7921 m) surveyed, with at least 14,000 ft (4265 m) of additional passage known to require re-surveying. Prospects for finding new passage are not great for large passages, but numerous small leads and mazes still await pushing and surveying.

The year's efforts will be added to the master map (scale: 1 in. = 20 ft) by the end of January, 1985, and an interim copy will be submitted to the National Park Service. Peter Bosted is planning to construct a three-dimensional model of the cave, using wire and clay. A model of Lost Soldier's Cave (scale: 1 in = 50 ft) has been completed for practice to prove the feasibility of such a project. The three-dimensional model will serve as a useful interpretive tool by aiding in the visualization of the complex relations among passages in maze-type cavern networks such as Lilburn Cave.

Cartography and Exploration in the Guadalupe Escarpment Area, New Mexico

Rich Wolfert

Guadalupe Escarpment Area JV's have been quite active this year, with most work centering around Carlsbad Cavern. Eight expeditions were fielded, and 16 new JV's have been recruited, bringing the total to 81 JV's active in the Guadalupe Escarpment Area.

As in past years, surveying has continued to be our primary activity. A water tube survey was completed in the Guadalupe Room and the New Section of Carlsbad Cavern to provide better vertical control in that part of the cave. A number of loop closure errors have been located and corrected, and maps have been field checked for accuracy, as work continues on the set of 50-feet to the inch quadrangles. Big Manhole Cave, a small cave near the park boundary, was also surveyed.

Carlsbad has surprising vertical relief in many areas of the cave. To better understand passage relationships, we have put considerable survey efforts into producing a series of profiles of the Cavern. A laser unit has been used to survey some of the high ceilings, and profiles of most major passages and rooms have now been completed. The Park Service will be remodeling the visitor center, and these profiles will be helpful in preparing new interpretive exhibits. The profiles also will aid in our understanding of speleogenesis at Carlsbad.

A new room has been discovered in Carlsbad to the east of the New Mexico Room. Named the Rim Room for a large corrosion rim in the passage leading to it, the room is about 100 feet (30.5 m) long by 40 feet (12 m) wide, and has ceilings 20 or more feet (6 m) high. It is fairly well decorated, and features tall broomstick columns at one end of the room. Located within a boneyard maze, the Rim Room has good air flow. This air movement, plus the presence of directional corrosion, suggests the existence of more cave beyond. The room is also of mineralogical interest, containing some rare conulites.

There have been several other projects and activities this year. A mapping school was conducted to familiarize new JV's with the techniques of cave surveying. Field support and use of CRF facilities was provided to independent researchers conducting work at Carlsbad. Mineralogy work has continued, with studies of moonmilk and beaded helictites taking place in Carlsbad and other caves. A detailed geologic study of the New Mexico Room has been started. This work is expected to aid in the understanding of processes of cavern development in Carlsbad and other caves of the Guadalupe Mountains.

Cartography and Exploration in the Sylamore District, Arkansas

Thomas A. Brucker

Arkansas area Cave Research Foundation volunteers fielded one expedition in 1984 to Sandy Flats Cave which was first entered at the final expedition of the 1983 field season. That preliminary reconnaisance into the impressive sandstone cave, and the unfortunate small size of Cave #41, a daylight shaft, led to a substitution of objective in the Cave Resource Inventory Contract.

Scott House and Doug Baker, together with several Missourians and the Forest Service Archaeologist, surveyed the cave and took samples of what may be charcoal, found in the back of the cave. Over 1000 feet (305 m) long, the passage at one point was 175 feet (53 m) wide, and developed throughout by collapse into solution pasages in underlying limestone. Sandy Flats Cave resembles nearby Hidden Springs Cave, mapped and inventoried in the second Sylamore Project.

A delay has pushed the final report and publication of the maps until February, 1985. With publication, the Cave Research Foundation will have completed the inventory of known caves in the Sylamore District, Ozark-St. Francis National Forest, Arkansas.

Fitton Cave, Arkansas Survey Project

R. Pete Lindsley

The National Park Service at Buffalo National River has accepted a proposal submitted by the Cave Research Foundation for the survey of Fitton Cave, Arkansas, with field work starting in the fall of 1984. The final survey is expected to exceed 7 miles. As the manager of the project, the Foundation has extended an invitation to interested surveyors and cartographers through selected publications and letters to NSS Grottos.

The primary goal of the Project is to complete a working map of most of the major trunk passage of the cave within the next two years. Emphasis will be placed upon enhanced sketch quality and survey accuracy. The long range goal will be to achieve a 0.1% closure error along a precision base line which will be integrated with the data base forming the working map. The map format will be a multiple quadrangle design that will allow the cartographers flexibility. The Project will have several Cartographers, each in charge of a particular section of the cave.

Initial staffing of the project includes the following:

Pete Lindsley—Project Manager
Paul Blore—Area Manager
David Hoffman—Chief Surveyor
Gary R. Schaecher—Project Cartographer
Robert L. Taylor—Project Cartographer
John P. Brooks—Project Cartographer
Mike Warshauer—Newsletter Editor

Similar to other CRF field operations, the Expedition Leader will be in charge of each expedition and will assume responsibility for party assignment as well as required data items. Party leaders will be assigned for each group working in the cave and will be responsible for maintaining survey accuracy and sketch quality. Expeditions are limited by the National Park Service to a maximum of 21 party members underground in interest of protection of the cave resource. It is expected that there will be a number of expeditions each year in support of Project goals.

The first expedition of the Fitton Cave Survey Project was held on the weekend of September 22-23, 1984, at Fitton Cave. The primary goal of this first expedition was to discuss future Project goals, general logistics, flow of survey data, duties of various Project personnel, and to review previous survey data. Survey accuracy and sketch detail was emphasized at the meeting. The cartographers believe that expeditions will be limited by the quanity of qualified party leaders and sketchers available. A scale of 1" = 50' will be used for the maps; however, a scale of 1" = 25' will be required for the original sketches in the cave. A number of brass caps, perhaps 30 to 40, will be placed in the cave in non-obvious locations to tie the surveys. Secondary expedition objectives included field trips into the cave and maintenance on the Chestnut Cabin which will used as Project Headquarters, weather permitting.

A total of four survey parties were fielded on the November 3-4, 1984 expedition, and a fourth surface party was fielded on the 4th. One party set 10 brass caps. The December 1-2, 1984 expedition saw a total of 12 JV's attending the expedition with three survey parties fielded. Total people-hours underground was 118.2 hours and approximately 2000 feet (609 m) of passage was surveyed.

Interested qualified cave surveyors are invited to participate in the Project and should contact the Area Manager, Mr. Paul Blore, at 2332 Hatfield, Fayetteville, Arkansas 72701, for additional information.

Cartography and Exploration in the Mammoth Cave Region, Kentucky

Richard Zopf

This year the Mammoth System moved into the realm of a 500 kilometer cave. The largest single area of CRF exploration was in upstream Mystic River in Mammoth. Inconclusive dye traces and ten year old leads prompted the discovery of a distinct drainage basin which still hasn't been fully delineated. A second major discovery has produced less new passage, but has been equally exciting. From the Albert's Domes area in Mammoth, an above base level series of passages connects to the Candlelight River area of Flint Ridge. This connection bypasses the difficult parts of the original route and still has side passages to explore. The greatest number of survey trips were made to the lower levels of Salts Cave where work continues to sort out the complicated S-survey canyon.

Much resurvey was done throughout the system in conjunction with several projects. The lack of detail in the manuscript maps of Turner and Mather Avenues in Flint Ridge inspired resurvey in this area to support the drafting of a new map. In conjunction with a project to make detailed maps of the passages containing tourist trails in Mammoth, significant amounts of resurvey and clean-up survey are being done. A resurvey of Smith Valley Cave has begun and a surface traverse from the Frozen Niagara Entrance to the new Doyel Valley Entrance was run. The formal opening of this entrance delayed survey work in the river area this year.

The cartography program produced the baseline map for a new map card of the system, a more detailed map of Salts Cave from Mummy Valley to about Station S-145, a detailed map of the Brucker Breakdown area, and support data for numerous ongoing projects. Software advances are beginning to allow us to use the mainframe data reduction programs written in the early 1970s on CRF's micro computer. While little headway has been made to establish a universal data base, progress has been constant in efforts to eliminate the backlog of unentered survey books and to produce useful line plots.

The year ended with a commitment to expedite the production of a universal set of maps of the system. The first step of this process with be to produce prototype maps and to evaluate various systems of map production. Negotiations with Mammoth Cave National Park have resulted in agreements to produce certain special management maps in exchange for financial support of CRF's cartographic program.

GEOSCIENCE PROGRAM

Figure 4: Impressive colonial coral found in upper Ste. Genevieve limestone in Foundation Hall, Flint Ridge. Solution of the surrounding limestone by water has exposed this fossil to view. Fossils such as this one can provide much information concerning the conditions that existed when the fossil (in this case, coral) was living. Fossils may also be used as "markers" to help correlate the stratigraphy of one area to another area. (Photo by Roger Brucker)

Investigation of the Hydrology of Redwood Canyon Karst

John W. Hess and Mike Spiess

The objectives of the research are to gain a better understanding of the physical and chemical hydrology of the Redwood Canyon Karst, Kings Canyon National Park. Hydrologic investigations to date have been limited to attempts to understand the ebb and flow nature of Big Spring discharge by recording water levels and water tracing experiments.

Specific objectives are to:

1. Investigate the isotope hydrology of the karst area.
2. Investigate the chemical hydrology of the karst area.
3. Analyze the Big Spring hydrographs.
4. Apply the results of the above to a better conceptual model of the physical hydrology of the karst including the ebb and flow discharge behavior of Big Spring.
5. Develop computer-based physical models of the karst hydrology.

Four sets of samples were collected in 1984 in February, May, July and October. Samples were collected for stable isotope and chemical analysis from surface streams, cave streams, drips and Big Spring. At the time of collection, temperature, pH and electrical conductivity were measured. Sixty-seven samples were collected at 24 different sites during the year. The stable isotope analyses are presently being performed. At least four sets of samples will be collected during 1985 including a winter set. An attempt will also be made to collect precipitation samples.

Preliminary results lead to three conclusions: 1) There are two different karst flow systems within the Redwood Canyon Karst. They are: a) Redwood Creek and the main Lilburn Cave stream which exhibit seasonal variations in chemistry and discharge, have uniform stable isotope ratios, and have short residence time with little mixing of different waters, and b) the tributaries which exhibit uniform chemistry and discharge, uniform stable isotope ratios and have longer residence time with mixing of different water. 2) The water source is the same for both flow systems. 3) Based on water chemistry, the rate of marble removal varies with both season and discharge from 10 to 90 cm^3/sec.

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

John C. Tinsley and Jeff Evans

Introduction

About 720 radiocarbon years ago, a silica-rich volcano erupted near the Mammoth Lakes area in the southern part of the Inyo Craters volcanic chain, south of Mono Lake in eastern California. The fine-grained 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 Redwood Canyon karst area. The powdery tephra then was washed from the hillslopes into the rivulets and gullies that feed into sinkholes. If the sinkholes were plugged to the extent that only seepage water was released to the cave system below, the tephra was efficiently trapped in the sinkholes. The tephra deposit can be regarded as an isochronous deposit (a deposit that has the same age everywhere) owing to its having been erupted, deposited on hillslopes, and eroded and redeposited in sinkholes within a very short span of geologic time, perhaps less that one year to probably not more than a few years. Geologists use isochronous deposits to help establish age equivalence among deposits that occur in widely-separated localities. In the present context, during the past 700 years or so various amounts of rock and soil have been washed into the sinkholes and have buried the tephra. Study of the relation of these recent sediments to the tephra enables geologists to estimate the rate of erosion of the upland areas under the coniferous forest cover and under the influence of modern climate.

Methods and Objectives

In this study, we use the tephra deposit as a marker bed or time delimiter. In each sinkhole, a series of auger-holes are bored and the respective thickness of tephra and of post-tephra sediment is measured. From a suite of measurements of thicknesses obtained in 20 to 30 augerholes per sinkhole, the respective volumes of tephra and post-tephra sediment are estimated. The quotient of the tephra volume or the sediment volume divided by the area of the basin feeding into the sinkhole yields a figure that corresponds to the average respective thickness of tephra or sediment eroded from the drainage basin, provided the sinkhole has been behaving and has not been "leaky." In this manner, by comparing as many sinkhole basins as possible, the apparent erosion rate for a population of small basins can be studied as functions of basin size, slope, aspect, vegetation, or other relevant parameter; this erosion rate would be applicable to the coniferous forest of Redwood Canyon for the past 700 years.

There are 65 sinkholes known in the Redwood Canyon karst; about 1/3 of these will be suitable for study. Some sinkholes contain abundant coarse detritus, such as boulders and cobbles and are unyielding opponents to the soil auger; sinkholes serving as principal input points to the Lilburn Cave system may not have trapped tephra or post-tephra sediment. Only by comparing results from a number of sinkholes can the best estimates be obtained from studies such as these.

Results

Seven sinkholes have been surveyed and augered as of this writing. Hillslopes of less than 10% tend to retain at least part of their ash mantle, which becomes mixed with the soil through biological and physical processes. Steeper slopes generally shed their ash mantle readily into the sinholes. Thus, steeper basins (those having slopes generally exceeding 10%) tend to yield tephra and sediment more efficiently than more gently-sloping terrains. The tephra blanket ranged in thickness from 1 to 5 cm thick in Redwood Canyon; erosion rates of the soil mantle in the Redwood Canyon area range from 0.5 to 1.5 cm/yr. I emphasize that these numbers may not be reliable, for the population of sinkholes studied is very small and not all important parameters have been tested.

Fluvial Hydrology at Lilburn Cave, Sequoia and Kings Canyon National Parks, California

Luther B. Perry

A major objective for 1984 that had been unsuccessfully attempted in three previous years was finally achieved—a dye trace between Pebble Pile Creek, a surface tributary stream, and the Lilburn Cave Stream. Detection was made at the cave stream resurgence at Big Spring, confirming the connection, but detectors placed in the cave to isolate the point of connection produced inconclusive results.

Significant problems were encountered in this dye trace as the transit time was greater than two days, but less than four weeks, and the strength detected was very low. The transit interval is too long for a single expedition, but much shorter than the intervals between expeditions. The weak signal may indicate that adsorption on native materials is much higher than anticipated. Further efforts will require special full scale expeditions at closer intervals (a difficult task) or installation of sensitive portable fluorometers to detect timing and concentration of dye.

The Pebble Pile Creek transit time was longer than expected, tending to support the hypothesis that transit time in the cave stream is relatively rapid (under 11 hours for 1600 m in the measured segment) and much slower for streams that appear to percolate into the cave (between 2.5 days and 2 weeks for 5800 m trace and between 2 days and 4 weeks for the Pebble Pile trace of some 500 m). By contrast, a previously measured transit time for a small tributary that is known to flow almost directly into the Lilburn Cave Stream showed a transit time to Big Spring of between 19 and 41 hours over a distance of 700 m.

The Origin of Rims

Carol A. Hill

A "cave rim" is a speleothem type first named and recognized by Herb and Jan Conn (1977) in Jewel Cave, South Dakota, although Burch (1967) previously reported a "rim around a hole" in the Caverns of Sonora, Texas, which made a "raised lip...more than a foot high, with the inside dry and flakey." A cave rim is a projection of crystalline material on bedrock or speleothems and which is smooth and scoured on the inside, rough and often coralline on the outside, and which usually (but not always) occurs as a shell around an aperture where a small passage junctions with a larger passage or room. Rims may be composed either of carbonate or sulfate material, and the shape of rims varies from "shell" or "ear" configurations to "vent" or "stalagmitic" rims. Their internal hole widens from the top to the bottom with a slope steeper than the external one and reaches a depth far lower than the base of the rim. In the United States rims have been found in South Dakota, New Mexico and Arizona caves (Table 1), in Premonition and Fixin-to-Die Cave, Colorado (Donald G. Davis, personal communication), and in Jester Cave, Oklahoma (Susan Bozeman, personal communication). They have also been reported from caves in Czechoslovakia and Cuba.

The origin of rims is not well understood, some authors favoring subaerial deposition from condensation water (Davis, 1982), and other authors such as Núñez Jiménez (1970) favoring deposition from bottom to top by rising water—either vadose, fluvial, geyser or capillary water. The condensation model is the more general of the two because it explains sulfate rims as well as carbonate rims. Gypsum has to deposit by evaporation rather than by carbon dioxide loss and thus a subaerial origin seems to be the only logical explanation for this type of rim formation. However, even sulfate rims (such as "the commode" in Endless Cave, Figure 5) remarkably resemble some of the askewed shapes taken by the "tremagmite" rims in the Gran Caverna de Santo Tomás, Cuba, as pictured by Núñez Jiménez, and his "vent" and "stalagmitic" tremagmite rims are almost identical to forms seen in Carlsbad Cavern and Jewel Cave. In both Carlsbad and Jewel, strange popcorn-covered stalagmites exist (hollow ones in the Big Room of Carlsbad and "hollow popcorn stalagmites" with holes down their centers much deeper than the base of the stalagmite in Jewel). These forms might have been deposited according to a "geysermite" or rising water origin as proposed by Núñez Jiménez for the Gran Caverna rims. Also in defense of a rising water model, it should be remembered that the condensation water model as first proposed by Davis is entirely subjective; no one has ever seen rims growing from condensation droplets.

Figure 5: "The Commode," an unusual rim speleothem found in Endless Cave, Eddy County, New Mexico (Photo by Alan Hill)

Based only on the rims personally observed, a condensation water origin, influenced by such factors as air flow, temperature, pressure, evaporation, carbon dioxide loss, and bodies of cave water which supply moisture to the air, is favored. Rims apparently form when moist warm air meets with drier cooler air, thereby causing droplets of moisture to condense out on the surfaces of bedrock or speleothems. Since carbon dioxide is more soluble in cold water than in warm water. These droplets become increasingly aggressive as they equilibrate with the cooler temperature of the rock or speleothem. If air flow is strong enough to move the condensation droplets across the surface of a rock or speleothem, then these surfaces will become corroded and "scoured" along the path of air flow, and the droplets will become increasingly saturated with respect to calcium carbonate. At a point of decreased air flow velocity, such as where a tight passage or aperture suddenly meets with a large room, turbulent eddies in the air are created which cause excess carbon dioxide still held in the moisture droplets to be released from solution, and some of the translocated calcium carbonate redeposits as rims around the lip of the aperture. Continued air movement continues to dissolve the inside of the rim lip, and hence it always appear scoured-looking.

This general model may be applied to specific rim localities. In the case of sulfate rims such as are found in Guadalupe caves

Table 1. Characteristics of rims found in caves in South Dakota, New Mexico and Arizona.

	Black Hills, South Dakota	*Guadalupe Mountains, New Mexico*	*Bisbee, Arizona*
Cave **Type locality*	*Jewel Cave**, Wind Cave, Reed's Cave	Carbonate: Carlsbad Cavern, Pink Panther Cave, Cave of the Madonna, Virgin Cave Gypsum: *Endless Cave**, Carlsbad Cavern, Cottonwood Cave, Hell Below Cave, Spider Cave	Higgins Mine Crystal Cave
Number of specimens	Hundreds	Carbonate: Various local occurrences altogether totaling a few dozen. Gypsum: Various local occurrences altogether totaling about a hundred.	About 1 dozen
Color	White	White	White, with light green (copper) tinging a few specimens
Shape	As lips of material which conform to shape of hole. Scoured insides, crusted outsides of lip. Rims point upward both on upper and lower lip. Sometimes upper lip may be absent. Many "vent"-shaped specimens. One "ear"-shaped convoluted rim of special note.	Carbonate: Projections of material on walls and certain speleothems. Shape of rim conforms to corroded areas. Vent-shaped specimens rare. Scoured insides, crusted outsides. Gypsum: Many "post-hole"-shaped specimens with lips projecting up above the hole. Smooth insides, rough outsides. One "commode"-shaped rim of special note (Fig. 2).	As vent-shaped lips of material around holes in the floor. Scoured on the inside and rough on the outside. (Fig. 3).
Size	Average size: 7.5-15 cm high, 1-5 cm thick at base. Maximum size: 25-40 cm high.	Carbonate: Average size: 3-6 cm high, 1-5 cm thick at base. Maximum size: 1 m high, 6 cm thick at base.	Average size: 15 cm high, 1-3 cm wide at base. Maximum size: 60 cm high, 5 cm wide at base.
Composition	Aragonite needles and popcorn moonmilk on top of a calcite base.	Carbonate: Partly aragonite, at least on the outer part of the rim lip.	Needle-shaped crystals; probably aragonite.
Occurrence	Rims occur: (a) around apertures of small holes where they junction with a larger passage or room, (b) on the floor where there is a lower level of cave with no large connection nearby, (c) at a constriction of a small cross passage connecting two larger passages, (d) where wet, lower areas connect with dry, upper areas, or (3) at the bottom of ceiling domes. Associated with subaerial popcorn.	Carbonate: In places where the limestone and speleothems are badly corroded; associated with wall crusts and stalagmites (Fig. 1). Rarely around small apertures where they junction with a larger passage. Gypsum: In floor blocks of primary gypsum corresponding to small holes in the floor.	As linings around small apertures in the floor wheré they junction with a large room.
Origin	Conn and Conn (personal communication): Moisture-laden winds carry drops of condensation from partially submerged passages into the relatively dry upper levels; a slight change of pressure and temperature of air emerging from a constriction causes precipitation. Palmer (1984): Air in a constricted passage is at a higher pressure than air in a large room: where the constriction is there is a decrease in pressure and precipitation insues.	Davis (personal communication): Where warm/moist air and cold/dry air currents interact, moisture condenses on the inner sides of projections and seepage transfers dissolved material to the outsides where evaporation and/or CO_2 loss causes re-precipitation.	Hill (1979): Wind currents move up through holes from below.
References	Conn and Conn (1977), Hil (1979b), Palmer (1984)	Davis (1982)	Hill (1979a)

Figure 6: A rim in Bisbee Mine Cave, Bisbee, Arizona. The rim has formed where a small hole in the floor intersects with a large room. (Photo by Alan Hill)

Figure 7: A stalagmite corroded in the direction of the Lake of the Clouds, Carlsbad Cavern, New Mexico. The carbonate rim flanks (and has itself been corroded flush with) the corroded part of the stalagmite. The ruler is pointing to the rim. (Photo by Cyndi Mosch Seanor)

or in Jester Cave, Oklahoma, moisture droplets condense in holes within primary gypsum, and sulfate material dissolves in this moisture. Air flow then translocates the droplets to a position where the holes meet with a large room, and at this site evaporation causes the gypsum to precipitate as rims around the holes (Figure 6). In the case of South Dakota caves such as Jewel which are exceptionally windy, a pressure gradient might exist between tight, constricted passages and large rooms so that condensation-corrosion-translocation occurs in constricted passages where air velocity is higher (Bernoulli's Principle), and then deposition occurs where the air emerges into a large room, the decrease in velocity and pressure causing outgassing of carbon dioxide and precipitation of calcium carbonate at the lip of the constricted passage. Temperature may be the prime factor in moving air from one area to another, a perfect example of this principle being in the Lake of the Clouds Passage, Carlsbad Cavern, where inflowing dry air picks up moisture from the Lake, is warmed by the higher cave temperatures at the bottom of the Lake of the Clouds Passage, and then flows up toward higher, cooler passages propelled by the temperature difference. As the air rises and cools, the amount of carbon dioxide dissolved in condensed moisture droplets increases, and bedrock and speleothems are preferentially corroded in a direction that faces the Lake of the Clouds (Figure 7).

Acknowledgements: I acknowledge the exchange of ideas concerning the growth of rims with the following people: Susan Bozeman, Herb and Jan Conn, Donald G. Davis, Paolo Forti, Alan E. Hill, Arthur and Margaret Palmer, and Cyndi Mosch Seanor.

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A Conulite Formed in Moonmilk, Carlsbad Cavern

Carol A. Hill

A conulite is a conical shell of carbonate material that visually resembles an ice cream cone, oriented with the apex downward. The conulite originates as a pit drilled by dripping water in soft sediment; the conical cavity subsequently becomes lined with calcite (Hill, 1976). Conulites usually form in mud, for example, in the New Discovery of the Flint-Mammoth Cave System, or in silt and sand (such as in Weber's Cave, Iowa). The Carlsbad Cavern conulite is unique in that it has formed in moonmilk—the only one of its its kind reported to date. The conulite in moonmilk is 12.5 cm high on its most exposed side and 5 cm high on its least exposed side; it varies from 6 cm to 7.5 cm across its top, and has a wall thickness of less than a centimeter. In shape, it resembles a horn coral, being vertically fluted on its inside due to a shifting of the drip point from which it originated. A piece of olive-green montmorillonite clay is attached to a lower, outside portion of the conulite. The conulite is located on the floor of a fissure passage which connects Lower Cave to the Boneyard.

The conulite in moonmilk originated in exactly the same manner as do conulites in mud. At first, water dripped from a ledge (about 1 meter above the conulite) and onto the moonmilk-covered floor, drilling a hole into the moonmilk. Later, the hole became lined with harder, more crystalline material, and when the moonmilk partially sluffed away from this hard lining, it left the conulite free-standing. Since the conulite is "one-of-a-kind," it was not sampled in order to determine its composition, but most likely the conulite itself is composed of crystalline calcite, and the moonmilk is hydromagnesite.

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Mineralogy at Fort Stanton Cave, New Mexico

Carol A. Hill

Fort Stanton Cave is located 17 km east of Capitan, New Mexico, on United States Bureau of Land Management property. It is developed in the Permian-aged San Andres Formation, a sparsely-fossiliferous, cherty, dolomitic and sandy limestone containing interbedded gypsum. The San Andres in the vicinity of Fort Stanton Cave is intruded by tertiary dikes and is intensely faulted. The regional drainage is subsurface; the supposed outlet for the cave is at Government Springs, located 2.6 km NNE from the cave entrance on the south bank of the Rio Bonito. Orientation of the major passages is defined by a NNE trending fault in the San Andres Limestone. The Main Corridor, Fort Stanton's most extensive passageway, is 1.5 km long, 13 m wide and 20 m high. Average cave temperature is 11° C and humidity varies between 80% and 97% depending on location and time of year. Sediment banks up to 12 m high occur along the Main Corridor; these contain illite, sericite and kaolinite clay (Kessler and Baer, 1971).

Fort Stanton Cave, at first called Government Cave, was discovered in 1855 by soldiers of the United States Cavalry stationed at nearby Fort Stanton. When the cave was first explored a "lake" (backed-up water from the Rio Bonito) blocked the Main Corridor, and a small boat or canoe was used to cross the "lake."

Biology includes cave rats, unidentified arthropods, and bats inside the cave, and Phoebe (birds) at the cave entrance (Ballinger and Smith, 1959).

Mineralogy

Fort Stanton Cave contains selenite needles, starburst gypsum, epsomite cotton and hair, velvet, calcite rafts ("snowflakes"), manganese coatings and opal-filled needles as well as the more usual speleothem types such as stalactites, stalagmites, draperies, flowstone, helictites, anthodites, moonmilk, coralloids, flowers and crust. This paper addresses only the unusual speleothem types.

Sulfates

Selenite Needles. Selenite, a clear variety of gypsum, $CaSO_4 \cdot 2H_2O$, forms as needles which vary from long (up to 30 cm), slender, clear varieties to stubby, tent-shaped varieties stained a brown-gray by clay impurities. Selenite needles grow from cave dirt which contains both microscopic and megascopic subhedral crystals of selenite. Ascending sulfate-bearing solutions reaching air pockets in the dirt form irregular selenite lumps by evaporation; solutions reaching the dirt-air boundary form euhedral, twinned crystals because crystal growth is not confined in the upward direction. As evaporation continues at each needle's base, already-crystallized gypsum is pushed further upward and out of the dirt so as to form vertical crystals or crystals intergrown in a "bird's nest" fashion.

The Fort Stanton selenite needles confirm that needles grow from the base. In some locations where the clay is hard and compact, the upward force of needle growth cracks the dirt—the needles appear as tiny plants sprouting in a garden. Other needles may have mud clots attached to their sides, mud clots which were raised by upward growth of the needle. Or, two needles may be joined along their sides, with the longer needle's base in the dirt and the shorter needle having been completely raised up out of the dirt by the faster upward growth of the longer needle.

Starburst Gypsum. Starburst gypsum consists of facets of gypsum radiating from a common center in a somewhat star-shaped pattern; growth is along (parallel to) cave walls. Starburst gypsum at the beginning of Crystal Crawl has grown into a continuous mat of intertwinning stars completely covering the entrance alcove. Less spectacular but more instructive are the small, 1 cm diameter, starbursts near the end of the Main Corridor. Here, starburst points have flaked away a thin, clay wall-coating, confirming that starbursts grow outward and away from the starburst center. Beneath the center of some starbursts are tiny vugs—possibly cavities along which sulfate solutions preferentially issued from the wall, and then spread out as thin sheets.

Epsomite Hair and Cotton. Epsomite, $MgSO_4 \cdot 7H_2O$, is found as fibrous cotton and as single fibrous strands of hair. Floor mounds of cotton contain masses of individual fibers 0.5 mm in diameter and 1 mm—1 cm long matted together in heaps. Individual hair strands are up to 12.5 cm long and hang from cave ceilings and wall ledges. Epsomite hair and cotton are very delicate; heat from a carbide lamp will cause the fibers to drift off the ceiling or turn into powder. The epsomite in Fort Stanton Cave sprouts up as a fuzzy growth during the winter months (from about January until late spring). In Summer and Fall the epsomite disappears into the floor dirt or cave walls, there to remain until the next winter when humidity changes again cause it to effloresce.

Carbonates

Cave Rafts. Very thin (1 mm), delicate cave rafts called "snowflakes" exist in the Snowflake Passage of Fort Stanton Cave where former pool levels are recorded by one dominant white water line and two, less conspicuous lines. The snowflakes grew as carbon dioxide was lost at the pool's surface, with crystals growing parallel to the plane of the raft. Impounded water drained out of Snowflake Passage without turbulence as indicated by the relatively unbroken nature of the fragile snowflake rafts lying on the floor.

Cave Velvet. Fort Stanton Cave is the classic location for cave velvet, a term which refers to the surface textural appearance of speleothems such as stalactites, stalagmites and flowstone. Tiny (1 mm long) dogtooth spar calcite ($CaCO_3$) crystals on the surface of these speleothems reflect light at various angles and so cause the velvety luster. Cave velvet is believed to form in high humidity environments (near 100%), such as might be expected for caves which have no entrance. The fact that Fort Stanton Cave has an abundance of velvet may indicate that its crater-like entrance sink collapsed fairly recently.

Silicates

Opal Coralloids. Opal ($SiO_2 \cdot nH_2O$) has been found in acicular needles of a popcorn-coralloid at the end of Snowflake Passage.

The needles are composed of calcite (probably altered from aragonite) and, less abundantly, of opal. Opal is a cave mineral which is usually found in lava tubes and not in limestone caves. The Fort Stanton opal probably derives from the Tertiary intrusives in the area.

Oxides

Manganese Coatings. Manganese occurs in Fort Stanton Cave as black coatings on the downward-hanging tips of wall pendants. This occurrence suggests that solutions containing the manganese flowed down or through the limestone wall until they reached the pendant tips. Evaporation concentrated the manganese in solution and caused its deposition.

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Virgin Cave, Guadalupe Mountains, New Mexico: A Preliminary Report On Its Geology and Mineralogy

Carol A. Hill

Virgin Cave, the only extensive Guadalupe Mountains cave to be found west of Lonesome Ridge, is located near the contact of the Capitan formation (massive member) with the overlying Seven Rivers and Queen (?) Formations. All of Virgin Cave is developed along a brecciated zone, with the exception of the lower section of the Four O'clock Staircase which is probably developed in an unbrecciated part of the massive Capitan (Donald G. Davis, personal communication). The Breccia can be seen in the walls and ceilings of the cave passages, and consists of angular clasts up to a meter or more in size cemented in a crystalline spar and/or sandy mudstone matrix. Contiguous with the brecciated zone are numerous dogtooth spar and spar casts.

Speleothems observed in the upper cave level from the Entrance to Beyond-the-Roots and in the middle level from the 20 m drop to the Lake Room include: stalactites, stalagmites, columns, soda straws, draperies, flowstone, bell canopies, coatings, rimstone, cave pearls, cave rafts, helictites, welts, subaerial nodular and "button" popcorn, and subaqueous "cauliflower" coralloids. Additional speleothem types reported by other people from the Four O'clock Staircase to the Cavernacle include balloons, shields, frostwork, and rims (see acknowledgements).

In the uppermost entrance level, speleothems are very dry and desiccated, but in the remainder of Virgin Cave the speleothems are very wet and active—among the most actively-forming in any Guadalupe cave. Many soda straws in the entrance area have been broken, probably by natural drying processes. "Button" popcorn in this same area also attests to the drying effect of entrance air flow; this type of speleothem is believed to form when layered popcorn nodules desiccate and "peel away" from the outside center of a nodule (Hill, 1976). One broken stalactite found Beyond-the-Roots exhibits a macrocrystalline core surrounded by a zone of light and dark-ringed layers of calcite corresponding to dry and wet periods, respectively. The internal arrangement of this stalagmite is consistent with that seen in broken stalactites and columns in other Guadalupe caves and may represent wet conditions associated with the last glacial period (the macrocrystalline core) followed by intermittent dry and wet conditions in the succeeding interglacial period (the alternating light and dark layers) (Hill, 1978).

A number of notable carbonate speleothems exist in Virgin Cave from the entrance area to the Lake Room. The "snake dancers" of the Snake Dancer Room are veriform (worm-like) helictites which have grown almost vertically up and along the wall, and have an enlarged bulbous tip so that they resemble cobras ready to strike. Near the "snake dancers" is a small pool in which calcite rafts are actively forming. A very fine film of calcite scum can be seen floating on the surface of the pool water, scum which conspicuously thickens where it attaches to the edge of a small rimstone dam lining the pool. Sunken rafts can also be seen in this pool stacked at various angles on its floor. One of the most impressive of all speleothems found in Virgin Cave is the compound drapery-column overlooking the Lake Room. The column consists of about 30 draperies hanging at various levels and angles all the way from the ceiling to the floor, the draperies being beautifully colored white and brown in layers.

One of the most intriguing aspects of all the travertine in Virgin Cave is its coloring. It is commonly streaked in various shades of brown, from light-tan to reddish-brown to deep chocolate brown. This brown coloring is most likely caused by mud impurities in the travertine. Virgin Cave is almost unique among Guadalupe caves in that it has a large amount of mud in it, most notably in the Mud Room and Grunge Hall. Mud in Guadalupe caves is never related to early-stage speleogenesis processes, but is always late-stage clastic material washed into the caves. In this case, the mud probably entered the cave passages along the brecciated zone in which Virgin Cave is developed. On the surface, southeast of the camping area and along the path to the cave, can be seen a collapse "graben" or valley about 20 m wide which roughly parallels the direction of Virgin Cave's main passages. This valley may be developed along the same zone of brecciation as Virgin Cave, and it may have also been responsible for siphoning water and mud down into the cave (thus accounting for the actively-growing, brown-colored speleothems).

Acknowledgements: I would like to acknowledge the correspondence and/or conversations I have had with Donald Davis, Harvey DuChene, Dave Jagnow, John McLean, Mac Deats and Jason Richards concerning speleothems and geologic features found in the Four O'clock Staircase and Cavernacle parts of Virgin Cave.

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Stratigraphy of the New Mexico and Guadalupe Rooms in Carlsbad Caverns, New Mexico

William L. Wilson and Donald W. Ash

Carlsbad Caverns is developed in carbonate rocks that are used as a standard reference section for the Guadalupian Series of the Permian System in North America. The Guadalupian rocks are perhaps the most investigated and most written about carbonate complex in North America. Striking lateral facies changes occur as one follows the rocks through three main depositional settings: 1) shelf, 2) basin margin, and 3) basin. Deposition of the rocks occurred in and around the Delaware Basin. A thorough understanding of the complex stratigraphy of the Guadalupian Series is essential for studying the development of Carlsbad Caverns, which is thought to represent the action of a rare, but dynamic set of groundwater conditions (Hill, 1981).

Carlsbad Caverns has the greatest vertical and horizontal development of any known cave in the Guadalupe Mountains (Jagnow, 1978). It therefore passes through a wider range of Guadalupian rocks than any other cave in the area. Carlsbad Caverns has been the focus of numerous geologic investigations, although none has clearly treated the stratigraphic setting of the cave in detail. The relation between cave levels and stratigraphy must be known to assess the extent of lithologic control on groundwater movement and cavern development.

The purpose of this paper is to summarize new evidence about the relations between cave levels and lithostratigraphic units. Questions about the stratigraphy of Carlsbad Caverns concern the identity of siliciclastic and bedded carbonate units that are present in the New Mexico Room and lower part of the Guadalupe Room, on the north side of the cave. These rooms are closest to the shelf/basin margin contact where changes in stratigraphy are most likely to occur. Identification of the stratigraphic units is complicated because, in the vicinity of the Caverns, most of the shelf/basin margin contact is not exposed on the surface.

Revised Stratigraphy

The floor of the New Mexico Room has an average elevation of 3,645 ft (1.11 km) and lies approximately 600 feet below the top of the Yates Formation as mapped by Hayes (1957). Because the Yates is less than 300 feet thick in the Carlsbad area, the sandstones in the New Mexico Room are too deep to be part of the Yates Formation as suggested by Black (1954) and Hayes (1964). The room and sandstones in question are also on the shelfward side of the Capitan Limestone. The sandstones are not part of the Bell Canyon Formation, as suggested by Moran (1955), because no basin sandstones pass through the Capitan. By the process of elimination, the simplest correlation of the sandstones is that they are part of the Seven Rivers Formation.

The correlation of the New Mexico Room sandstones with the Seven Rivers Formation was not previously considered because Hayes (1964) showed the Seven Rivers pinching out north of Oak Spring, on the south side of Walnut Canyon. Hayes' cross-section was not based on subsurface information because no drilling has been done in the National Park. Rather, he projected outcrop observations from Rattlesnake Canyon, which lies four miles southwest of the Caverns.

At question here is the slope on the top of the Capitan Limestone. Is it eight degrees or less as seen in canyons that lie southwest of Carlsbad Caverns, or, is it as much as 23 degrees as suggested by measured sections in the Caverns? If the paleotopographic slope into the Delaware Basin was especially steep in the vicinity of Carlsbad Caverns, then the basin marginal mound may have built upward as the basin subsided, without advancing as far basinward as at other localities. Carlsbad is the longest and deepest cave in the Guadalupe Mountains. Perhaps the unusual steepness of the basin marginal mound at the Caverns is a factor that contributed to the extensive cavern development.

The base of the Yates Formation was surveyed at an elevation of 3,922 feet (1.195 km) in the Guadalupe Room. The room has 296 feet (90.18 m) of relief and extends from 3726 to 4022 feet (1.135 to 1.226 km) above mean sea level. Bedded pisolites, reddish brown siltstones and thin bedded dolomites of the Yates Formation are seen to end approximately 100 feet (30.47 m) by Hayes (1957). Consequently, the Yates is approximately 293 feet (89.27 m) above the Guadalupe Room.

Rocks below the Yates Formation in the Guadalupe Room were commonly assigned to the Capitan massive limestone because they appeared to be massive. In fact, the walls are heavily encrusted with gypsum and aragonite. Bedding is visible in the walls where rocks have collapsed and exposed fresh surfaces. Bedding is definitely present in the middle third of the room's vertical extent, from approximately 3820 to 3922 feet (1.164 to 1.195 km). The lower part of the room has no readily accessible fresh rock surfaces, so the presence or absence of bedding remains uncertain.

The bedded rocks below the Yates Formation in the Guadalupe Room are probably high-magnesia calcites of shelf-margin facies of the Seven Rivers Formation rather than Capitan massive limestone. Some of the massive member may be present in the lower one-third of the room. The Guadalupe Room is 600 feet (182.8 m) east of the New Mexico Room and is in a slightly more basinward position. The floor of the Guadalupe Room is at approximately the same elevation as the ceiling of the New Mexico Room. The presence of bedded carbonates in the lower part of the Guadalupe Room is therefore consistent with the presence of the Seven Rivers Formation in the New Mexico Room. The stratigraphic relations described above are illustrated in Figure 8. The revised stratigraphic correlations will aid in assessing the extent of lithologic control on groundwater movement and cavern development.

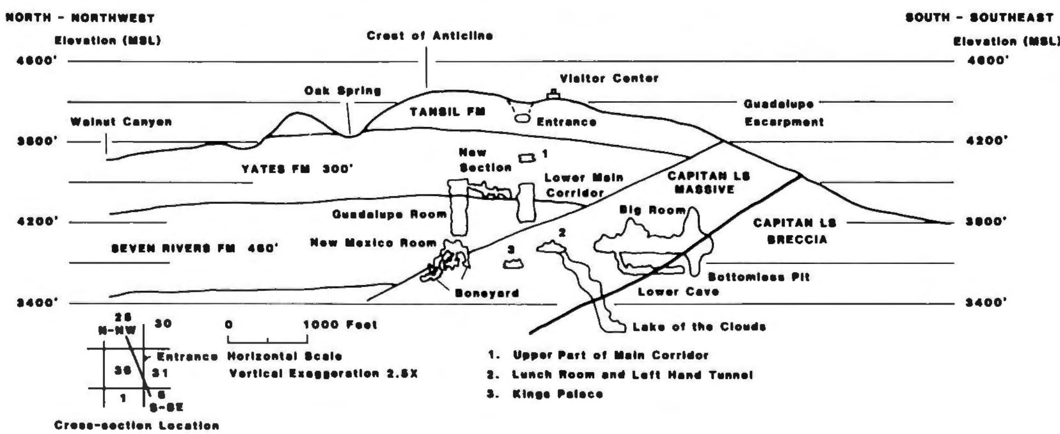

Figure 8: Revised stratigraphic relations. Some passages are projected to the plane of the cross-section.

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The New Mexico Room As A Model of Cavern Development in the Guadalupe Mountains, New Mexico

William L. Wilson and Donald W. Ash

Introduction

Caverns in the Guadalupe Mountains of southeastern New Mexico and western Texas are unlike most other cave systems in the United States. The Guadalupe caverns generally are not integrated subsurface drainage nets; neither are they related to specific surface-water catchment areas nor base level resurgences. Most of the caves consist of large blind-ended corridors, single large rooms, or groups of rooms, that often appear to be connected only by fortuitous methods. Carlsbad Caverns is the deepest and most extensive example of Guadalupe-type cave systems.

The unusual geometry of the caverns suggests that they have developed in response to a rare, but effective, set of geologic and hydrologic conditions. Some authors, notably Davis (1980) and Hill (1981), have suggested that sulfuric acid from hydrogen sulfide gas is responsible for cavern development. The nature of these conditions is poorly understood and warrants further study.

The New Mexico Room in Carlsbad Caverns was selected for detailed study of cavern geometry, stratigraphy, geochemistry, and fracturing. The room is typical of the large, semi-isolated rooms in Guadalupe-type caverns. It is also accessible, well-mapped, and removed from visitor traffic. A brief summary of the results is presented below. Based on the geologic setting and cavern geometry of the New Mexico Room a model is presented for the mechanism of cavern development. The model may be generally applicable to other caves in the Guadalupe Mountains.

Geologic Setting and Geometry of the New Mexico Room

The New Mexico Room is located on the northwest margin of Carlsbad Caverns. The room measures up to 260 feet (79 m) wide, 310 feet (94 m) long, and 70 feet (21 m) high. It appears roughly rectangular in plan view (Figure 9). Although the floor is topographically irregular, the average elevation of the floor is about 3645 feet (1,111 m). The ceiling of the room is approximately 740 feet (226 m) below the surface. Sandstone beds and bedded carbonates that crop out in the room above 3650 feet (1113 m) are probably correlative with the Seven Rivers Formation (Permian). Solutionally enlarged joints pass N25W through the room along the trend of the entrance passage and the Ranger Room. Other solutionally enlarged joints pass mostly N55E through the southeast passage and the Balcony. Although some breakdown is present in the room, most of the floor is bedrock in which boneyard is extensively developed. Boneyard extends 85 to 165 feet (26 to 50 m) below the floor of the room. Some boneyard areas, such as the Lower Pit Series, have as much as 200 feet (61 m) of relief. Around the edges of the room, boneyard descends away from the room at angles of 30 to 60 degrees; although pits are developed in some areas (Figure 10). Some boneyard is present at the ceiling level of the New Mexico Room in the Balcony and Sand Passage. These passages are aligned along a joint that also trends through the Guadalupe Room, which occurs 600 feet (183 m) east of the New Mexico Room and slightly higher.

Boneyard (or spongework) is one of the most hydrologically enigmatic features of the Cavern. It consists of vaguely spheroidal pockets and voids that are randomly interconnected. Their phreatic, solutional origin is obvious, but their shape is inconsistent with solution by flowing, phreatic groundwater, which always excavates tubular conduits. Boneyard appears to have formed by ion-diffusion through standing groundwater.

Mechanism of Cavern Development

Recent models of cavern development by a sulfuric acid reaction initiated by ascending hydrogen sulfide gas (Davis, 1980; Hill, 1981) may be modified to explain the configuration of the New Mexico Room and its associated boneyard. The mechanism of cavern development that we propose, operates in the following manner: Hydrogen sulfide is produced by bacterial reduction of sulfates along the Castile-Bell Canyon contact, or along the Castile-Capitan contact. Sulfur-reducing

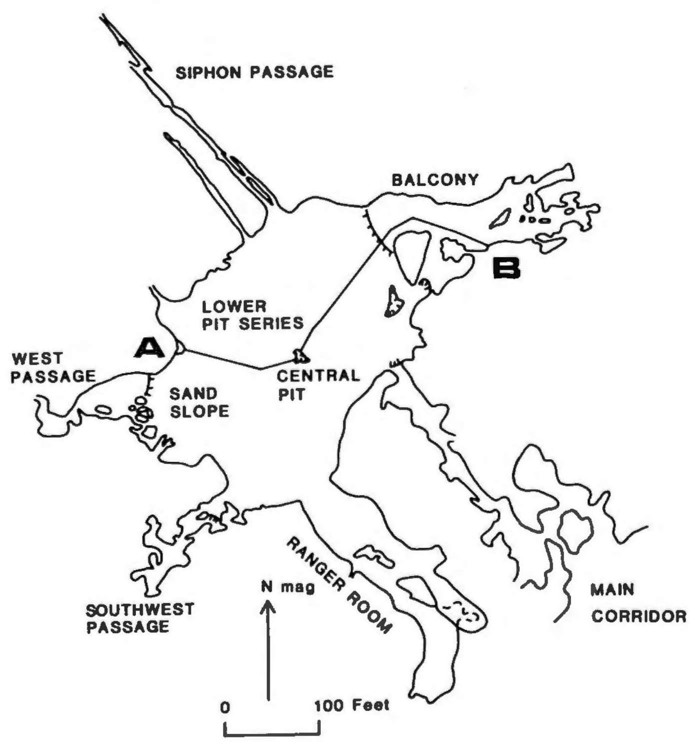

Figure 9: Plan view map of the New Mexico Room, Carlsbad Caverns. (Line of section AB is the west-to-east profile shown in Figure 10.)

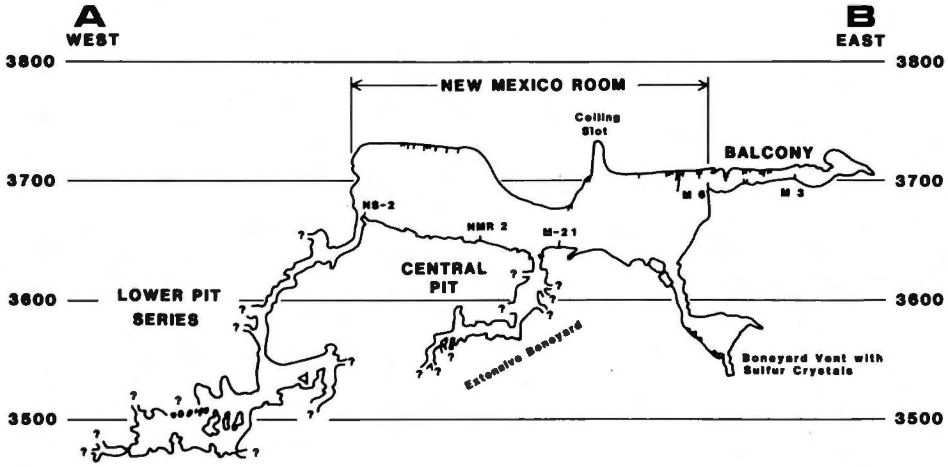

Figure 10: Cross-sectional view of the New Mexico Room. (Section shown as line AB in Figure 9.)

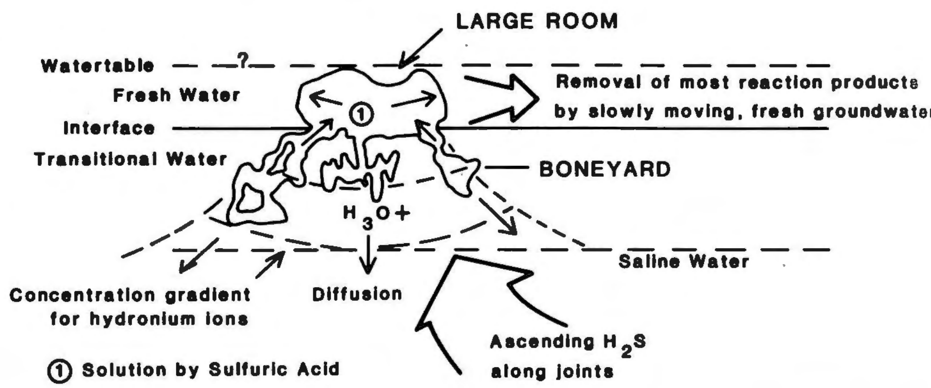

Figure 11: Proposed model of cavern development.

bacteria such as *Thiobacillus* and *Desulfovibro* inhabit near-neutral pH, non-oxygenated, saline water. Saline conditions develop at depth because the groundwater has no outlet and is moving little, if at all. The geochemical nature of the saline water is characterized by a high dissolved mineral and low dissolved oxygen content. The saline water probably grades upward into a transition zone where the water contains lesser amounts of dissolved minerals and little dissolved oxygen. Saline water is commonly found 770 feet (235 m) below the surface of the Pecos Valley at present, is overlain by 750 feet (229 m) of fresh water (Hiss, 1977). Hiss did not provide information about the position of a transitional groundwater zone. The fresh water contains low amounts of dissolved solids and high amounts of dissolved oxygen because it is flowing to some outlet and thereby flushes dissolved solids through the system. Similar groundwater conditions may have existed in the past during the formation of Carlsbad Cavern.

Hydrogen sulfide ascends through the saline and transitional groundwater, in dissolved form or as micro-bubbles, until it encounters the overlying fresh water where it oxidizes to sulfuric acid. The sulfuric acid reacts with and dissolved the limestone in the freshwater zone. Hydronium ions are produced by the oxidation of hydrogen sulfide and some move downward into the transitional water by diffusion where they randomly dissolve voids that become boneyard. Boneyard is therefore genetically linked to the formation of large rooms and develops below the rooms in poorly oxygenated groundwater (Figure 11).

The location of major rooms is controlled by the location of ascending hydrogen sulfide plumes. The size and shape of a room are controlled by: 1) the size and shape of the hydrogen sulfide plume, 2) the pattern of the joints along which the plume ascends, 3) the thickness of the freshwater zone that overlies the saline groundwater, 4) the length of time the hydrogen sulfide plume persists and 5) the concentration of hydrogen sulfide in the plume. The vertical position of the room is controlled by the position of the freshwater-saline interface. Thus, large Guadalupe caverns may form far below base level, but are not gentically linked to peneplains as was thought by Bretz (1949). Any reduction in the ability of the fresh groundwater to transport the products of solution away from the reaction site will cause supersaturated conditions at the reaction site and result in the precipitation of gypsum. The presence of thick gypsum deposits on the floors of Guadalupe caves is very common. Boneyard produced during one episode of room formation could be intersected and modified by fresh water as water tables drop in elevation. This could explain the occurrence of boneyard in the Balcony area of the New Mexico Room. The boneyard in the Balcony may also be related to development of the Guadalupe Room.

The hydrology of speleogenesis presented above is merely a brief outline. The discussion is limited to a ***mechanism*** for cavern development and does not address the far more complicated question about the *history* of Carlsbad Caverns. Additional vertical profiles of large rooms and their associated boneyard should be surveyed to test the predicted relationships. Continuing studies are planned by students and faculty of the Department of Geography and Geology, Indiana State University.

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Effects of Urban Development on the Quality and Quantity of Stormwater Runoff Recharging Through Caves into the Edwards Acquifer, Bexar County, Texas

George Veni

Introduction

San Antonio, Texas, is one of America's largest and fastest growing cities. Much of its projected growth is onto the recharge zone of the Edwards (Balcones Fault Zone) Aquifer, the sole source of water for over one million people. Urban expansion has triggered substantial concern about maintaining the aquifer's natural high level of purity and whether the Edwards can continue to supply the increasing water quantities demanded. The intent of this research is to study the impact of urbanization upon this carbonate aquifer through the many caves in its recharge zone.

Research to Date

The first and most vital task has been to examine the caves of the San Antonio area. This has involved cave locating, exploring, surveying, defining drainage basins, and making assessments of the hydrogeology. Almost 190 caves are known in Bexar County (where San Antonio is centrally situated). Of these, 77 are within the aquifer's recharge zone. Nineteen caves within adjacent limestone units are not recognized as part of the Edwards' recharge zone but show evidence of draining into the aquifer nonetheless.

Areas potentially sensitive to contamination by urban growth are being determined by mapping:

—sites where numerous caves and sinkholes occur;
—losing surface streams;
—locations of faults and other structural lineations;
—stratigraphic horizons (exposed on the surface) which are more prone to dissolution than other horizons within the limestone unit.

A dye trace from a major urban recharge cave to nearby water wells has been unsuccessful, due to equipment malfunctions (pump motors burning out, etc.) prompting a repeat attempt of the trace. Recent contamination of 12 water wells, following a significant recharge event, supports the thesis of this study—that urbanization will have a detrimental effect upon the aquifer's water quality.

A drought lasting a year and a half has stymied the collection of stormwater runoff into select recharge caves. However, surface water data for many of the streams in the San Antonio area has been collected by the U. S. Geological Survey. The author is studying that data to determine if changes in water quality have ensued over time and within individual watersheds, from their rural upstream reaches to their urban downstream catchments.

Research to Complete

Some of the work in progress, as described above, remains to be completed. Most of the data, however, has been collected, and much of the remaining work is purely analytical. If the weather cooperates, stormwater runoff into recharge caves will be collected for analysis, and total inflow will be quantified. Aquifer hydrographs will also be studied to examine the aquifer's hydrologic response to recharge events.

The data collected thus far indicate that urbanization has a definite detrimental effect upon the Edwards Aquifer's water quality and also in diminishing the volume of insurging water. How much of an effect the impact on the water supply cannot be ascertained until this study is completed.

Lineaments in the Central Kentucky Karst, Mississippian Plateau Region, Kentucky

Angelo I. George

Remote sensing affords a unique opportunity to better understand the special relationship of karst features to lineaments. A lineament is thought to be the surface signature of presumed geologic structural features buried at depth below landsurface. Lineaments exceed one mile (1.6 km) in length and are thought to have the same hydrogeologic properties as their smaller counterparts, the fracture traces (less than one mile (1.6 km) in length). Both are believed to represent a zone of maximum hydraulic conductivity for the flow of groundwater (Parizek, 1976).

This paper concerns itself with larger-scale lineaments; that is, those lineaments of 5 miles (8.05 km) or greater length as interpreted and mapped from LANDSAT space satellite photography (Figure 12). The Central Kentucky Karst within the Mississippian Plateau Region, Kentucky, was selected as a test locality because of its familiarity to field geologists; the large caves, especially the Mammoth Cave System; the numerous large springs along the Green, Barren, and Little Barren Rivers; and the nest of sinking streams flanking the southern and eastern edge of the Sinkhole Plain.

Research is centered on a LANDSAT II photograph taken on 22 December 1975. Best resolution and detection of lineaments is accomplished by processing the photo using the second near-infrared wave length, Band 7 (0.8 to 1.1 um). Lineaments were mapped directly onto the LANDSAT photograph (scale 1:250,000). Significant karst features were marked on Army Map Service maps of the same scale. The lineament map was then superimposed over the Army Map Service karst feature map. Good data fits were obtained by limiting the area of transfer to geographic blocks of 40 square miles (64.36 km) or less.

Analysis of the Central Kentucky Karst LANDSAT photograph revealed 103 lineaments. There are 105 selected karst features occurring on or near these mapped lineaments. This suggests a strong association between the point location of the karst feature or geomorphic landform to the position of the lineaments. A similar association has been shown by Parizek (1976) to account for the occurrence of high yield water wells in carbonate and other terranes in Pennsylvania. Such an association helps to strengthen the idea that lineaments corresponds to zones of concentrated fractures giving rise to linear tracks of enhanced hydraulic conductivity.

Major karst features, such as springs, karst windows, cave entrances, and ponors were mapped and compared with the mapped positions of LANDSAT lineaments. Many of the major karst features coincide with lineament traces. Several famous

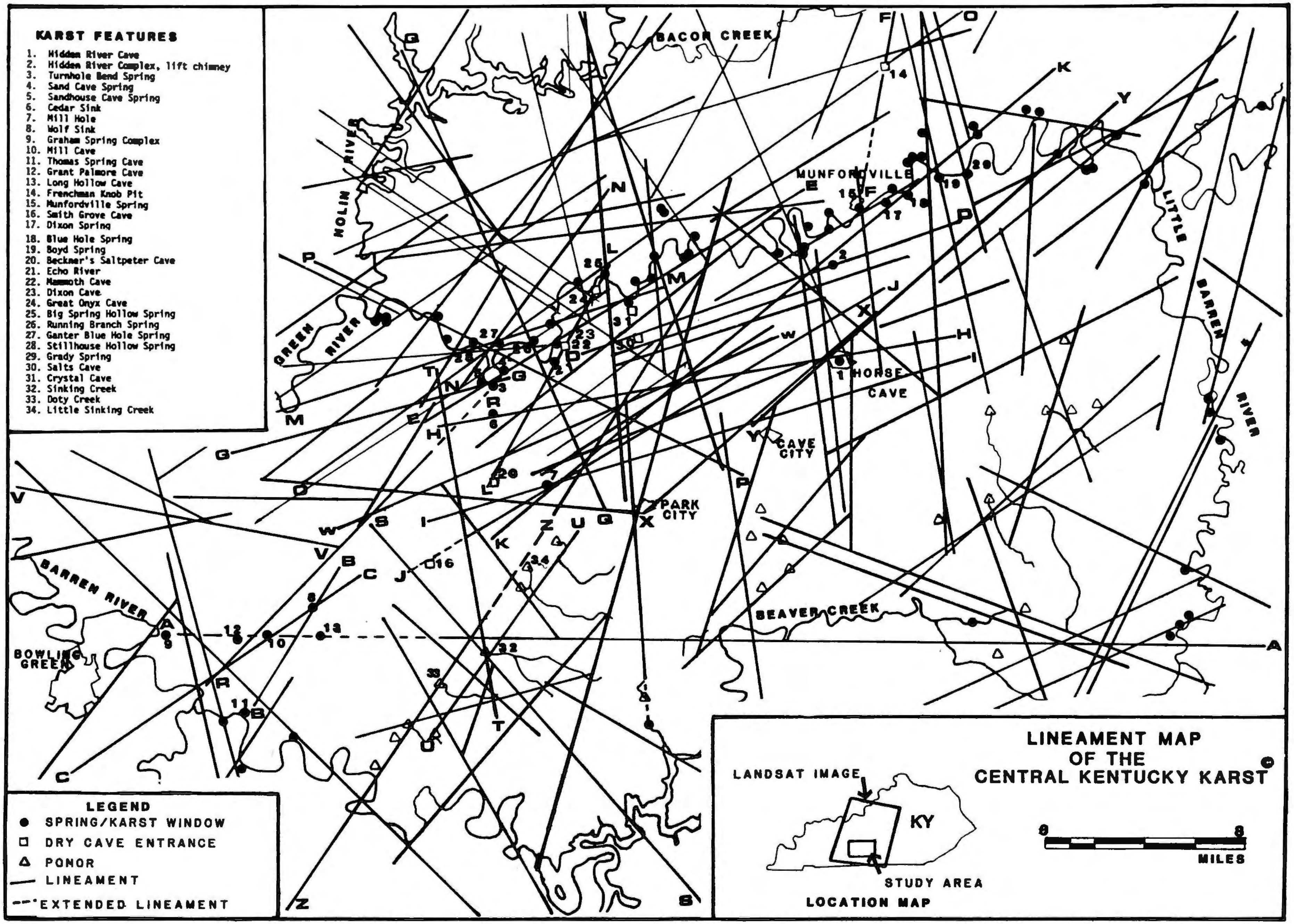

Figure 12: LANDSAT Lineament Map of the Central Kentucky Karst.

karst features in the Central Kentucky Karst are defined by multi-lineament intersections, e.g., Turnhole Bend, Mill Hole, Wolf Sink, Mill Cave, and the ponor of Sinking Creek. Some individual lineaments have exercised some control on the location of more than one karst feature. One of these lineaments has six karst features along its 5-mile (8.05 km) length. This includes Beckner's Saltpeter Cave, Echo River Spring, Mammoth Cave Historic Entrance, Dixon Cave and Great Onyx Cave entrances, and Big Spring Hollow Spring. There is a master east-west structural lineament detectable for over 68 miles (109.41 km). This one feature is thought to constitute a 2-mile (3.22 km) wide swath of enhanced hydraulic conductivity. This one feature bisects 5 karst features, consisting of Graham Spring Complex (the largest discharging spring in Kentucky), Grant Palmore Cave, Mill Cave, and Long Hollow Cave, the ponor of Sinking Creek, and a 6-mile (9.65 km) long straight reach of Beaver Creek found just north of Glasgow. Furthermore, the water-table contour lines as mapped by Quinlan and Ray (1981) are depressed and widely spaced along the axial length of the western section of this one lineament. Groundwater is converging toward the axis of the lineament and then flows along its length by way of the major trunk conduit caves to the Graham Spring Complex.

Significant portions of the Chester Escarpment are marked by the mapped presence of lineaments. The influence of these presumed structural features becomes apparent as the lineaments control the direction of groundwater movement. The potentiometric surface is shallow beneath the Sinkhole Plain; as the edge of the escarpment and lineament is approached, groundwater starts to descend steeply beneath the escarpment edge, only to shallow out on its last leg to base level Green River. The steep hydraulic gradient beneath the Chester Escarpment can better be explained by the interaction of lineaments as the preferred avenue of enhanced hydraulic conductivity in the fracture carbonate rock aquifer. In this cave, the lineaments are acting as barrier boundaries to the horizontal flow of groundwater. The greatest hydraulic conductivity is in the vertical direction along the lineament. Hence, the lineament becomes the preferred avenue along which groundwater flow lines may converge downward or upward on their route toward local base level.

Lineaments apparently act as a demarcation zone in which the hydraulic conductivity is different within the confines of the lineament. For example the fracture feature will act as a vertical plane in which groundwater flow lines are refracted from rocks with a hydraulic conductivity of K1 into rocks within the lineament with a hydraulic conductivity of K2. Snell's Law of Refraction has direct application in understanding the behavior of karstic groundwater flow in secondarily permeable rocks of contrasting hydraulic conductivity.

If some of the lineaments behave as barrier boundaries to the horizontal flow of groundwater, then specialized karst features may develop along the fracture feature. This includes: karst windows (Cedar Sink, Mill Hole, Hidden River Cave, and Wolf Sink); springs (Turnhole Bend, Echo River, Styx, Pike, and 300 springs); ponors (Sinking Creek, Little Sinking Creek, Gardner, and Doty); and the +54-foot (16.5 m) deep lift chimney in the Hidden River Complex.

Acknowledgements

Thanks to Dr. James F. Quinlan for supplying cave and spring location data in the Central Kentucky Karst.

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Cave Passage Modification Changes in Relation to Lineaments, Mammoth Cave National Park, Kentucky

Angelo I. George

A companion paper in this Annual Report (George, 1984) has shown a relation between the occurrence of major karst features in the Central Kentucky Karst and the presence of lineaments as interpreted from LANDSAT space satellite photographs. The lineament data were transferred onto a map of the Mammoth Cave System (Figure 13). The intersections of the juxtaposed cave passage and lineaments can help to account for anomalous morphological changes in cave passage cross section, plan, vertical attitude, and longitudinal profile.

Cave passage morphology is a product of the hydraulic geometry of groundwater flow. As the cave passage or groundwater flow lines encounter the lineament, zone(s) of fracture control the flow lines or the cave passage is refracted along the strike of the lineament. Once the prototube breaches the other side of the lineament strike, the passage resumes its prior direction of travel. In the more extreme case, this forms the impression of an S-bend in the cave passage because the lineament acts as a barrier boundary.

Figure 13 shows some of the most prominent anomalous cave passages. Some of the areas in the cave system where lineament-induced barrier boundaries occur are good examples of the refraction effect. One lineament passes through Main Cave between The Cataracts and Wrights Rotunda, and includes the S-bend in its effect. This same lineament passes through the right angle bend adjacent to Paradise in New Discovery; and in the other direction through the S-bend in the Grand Forks of Salts Cave. Another lineament bisects the Acute Angle in Main Cave, Echo River Resurgence, Colossal Cave Entrance, and then through the vicinity of Dismal in Salts Cave. As with S-bends (or acute angle bends), development of maze or braided cave passages is also characteristic of lineament interaction within the system.

Change in cross-sectional character can also occur when a cave passage is bisected by a lineament. A classic example is a change from the keyhole-shaped Boone Avenue to a tube passage in Cleaveland Avenue. Or there can be a change from canyon to tube and then back to canyon cross section. Deike and White (1969), and White and White (1970) have pointed out the undulatory character of prototubes in the Central Kentucky Karst. The vertical attitude as well as the longitudinal profile of a cave passage can change as it passes through the influence of a lineament. Swinnerton Avenue is a tube-shaped passage associated with one of these fracture features. Palmer (1975, in manuscript) leveled this passage and found the prototube in the cave drops about 20 feet in elevation only to climb again further down the passage to its prior level. The decline and assent is accomplished along prominent joints. Examination of the lineament-cave intersection map reveals the bisection of a lineament with Swinnerton Avenue. The lineament crosses through the cave passage at its lowest downward inflection. Under prior water table conditions, this dip and rise in a cave passage would be a sump or syphon. The recent connection of Roppel Cave and Mammoth Cave occurred through a sump bisected by one of these lineaments. Also there is a change in cave passage character from low and wide to trunk canyon.

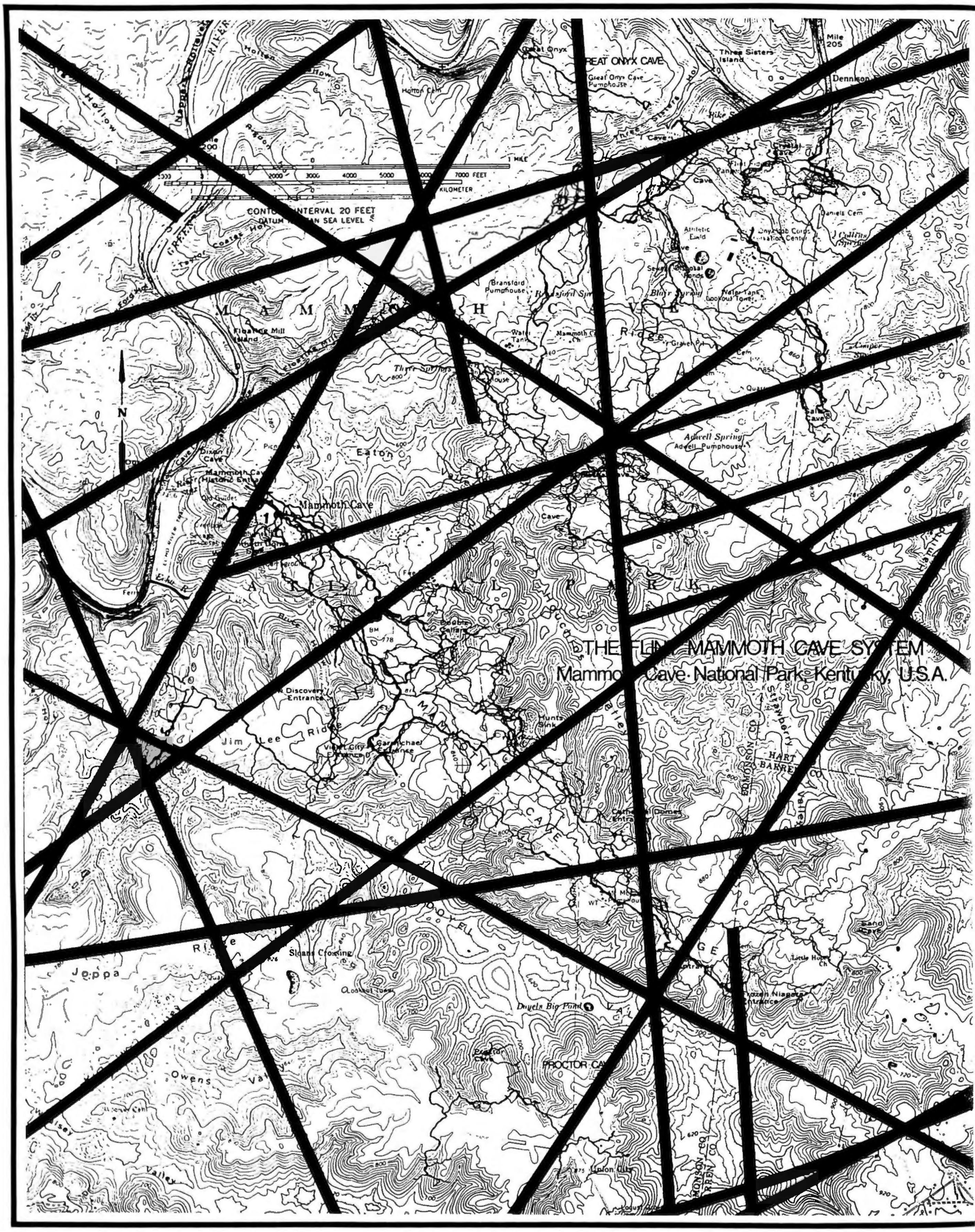

Figure 13: Lineaments in the Mammoth Cave area.

Presence of fossil or active siphons and sumps is another criteria used to suggest the presence of lineament-cave passage interaction.

Another more striking example of lineament intersection and consequent cave passage modification is the occurrence of breakout domes. Brucker Breakdown is a prime example of a cave feature formed within the zone of a near triple lineament intersection. Here is a case of maximum rock fracturing (enhanced by multi-lineament intersection) and upward stoping below the thalweg of a first-order stream valley (fracture-trace controlled) of Three Sisters Hollow.

Figure 13 suggests the lineaments have exercised a tremendous amount of structural control upon the three dimensional orientation of the Mammoth Cave System. The lineaments and fracture traces are not the actual cause of these anomalous changes in cave passage morphology. The lineaments and fracture traces are the outward sign of changes in local structural integrity of the rocks containing the cave passage, for example, local rock dip reversals, swarms of fractures, fracturing along small or large scale crests of anticlines and synclines, enhanced litho-packing of the rock fabric, and/or a change in facies. These can be related to deep-seated structural features of which the lineaments and fracture traces are an apparent association. Lineament and fracture trace analysis can be used to better understand the speleogenesis of large cave systems.

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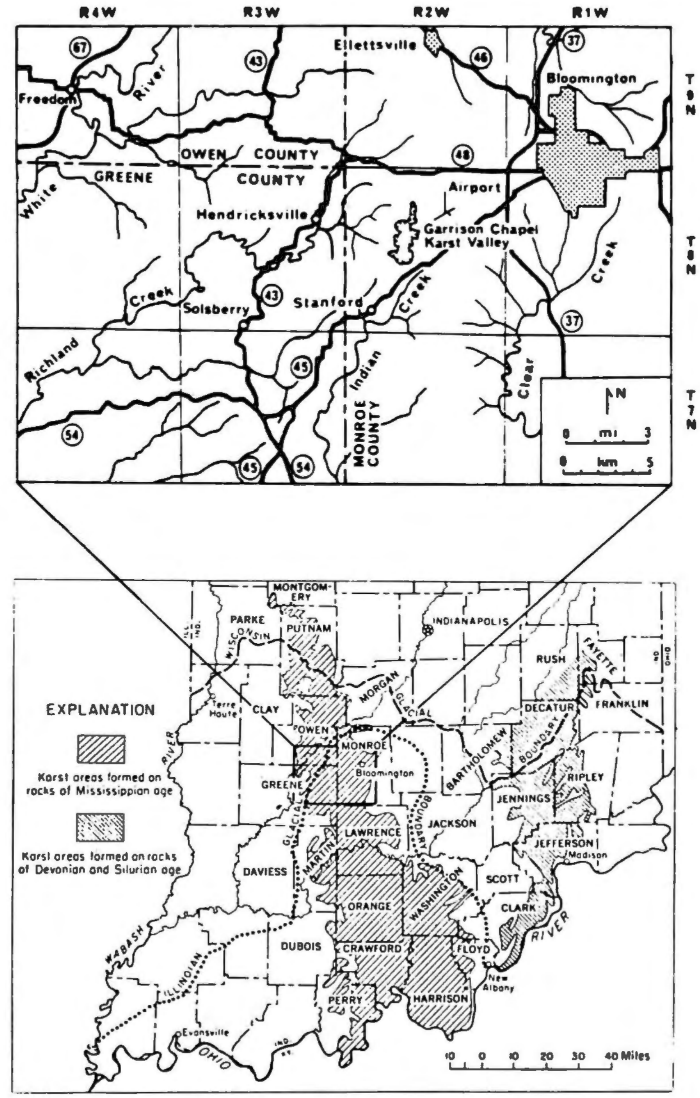

Figure 14: Location of the Garrison Chapel, Indiana study area.

Lithologic and Base Level Control of Cavern Position in the Garrison Chapel Area, Indiana

William L. Wilson

Introduction

Lithologic and base level control of cavern position in the Garrison Chapel area, Indiana, is the topic of a Master's thesis in geology by William L. Wilson. The student's advisor is Dr. Donald W. Ash, Associate Professor of Geology, Department of Geography and Geology, Indiana State University, Terre Haute, Indiana. Funding for field and laboratory work was received from the Indiana Academy of Science, Cave Research Foundation, the National Speleological Society and Sigma Xi. Interim results of the study-in-progress are presented. The study area includes a karsted valley and adjacent ridges located approximately 11 km southwest of Bloomington, in western Monroe County, Indiana (Figure 14). In the 21 km_2 area, there are 12 major caves and more than 27.3 km of surveyed passage. The surface valley formerly drained from north to south. At present four separate karst drainages underlie the karst valley and adjacent ridges. The karst drainages convey water from east to west, to resurgences along tributaries of Richland Creek that are entrenched up to 50 m deeper than the floor of the karst valley. Two to four abandoned cave levels and one active level occur in each of the karst drainages. The levels seemingly record the decline of groundwater zones in response to progressive lowering of base level.

The Garrison Chapel area is often cited as an example of subterranean piracy; however, the lithostratigraphic position and hydraulic gradients of the cave passages have never been documented. The hydrologic conditions that effected the piracy cannot be interpreted without such information. The objective of the study-in-progress is to characterize the geologic setting and fluvial geomorphology of the karst drainage levels in the Garrison Chapel area. Conclusions will be drawn regarding the relative influence of rock fracturing, rock solubility, base level position, and hydraulic gradients on the spatial position of groundwater flow paths.

Groundwater Drainage Levels

Persistent relationships between cave levels and stratigraphy are seen throughout the karst drainage basins in the study area. Out of 27 passages examined to date, 24 are developed in the middle one-third of the upper 30 meters of the Ste. Genevieve Limestone. In the area only 34 m of limestone lie above base level and are available to host karst drainage. Three passages are known to occur in either the Paoli Limestone (Mississippian) or the very top of the Ste. Genevieve. Upper levels are highly accordant with lithologic units and may be either generally strike or dip-oriented. Active streams in the lowest level occur in the Spar Mountain Member or upper part of the Fredonia Member of the Ste. Genevieve. The lowest level is usually dip-oriented and down-cuts through the stratigraphy.

Passage Gradients

Upper levels that are strike-oriented have gradients of 1.7 to 2.5 m/km. Dip-oriented upper levels have gradients of 3.8 to 7.6 m/km, which is accordant with local dip. Modern cave streams have gradients ranging from 7.6 to more than 11.4 m/km, and usually down-cut through the stratigraphy.

Rises and falls in the ceilings of strike-oriented upper levels indicate that they formed under at least 2.4 to 4.6 m of hydrostatic pressure. The low gradients and large cross-sections indicate that the upper levels formed in a landscape with less relief than the present one, and represent well-integrated subsystems for water conveyance through the karst drainage basin.

Lower levels are often very low and have small cross-sections. The steep gradients and dip-orientations of the passages indicate that they may have formed in response to either lowered, or steepened, water tables that formed in response to rapid down-cutting of surface streams. Surface stream entrenchment is thought to have occurred in the early Pleistocene when the Nebraskan Glacier diverted the Teays River into the ancestral Ohio drainage.

Future Work

Field and laboratory data will be used to interpret the geomorphic history of groundwater zones and groundwater flow paths in the Garrison Chapel area. The relationship between base level lowering of surface streams and the development of karst drainage levels will be established. In addition, the relative influence of bedrock units on groundwater flow paths will be assessed. Synthesis of a model for groundwater flow paths based on stratigraphic anisotophies may assist in the effective management of water resources in other karst terrains.

ECOLOGY PROGRAM

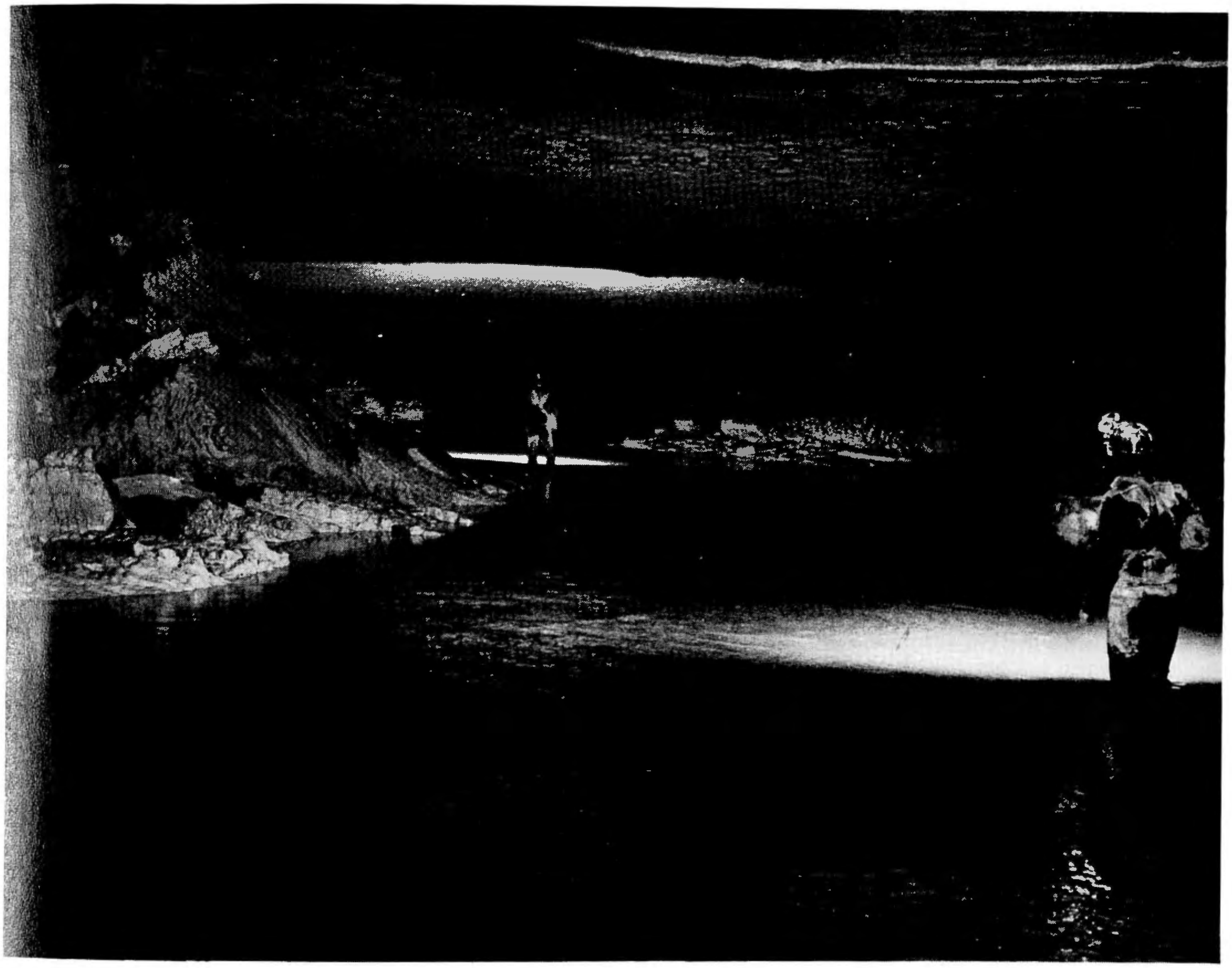

Figure 15: Cave life in Hawkins River, Proctor Cave, Kentucky, faces possible eradication from pollution being created in urban areas. Contaminated surface water can very easily pollute these underground conduits through the numerous sinkholes of the area. It is doubtful, given the precarious ecological balance that exists in caves, that life would ever return to these areas should it once be wiped out. (Photo by Arthur N. Palmer)

Nocturnal Cave Exodus and Return: Cave vs Camel Crickets

William Leja and Thomas L. Poulson, Ph.D

Methods and Study Site

We report data on nocturnal exodus and return to Great Onyx Cave (Mammoth Cave National Park) by cave crickets (*Hadenoecus subterraneus*) and camel crickets (*Ceuthophilus stygius*). The study was possible because the crickets used a 10 x 15 cm hole at the top and back edge of the blockhouse over the present entrance but not the nearby natural entrance which has been plugged by debris. From June 19-23, 1983, Leja checked this hole from dusk until dawn and recorded crickets leaving and entering by time, direction, species, sex, body length in mm, and gut fullness. In well-fed crickets the membranes between abdominal segments are visible due to stretching; in addition, crop contents are visible through the translucent exoskeleton of the cave crickets. All data were taken by Leja as a project during the WKU—MCNP Cave Ecology course and interpreted with the help of the course professor, Dr. Poulson.

Between Night Patterns

Minute-by-minute data were taken on the night of June 20-21, 1983 since many crickets were active but on the previous and following nights there was little cricket movement. On June 19-20 it had been warm and dry for several days in a row and few crickets exited the cave. On June 21-22 there was a steady but light rain and no crickets exited; few cave crickets even moved up into the blockhouse "staging area" from their roosts 25-35 m down into the cave. This may have been due to satiation as much as weather as many of the crickets fed outside on the previous night when the humidity ranged from 97-99% at temperatures of 19-21° C. Inside the blockhouse it was 18° C and 87% humidity, the lower relative humidity being due to the fact that the lower absolute humidity of saturated air at cave temperature of 14 deg C was blowing out but had not yet equilibrated with the higher absolute humidity of near-saturated air outside the cave. Presumably the crickets use the long sensory hairs on their cerci to detect the air blowing out of the exit hole but scent trails are possible accessory cues.

Within Night Patterns

Timing: Figure 16 shows that many camel crickets had exited by 2200 when the cave crickets were just starting to leave the cave. This is probably because the camel crickets roost inside the blockhouse and are ready to exit at dusk. Indeed from 2113 to 2139 four camel crickets came part way out and re-entered before six exited suddenly from 2146-2147. Figure 16 shows the data by 15-minute intervals and so does not reflect the suddenness of the initial exodus or that two more exited at 2205 and three more at 2225 all within a few seconds of one another and very quickly. This high rate of exodus only started for cave crickets around 2330 even though they most certainly have a circadian clock and so could time their arrival at the exit hole from deeper cave roosts to coincide with dusk. At 0142 there were still 14 cave crickets on the ceiling in the blockhouse though only 3 of these re-entered and only 2 were yet to leave. In contrast, there was no timing overlap for camel crickets exiting and re-entering the hole.

Considering inter-individual differences in time to find food, it is not surprising that both species re-entered the cave more slowly than they exited (Figure 16). Two of the three camel crickets that could be assessed for gut fullness had fed a lot

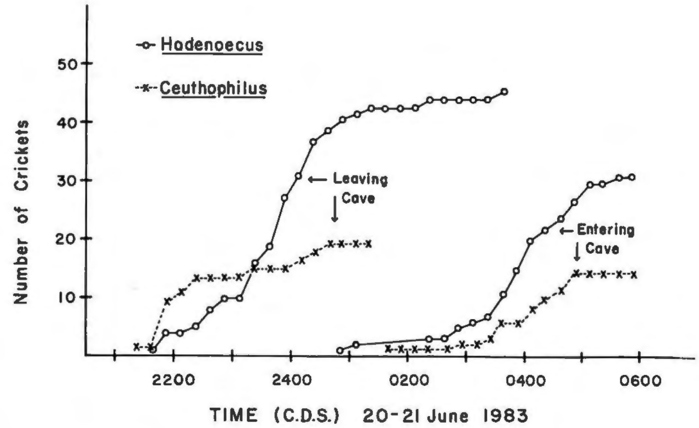

Figure 16: Timing of exit and re-entry of cave and camel crickets at Great Onyx Cave.

outside and one had not. The majority of cave crickets could be assessed and all but one, a 3-mm individual, were full or very full at re-entry. This leads to the suggestion that the difference between numbers exiting and re-entering was due to individuals that remained outside because they were not satiated. It seems unlikely that they were lost to predation since 10 of 42 per foraging night is an impossible loss rate to sustain for cave crickets that forage for about 1½ years.

Sizes: Nine of the non-returning cave crickets were in the 3-7 mm size class (Table 2) and it seems especially likely that they sought refuge outside without having filled their guts. We know from Levy's earlier work (1975 Annual Report) that small crickets are less efficient than large ones at finding their usual food of decaying organic matter. The camel cricket is more ominvorous, but 3 of 4 non-returnees were at the small end of the size range. In addition to uncertainties in estimating body length, the more expanded body of full cave crickets is responsible for the mismatch in length estimates for exiting and returning individuals. This is most evident for the larger size classes

Table 2. Lengths and sexes of cave and camel crickets going out from and coming into the cave.

Length	Camel C.		Cave C.	
mm	out	in	out	in
17	0	0	3	0
16	0	0	1	1
15	0	1	6	2
14	1	0	2	3
13	0	1	0	4
12	2	2	2	3
11	1	2	0	1
10	4	5	2	0
9	3	2	1	0
8	8	5	0	0
7	8	6	1	0
6	4	5	0	0
5	3	0	0	0
4	4	2	0	0
3	4	1	0	0
2	0	0	0	0
Total	42	32	18	14
female	9	10	13	6
male	13	5	2	6
not sexed	5	9	3	2
not sexable	15	8	0	0

where the observed number returning is close to the number that left earlier that night. If we adjust the number returning to equal the number exiting (Σ exit/Σ return • # returning in each size class) and plot the size-frequency graph, it is apparent both that the length estimates for the larger crickets are slightly longer and that this size expansions from feeding cannot account for the new small individuals; i.e., many of the smallest crickets really did not return that night.

Camel crickets had a narrow range and large average size reflecting the shorter life cycle for this species compared to the longer lived cave cricket. Cave crickets hatch deep in the cave in sandy areas from May-July, migrate to entrances from which they forage for 1½ years, and become adults in the fall and migrate back to the sandy cave areas to mate and lay eggs in winter. Thus they have about a 2-year lifespan. Camel crickets hatch in summer and begin feeding, hibernate in tight cracks in cave entrances or elsewhere in winter, grow to maturity in spring, and mate and lay eggs during the early summer. Thus they have about a 1-year lifespan.

Sexes: None of the >10 mm male or female cave crickets were sexually mature, but we believe that all of the >10 mm cave crickets were mature. Norton was the first to note that large cave crickets do not have sclerotized (black) genital plates until they start migrating into the cave to mate in fall. At the time of our study, none of the large individuals checked inside the Great Onyx entrance had sclerotized genital plates. This field mark of maturity was hard to assess in the heavily-pigmented camel crickets, but their behaviors were consistent with sexual maturity. In the past, Poulson has seen camel crickets in copulo 9 times between June-July inside the Great Onyx Cave blockhouse. And, during the night of 20-21 June, Leja noted antagonistic behavior several times near the exit hole. Perhaps he was seeing male-male interactions reflecting competition for females since there was an asymmetry in sex ratio exiting vs re-entering and timing of male-female vs male-male or female-female intervals suggests pairing behavior on re-entry. For closest times (1-12 minutes) of paired hole use by sexed individuals, none of the 8 paired exits were male-female (2 male-male, 6 female-female) but 5 of 6 paired re-entries were male-female (1 female-female). The overall sex ratio for camel crickets was 19 female to 8 male, perhaps reflecting greater risks and shorter longevities for males. The sexable cave crickets were all immature and the sex ratio was close to 1:1 (19 female:18 male) as expected when there is no differential risk between sexes associated with reproductive behavior.

Directional Orientation: Table 3 summarizes directions (as habitats and clock hours) toward which crickets exited the hole and from which they returned. In general both species exited in a variety of directions, but most returned from the forest rather from the top of the blockhouse or adjacent clearing. This trend was strongest for the camel cricket, and this is surprising both because that species is omnivorous and its sensory systems seem marginal at getting directional information since it has shorter antennae, cerci and cercal hairs than for the cave cricket.

Table 3. Direction of exit toward and entry from hole, by habitat and clock hour.

	observer & forest	*forest*	*roof & ceiling*	*roof*
	6-8	*9-11*	*12-2*	*3-5*
Camel Cricket				
exit	3	3	5	0
entry	1	10	0	2
Cave Cricket				
exit	8	6	4	17
entry	17	12	0	1

For cave crickets there were some differences in exit direction by size, but these were not consistent with increasing size and the unexplained bias of exit toward the blockhouse roof was seen for all sizes.

Risks from Predation: Anecdotal observations on cave salamanders (*Eurycea lucifuga*) and large hunting spiders were made which suggest that they are predators of crickets. For the past 10 years there have usually been 1-2 spiders of 8-15 cm leg-spread in the blockhouse and these certainly prey on crickets. A spider was observed eating a camel cricket, the carcass of which was stolen from the spider's "jaws" by a 12 mm cave cricket. Seven salamanders were seen to move from the floor and steps and align themselves along a wall crack leading to the exit hole by about 2200 hours. Only one salamander exited the hole. It appeared that the crickets would have to "run the gauntlet" past the salamanders both when leaving and re-entering the cave. One juvenile cave rat or adult mouse exited the hoke, and they too could be predators of crickets, unlike the spiders and salamanders, these rodents do not depend much on live prey.

Discussion and Perspective

The observational approach reported here is labor intensive, but can be used by minimally-trained individuals who will be provided with rich detail and insights that could not come from some more sophisticated approaches. An electric eye system could not have distinguished species, sexes, gut fullness or orientations, but it might be adapted to distinguish size and exit vs entry and it certainly can give data on timing. In conjunction with light, moisture and temperature sensors, an automated timing system would allow week to year-long tests of our preliminary hypotheses about Between Night Patterns. If we could improve techniques, marking of individuals could give data on frequency of feeding, survival rates and movements inside of vs outside of caves and via different entrances. This would allow testing of hypotheses about sizes and sexes. There is still potential for baiting and observation of individuals and locations, in addition to the exit hole, to answer questions about risks from predation and activities in the forest. We suggest use of dim light and binoculars or a night-vision scope.

A Biological Survey of Puerto Rican Caves

Edward A. Lisowski

Puerto Rico, the easternmost island of the Greater Antilles, has a surface area of 9000 square kilometers. About 20% of the island has limestone exposed or near the surface of the ground. The major limestone area occurs along the northern coast, and a minor limestone area occurs along the southern coast. In the island's tropical, humid climate, these carbonate rocks rapidly dissolve, resulting in a classic haystack karst where much of the drainage is subterranean.

I conducted a biological survey of several caves on the northern coast of Puerto Rico between 28 January and 12 February 1984. Some of the caves were typical tropical caves with a rich and diverse biota. Cueva de los Culebrones has a bat population that numbers in the tens of thousands and gets its name because of federally endangered Puerto Rican boas (*Epicrates inornatus*) that hang at the entrance and prey on bats as they leave the cave. In the interior of this cave, the temperature exceeds 38° C. and cockroaches reach densities of hundreds per square meter on thick guano deposits. One of the caves, Cueva Sorbetos, was unique because of a paucity of animals. The only entrance to this cave recently opened up. The Sociedad Espeologica de Puerto Rico (SEPRI), in cooperation with the Departamento de Recursos Naturales de Puerto Rico, installed a gate on the entrance to protect this pristine cave. The gate also excludes bats and other animals, so the organic input to cave is extremely low relative to other tropical caves. Here I observed one *quavá* (amblypigiid) (*Tarantula fuscimana*), a troglobitic mite, and six white and eyeless Collembola. Dr. José A. Mari Mutt, Universidad de Puerto Rico en Mayagüez, is describing these Collembola as a new species.

I ran a series of baited pitfall traps in three large river caves: Angles Section of the Rió Camuy System, Cueva del Rió Encantado, and Boca del Infierno. I will perform a principal components analysis on data from these traps to reveal ecological factors that influence the distribution of terrestrial invertebrates in these caves.

During a biological survey, I found an aquatic amphipod, *Alloweckelia qurneei*, in the Angles Section and in Boca del Infierno. Previously, this amphipod was found only in a single pool in the Empalme Section of the Rió Camuy System.

Acknowledgements

I thank Don Coons for organizing an expedition to Puerto Rico. I also thank members of the Comité Ecología/Biología, SEPRI, and in particular, Sr. Carlos Conde Costas, for assistance with field work.

The Cave Arthropods of Redwood Canyon Caves, Kings Canyon National Park, California

Vincent F. Lee

The results of the collections of arthropods made by Thomas S. Briggs, Vincent F. Lee and Darrell Ubick on 16-17 August 1984 are summarized in the following list.

Of these collections, the significant finds are specimens of *Macrovelia hornii* from Cedar and Lilburn Caves, previously unreported from caves, and the undetermined linyphiid spider which appears to be troglobitic. Some of the other arthropods are probably troglophiles (the mycetophilids, *Tropidischia*, and perhaps the tipulid and nesticid). Most of the remaining specimens, however, are either trogloxenes or epigeans.

CEDAR CAVE

COLEOPTERA
- Staphylinidae
  - gen. and sp. undet.

COLLEMBOLA
- Entomobryidae (probably)
  - gen. and sp. undet.

DIPTERA
- Heleomyzidae
  - *Aecothea specus*? (Aldrich) (det. DFG)
- Mycetophilidae
  - *Exechiopsis* sp. (det. DFG)
  - *Mycetophila* sp., group D (det. DFG)
  - *Rymosia* sp. (det. DFG)
- Phoridae
  - *Megaselia* (*M.*) sp. (det DFG)
- Sphaeroceridae
  - *Spelobia* (*S.*) sp. (det DFG)
- Tipulidae
  - *Limonia* (*Limonia*) *nubeculosa sciophila* (Osten Sacken (det. DFG, VFL)

HEMIPTERA (HETEROPTERA)
- Macroveliidae
  - *Macrovelia hornii* Uhler (det. VFL)

HYMENOPTERA
- Diapriidae
  - gen. and sp. undet.

OPILIONES
- Ischyropsalidae
  - *Taracus* sp. (det. TSB)
- Nemastomatidae
  - *Hesperonemastoma* sp. (det. TSB)
- Phalangiidae
  - gen. and sp. undet.

MAY'S CAVE

ARANEAE
- Amaurobiidae
  - **Callobius* sp. (det. DU)
- Linyphiidae
  - *Pimoa hespera* (Gertsch and Ivie) (det. DU)
- Nesticidae
  - *Nesticus* sp. (det. TSB)

COLEOPTERA
- Carabidae
  - *Omus californicus* Eschscholtz (dead) (det. DHK)

COLLEMBOLA
- Entomobryidae (probably)
  - gen. and sp. undet.

DIPTERA
- Mycetophilidae
  - *Exechiopsis* sp. (det. DFG) gen. and sp. undet. (larvae)
- Tipulidae
  - *Limonia* (*Limonia*) *nubeculosa sciophila* (Osten Sacken) (det. DFG, VHL)

GRYLLOBLATTODEA
- Grylloblattidae
  - ***Grylloblatta* sp. (reported by Lee 1967)

OPILIONES
- Ischyropsalidae
  - *Taracus* sp. (det. TSB)

ORTHOPTERA
- Rhaphidophoridae
  - *Tropidischia* sp. (det. VFL)

LILBURN CAVE (MAIN ENTRANCE)

ARANEAE
- Linyphiidae
  - *Bathyphantes* sp., near *diasosnemus* Fage (det. DU)

COLEOPTERA
- Carabidae
  - *Pterostichus lama* Menetries (det. DHK)
  - ***Scaphinotus* (*Brennus*) *riversi* Roeschke (formerly known as *S. B.*) *oreophilus riversi*; presumably this record is from specimen(s) taken from the main entrance)
- Family?
  - gen. and sp. undet. (dead; abdomen only)

COLLEMBOLA
Entomobryidae (probably)
gen. and sp. undet.

DIPTERA
Heleomyzidae
Aècothea specus? (Aldrich) (det. DFG)
Tipulidae
Limonia (*Limonia*) *nubeculosa sciophila* (Osten Sacken) (det. DFG, VFL)

HEMIPTERA (HETEROPTERA)
Macroveliidae
Macrovelia hornii Uhler (det. VFL)

HYMENOPTERA
Formicidae
gen. and sp. undet.

OPILIONES
Ischyropsalidae
Taracus sp. (det. TSB)

LILBURN CAVE (MEYER'S ENTRANCE)

ARANEAE
Linyphiidae
Pimoa hespera (Gertsch and Ivie) (det. DU) gen. and sp. undet. (det. DU)

Identifications by:
TSB Thomas S. Briggs
DFG Daniel F. Gross
DHK David H. Kavanaugh
VFL Vincent F. Lee
DU Darrell Ubick

* These specimens were collected in November 1966 by Vincent F. Lee.

**These two species were not collected during this trip, but are recorded in an unpublished manuscript by D. C. Rudolph, W. R. Elliott, J. R. Reddell, and T. S. Briggs, *The Cave Fauna of California*.

ARCHAEOLOGY, ANTHROPOLOGY AND PALEONTOLOGY PROGRAMS

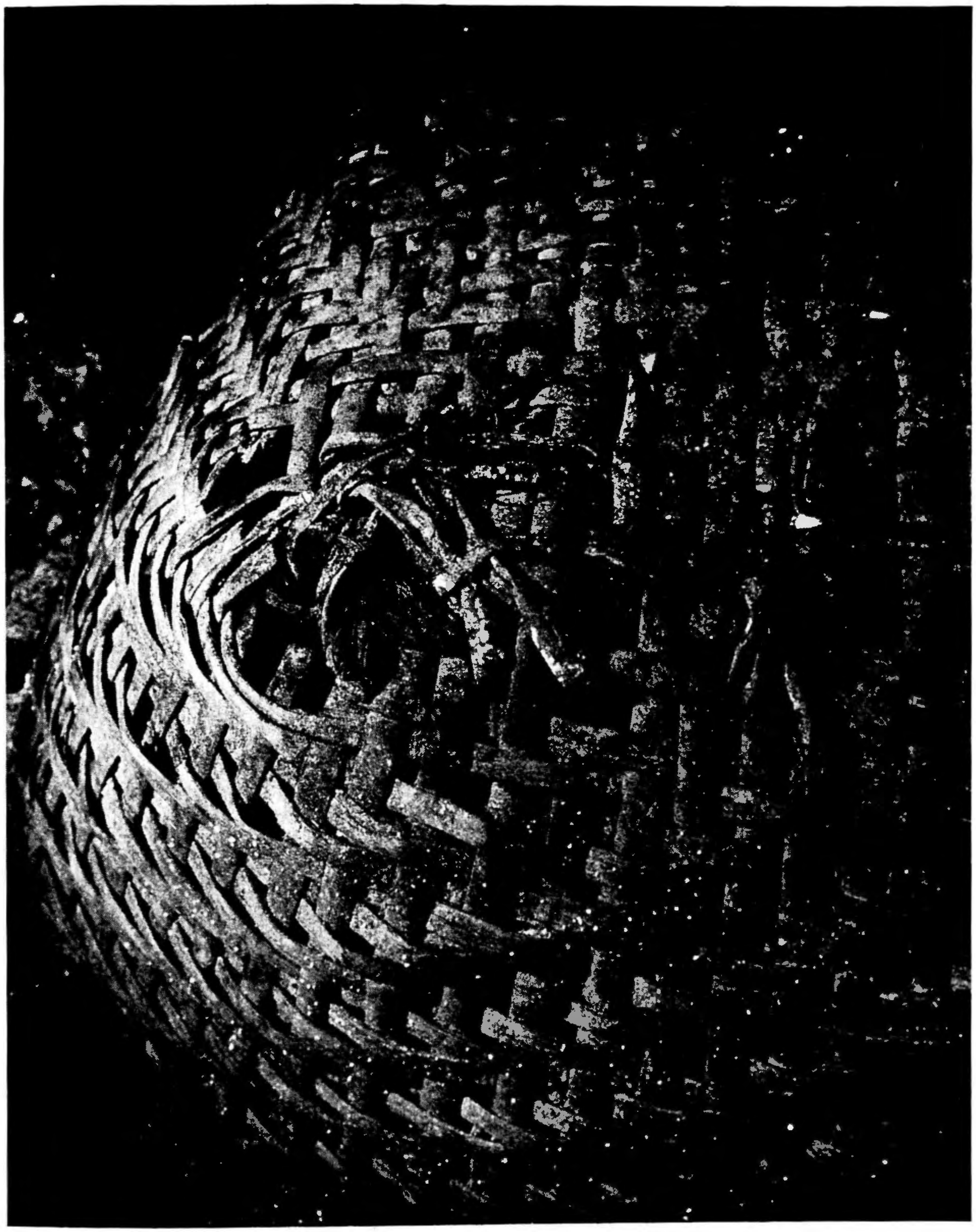

Figure 17: A complete split-cane basket, probably aboriginal, found by a CRF mapping party in Ganter Avenue, Mammoth Cave, in 1969. The basket is 14 cm high with a 31 cm diameter rim; the squared bottom is 18 cm on a side. Note the repair cord used on the basket corner. (Photo by Roger Brucker)

CRF Archaeological Project—1984

Patty Jo Watson

This was a rather active year archaeologically that began with a trip to Ganter Cave in Mammoth Cave National Park on February 4, 1984. Ganter is on the North side of the Green River between Mammoth Cave Ferry and Turnhole Bend. It was scheduled to be opened for small-group wild-caving during the summer of 1984, and hence had to be examined for prehistoric or historic materials that might be affected by modern traffic. A party of four archaeologists (P. DiBlasi, J. Hemberger, M. Kennedy, P. Watson) and one zoologist (R. Wilson) examined the cave with the help of four National Park Service rangers (P. Veluzat, H. Holman, E. Wells, J. Ravenell). We found no prehistoric remains, but we noted many interesting signatures from the late 19th and early 20th centuries, as well as a variety of historic artifactual material (iron tools, a ladder, old stairs, tin cans) and a couple of climbing ropes left by the North Side Task Force who mapped the cave in the mid to late 1970s. Our advice to the Park Service was not to open the cave for recreational purposes because of the number of caves accessible to the public outside the Park; if they were compelled to do so, then to keep the parties few and small, and to check the cave between trips.

The next archaeological trip was to Jaguar Cave (March 3, 1984) to disentangle a mapping problem. We succeeded in doing this and Mike Voligny has now finished and inked a marvellous 3 ft x 10 ft map with 274 footprints on it.

May 12-14, 1984 we returned to Sinking Creek Cave near Bowling Green (see the 1983 CRF Annual Report) because the vandalism had reached an unprecendented level. A local relic collector had set up a high-pressure hose to wash away the cultural deposit and expose collectible objects causing tremendous destruction to the site. A crew comprising three Washington University graduate students (Chris Hensley-Martin, Adria LaViolette, Gail Wagner) and Pat Watson joined archaeologists Phil DiBlasi, Jan Hemberger and Ken Carstens to help record profiles and obtain any other documentation possible. The person responsible for the damage was arrested and litigation is in process.

From June 16-25, 1984, Pat Watson taught Cave Archaeology in the Center for Cave and Karst Studies program of the Department of Geography and Geology at Western Kentucky University. An unusual feature of this year's course was a visit to Crystal Onyx Cave in Prewitts Knob where the class examined skeletal remains first found there in the 1960s and believed to be prehistoric on the basis of a single Teledyne radio-carbon determination of 680 B.C. ± 95 (uncalibrated; Libby half-life, 1950 base date).

We returned to Prewitts Knob on August 4-5 to continue recording the fragmentary skeletal material. We had a larger group this time including Lisa Dolehide, Richard Hand, Valerie Haskins (whose Master's Thesis is on the prehistory of Prewitts Knob), Mary Kennedy, Tony Schwinghamer, Marsha Weinland, Karli White, Ron Wilson and Pat Watson. On August 15, Valerie and Karli returned to Crystal Onyx to sort and package some of the bone for transfer to Wasington University where it can be cleaned, preserved with polyvinyl acetate, cataloged and studied.

New light is being cast on prehistoric mineral mining in the Mammoth Cave System as a result of research by Patrick and Cheryl Munson, Ken Tankersley, John Bassett and Sam Fruschour. They have found evidence of quarrying for selenite crystals and for satinspar in sediment beds and veins in both Mammoth Cave and Salts Cave. We examined several locales in each cave on September 15 and 16. Besides those already mentioned, the study group included Peggy Bassett, Phil O'Dell and Kimberly Owens. We also checked Mummy Ledge where sediment was dug away extensively in prehistoric times, apparently in search of satinspar crystals. A set of papers is planned for the Society of American Archaeology meetings to be held in May, 1985 to report these results.

As a result of several unanticipated snags, the Shell Mound Project (see CRF Annual Reports 1977-1982) book manuscript is not yet completed. Hence, no further field work has been done in the Logansport, Ky area; Christine Hensley-Martin is examining some of the artifactual material from a bluff-top shell mound, the Read site (15 B + 10), in preparation for undertaking a Master's thesis project. This material was excavated in the late 1930s by local workmen under the supervision of WPA archaeologists and has never been fully described nor analyzed. On October 22, 1984, Chris brought the first installment of the B + 10 collection to Washington University to begin sorting, tabulating and describing it.

On November 10-11, Mary Kennedy, Bill McCuddy and Pat Watson joined John Bassett, Sam Frushour, Cheryl Munson, Patrick Munson and Ken Tankersley in a photo and mapping trip to Flint Alley and Mummy Ledge in Mammoth Cave. Our objective was to document those areas where the prehistoric people seem to have been rather intensely mining selenite and satinspar. In several places, marks of the wooden digging sticks are clearly visible in the compact cave sediment (Figures 18 and 19).

Figure 18: Gourd fragments and probable prehistoric digging stick on a breakdown rock on Campbell Ledge, Mammoth Cave. (The gourd fragments are covered with historic period soot.) (Photo by William McCuddy)

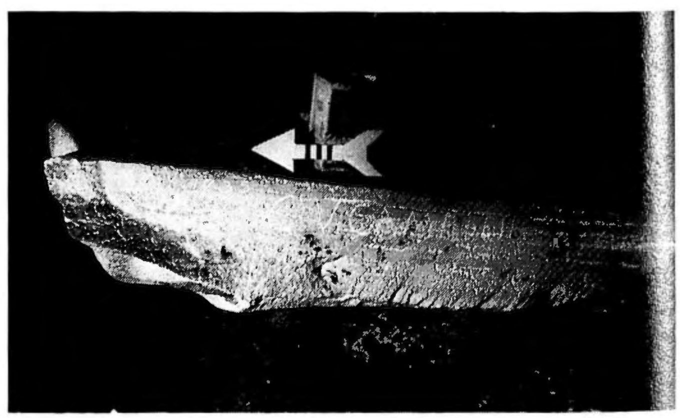

Figure 19: Grover Campbell's signature with the date of May 1935, on a ledge south of Mummy Ledge in Mammoth Cave Grover Campbell and Lyman Cutliff were the discoverers of the Mammoth Cave mummy in June, 1935. The North arrow is 25 cm long; each mark on its midshaft equals 1 cm. (Photo by William McCuddy)

On November 29, Mary Kennedy, Pat Watson and Ron Wilson met a group of Kentucky archaeologists at Flint Ridge to guide them through a part of Upper Salts Cave, Floyd Collins Crystal Cave and Great Onyx Cave. The conference was organized by Phil DiBlasi and Jan Hemberger of the University of Louisville Archaeological Survey to address the issues of cave conservation legislation in Kentucky and of a state archaeological association.

Acknowledgements

We are grateful to the officials of Mammoth Cave National Park, especially Superintendent Robert Deskins and Manage-agement Assistant James Wiggins, for their interest in and support of our research. At Crystal Onyx Cave, Wesley Odle, Carma Odle, Norbert Hay, Ed Hay and Pam Lapka have enthusiastically aided our investigation of Prewitts Knob. Gordon Smith and Harold Meloy were, as always, very generous in providing relevant data from their wealth of historical information about Mammoth Cave National Park. Gordon Smith kindly lent us several Ganter Cave postcards to aid us in our report on the history of early commercialization there. In Lexington, KY, Dr. George Milner the curator of the University of Kentucky, archaeological collections was extremely patient and helpful in aiding Chris Hensley-Martin with the B + 10 material.

Although we did no field work in the Logansport area (the Big Bend of the Green River), some of us did spend a few days there in early June working on the Shell Mound Archaeological Project report. We were as always more than hospitably received by the residents of the Big Bend, especially John L. Thomas, Kathleen Thomas, Waldemar Annis and Ethie Annis. We are very deeply indebted to these kind and generous people.

Cultural and Paleontological Resources of Northwest Central Kentucky Caves

Philip J. DiBlasi and Ronald C. Wilson

During the summer of 1984, the authors acted as Principal and Co-Principal investigators on a Federal matching grant-in-aid research grant administered by the Kentucky Heritage Council. The primary goal of the project was to assess the cultural (prehistoric and historic) and paleontological resources in small caves within the Falls of the Ohio Region. Six Kentucky counties were sampled using a stratified random sampling strategy that involved the surface examination of approximately 50 square kilometers. As a result of the surface survey and literature review, a total of 82 caves were examined. The examination of the caves included collection of archaeological and paleontological materials, mapping all of the caves that were found, as well as the excavation of test units. A total of ten of the caves were tested; all produced significant data although analysis is not yet complete.

A major aspect of this project has been the development of a uniform cave inventory form that considers not only the archaeological and paleontological remains, but also includes the geological, biological and other speleological data.

In general the paleontological results, to date, appear to be considerably more spectacular than the archaeological results. Jaguar, wolverine and giant armadillo were recorded for the first time in Kentucky. Some of the other finds include mastodon, plains pocket gopher, northern red squirrel, cf snowshoe hare, extinct horse, spruce vole, yellow-cheeked vole and porcupine. One significant find in a small cave (less than 30 meters) was a herd of flat-headed peccaries that include fetal to aged specimens.

However, some of the archaeological results are combined with the paleontological finds. In Hall's Cave artifacts were found in situ with fossil bone (which has not been identified) and in a mixed context with mastodon remains. Generally, the prehistoric archaeological finds were confined to the entrance areas of the caves.

We expect the results and methods employed in this study to serve as a model for future work in other regional cave studies.

Archaeological Investigation of Bugtussle Rockshelter

Charles L. Hall

Recently a dry rockshelter was discovered by collectors of Indian relics in Macon County, Tennessee. Due to its situation beneath chert-capped shale-bearing limestone, and its southeast-facing aspect, the sheltered area has been perfectly protected from the weather, and the deposit has always been dry. As a result, those materials which decay in unprotected contexts were preserved at this shelter. These materials included unprocessed plant remains, plant materials processed in some way (textiles and tools), human paleofeces, and animal tissues (including human skin and hair, and animal hides).

While it was the collector's efforts which brought the site to the attention of the Department of Anthropology, University of Tennessee, Knoxville, they also represented a real and imminent threat to this valuable resource. An investigation of the site was proposed with the stated goals of determining the integrity and depth of the deposit, the age of the prehistoric material, and the potential of the site for continued scientific investigation. Funding for the testing was provided by the Cave Research Foundation, and the work was undertaken during the summer of 1984.

Description

Bugtussle Rockshelter (40MC1) is located at the base of a near-vertical bluff along the west or left bank of Salt Lick Creek in Macon County, Tennessee (Figure 20). The overhanging limestone ceiling is approximately 3 to 4 m above the deposit surface and extends along 22 m of the bluff face. The depth of the overhang varies from 5 to 6 m and so shelters approximately 80 m^2. Numerous massive limestone slabs are present on the deposit surface. At the initiation of field work this past summer, four excavations were present and were assumed to be the result of the activities of the local relic collectors. These excavations involved approximately 15 m^2 of the sheltered area and average 30 to 50 cm in depth.

Field Work

Test excavations were positioned partly within the relic collector's pits. In this way, the relationship between the disturbance apparent on the surface and the actual disturbance to the deposit could be assessed. Additionally, this strategy was designed to provide both a profile of the rockshelter's sediments and a sample of the archaeological material they contained while involving as little of the remaining deposit as possible. Three contiguous 1 m^2 excavation units were placed along the outside edge of the largest collector's pit parallel to the shelter's long axis. Excavation proceeded within arbitrary 10 cm levels which were subdivided horizontally and/or vertically when possible based on observable differences within the

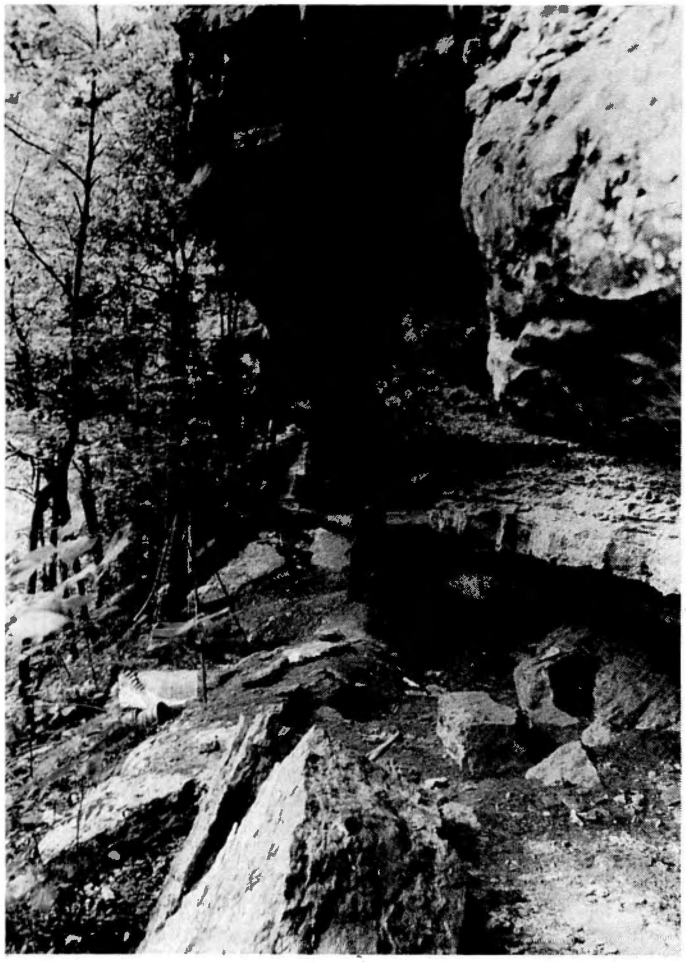

Figure 20: Bugtussle Rockshelter in Macon County, Tennessee (view to the southwest).

deposit. Excavation within the first unit was terminated at bedrock. The subsequent two units were taken only to the depth extent of the dry deposit.

Results

Although the laboratory processing and analysis of the recovered materials is far from complete, enough is known to address the goals of the investigation.

Integrity of the deposit. In all three units excavated, the surface limits of the relic collector's pits coincided with the actual disturbance to the deposit; their impact on the integrity of the deposit may be directly assessed from an inspection of the surface.

Great quantities of dung were observed in discrete and packed strata which appear to represent at least two intense episodes of utilization of this rockshelter by goats. Where the goat dung strata occurred, the archaeological deposits were severely disturbed. The deposit had also been disturbed by the activities of some burrowing rodent, probably woodchuck. Both the goat and rodent disturbances were easily identified and readily separated from uneffected portions of the deposit.

Depth and Character of the Deposit. The deposit consists of two portions: a dry portion containing perishable materials, and an underlying moist portion lacking perishables. The dry portion begins at the ground surface and is an average of 55 cm in thickness. An abrupt contact separates the dry deposit from the moist sediment, which continues to bedrock. Where unaffected by goat and rodent disturbances, the dry portion of the deposit is complexly stratified with thin lenses of homogeneous, packed leaves, white ash, grey ash or burned vegetable material. Occassional strata of grey ash loam are present and apparently represent mixed midden.

Age of the Archaeological Material. Archaeological material was abundant throughout the dry portion of the deposit. The only temporally diagnostic artifacts recovered, however, were ceramic shards. All shards were tempered with crushed calcite and had lightly impressed or smoothed-over cord-marked surfaces. Similar material has been found in late Middle Woodland or early Late Woodland contexts elsewhere in Tennessee (Faulkner, 1978). The lower moist sediment yielded only scattered flakes and one projectile point/knife which was similar to the *White Springs* type (Faulkner and McCollough, 1973), a Middle Archaic form.

Based on the evidence cited above, it is tentatively suggested that the occupation represented in the dry portion of the deposit occurred between A.D. 400 and A.D. 900. The moist sediment contains material potentially several thousand years old.

Conclusion

The Bugtussle Rockshelter remains an important archaeological resource withstanding many human and natural disturbances. Undisturbed dry deposits are present. A more intensive investigation of those deposits should be undertaken. In this way it may be possible to enhance our picture of prehistoric life in general, our knowledge of the prehistory of a relatively unknown region, and our understanding of the manner in which sheltered sites were used in the past.

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Excavation of Caves in Grand Canyon, Arizona

Steven D. Emslie

During the summer of 1984, excavations were completed in four caves, with an additional 19 surveyed, in Grand Canyon, Arizona. These investigations, supported by grants from the National Geographic Society, the Grand Canyon Natural History Association, and the Cave Research Foundation, were completed in order to: 1) collect vertebrate fossils of Pleistocene age, particularly of birds, 2) investigate the paleobiology of specific avian species such as the condor *Gymnogyps*, sp., which nested in the canyon during the Pleistocene, and 3) study the taphonomic processes involved with bone accumulation in caves. Caves selected for this project were located high on vertical cliffs, inaccessible to most animals except birds and small, cliff-dwelling vertebrates. These caves were accessed by vertical climbs from below, rappels from above or traverses along cliff edges using appropriate climbing equipment and personnel. Results of this project so far have been significant towards fulfilling the three research objectives.

Fossil remains of condors were found in seven caves, more than doubling the previous number of six sites from which this species was known in Grand Canyon. The most striking finds included a complete condor skull found on the surface in one cave, and parts of five condor skeletons excavated from packrat midden in another cave. The skull was so well preserved that it retained dried tissue on the sides and an intact beak. A carbon-14 date on the tissue, using the new accelerator process at the University of Arizona, has produced a date of over 12,000 years B.P. for this specimen.

The remains of the condor skeletons came from a cave that also contained a large number of condor feather and eggshell fragments and numerous fragments of bones from large mammals. This evidence suggests this cave was once a nest cave for condors. The mammal bones, which include bones of bison, horse, camel and mountain goat, may be food bones left by the condors. Carbon-14 dates from this cave are also late Pleistocene, 11,000-13,000 years B.P. These dates are the first series of dates completed on a Pleistocene bird and indicate the condor became extinct in the canyon at the close of the Pleistocene, and did not exist there during the Holocene. The cause of their extinction was probably directly related to the disappearance of the large mammals that comprised the bulk of the condor's diet. These conclusions need to be considered before the canyon is used as a relocation area for living condors as part of the condor recovery program. Since condors could not survive in Grand Canyon after the close of the Pleistocene, when modern floral and faunal communities were established, it is unlikely it could survive there now unless supplemental food supplies are provided on a regular basis.

Speleothems were not often found in the caves. The most commonly observed features were calcite deposits on the cave walls, and gypsum "cave flowers" found in nearly every cave that was visited. Only one cave, visited on 1 July 1984, contained well-developed speleothems including stalactites, stalagmites, flowstone and columns indicating it had been a wet cave at one time. Another interesting feature of this cave is the living invertebrate organisms it contains. Just within the dark zone at the entrance, hundreds of cave harvestmen (*Phalangodes* sp.) were observed in aggregations on the cave walls. Although harvestmen had been observed in nearly every other cave that was visited, never had they been seen in such large numbers or in these aggregations. This part of the cave also contained a swarm of small flying insects, probably gnats. This cave could prove valuable for studies of cave invertebrates by a zoologist. The project will be completed in Grand Canyon during the summer of 1985.

CRF FELLOWSHIP AND GRANT SUPPORT

Figure 21: River Styx Spring, which lies at the level of the Green River, is one of the major outlets for the water that flows through Mammoth Cave. This spring serves as an overflow route for Echo River Spring which drains Mammoth Cave Ridge, Houchins Valley, Doyel Valley, as well as parts of Flint Ridge and Joppa Ridge. (Photo by Arthur N. Palmer)

CRF Fellowship and Grant Support

John C. Tinsley

Each year, the Foundation may award up to $4,000 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 $2,500); meritorious proposals may receive one or more karst research grants, in amounts less than $2,000, awarded to qualified students in graduate programs in the natural or social sciences. Applications are screened by a committee of scientists. The judges seek promising or innovative topics, supported by evidence that the student has command of the literature and the methodology. A detailed announcement is mailed in late Autumn, and the deadline for the receipt of the proposal, supporting documents and letters of reference is January 30. 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 1984, five proposals were received and the following Grants were awarded:

1. A CRF Karst Research Grant ($1,500) to Mr. George Veni Department of Geology and Geography, Western Kentucky University, Bowling Green, KY 42101, for his proposal entitled "Effect of Urban Development on the Quality and Quantity of Storm Water Runoff Recharging through Caves into the Edwards Aquifer, Bexar County, Texas."
2. A CRF Karst Research Grant ($800) to Mr. William L. Wilson, Department of Geography and Geology, Indiana State University, Terra Haute, IN 47809, for his proposal entitled "Lithologic and Base Level Controls on Cavern Levels in the Garrison Chapel Area, Indiana."
3. A CRF Karst Research Grant ($700) awarded to Mr. Charles L. Hall, Department of Anthropology, University of Tennessee, Knoxville, TN 37996, for his proposal entitled "Investigation of Bugtussle Rockshelter, Macon County, Tennessee."
4. A CRF Karst Research Grant ($500 awarded to Mr. Steven D. Emslie, Department of Zoology, University of Florida, Gainesville, Florida 32611, for his proposal entitled "Pleistocene Avifauna of the Grand Canyon, Arizona: A Study in Paleoecology and Taphonomy."

Research summaries and progress reports submitted by these investigators are published elsewhere in this Annual Report. Please refer to these summaries for additional details of objectives, methods and results.

INTERPRETATION AND EDUCATION PROGRAMS

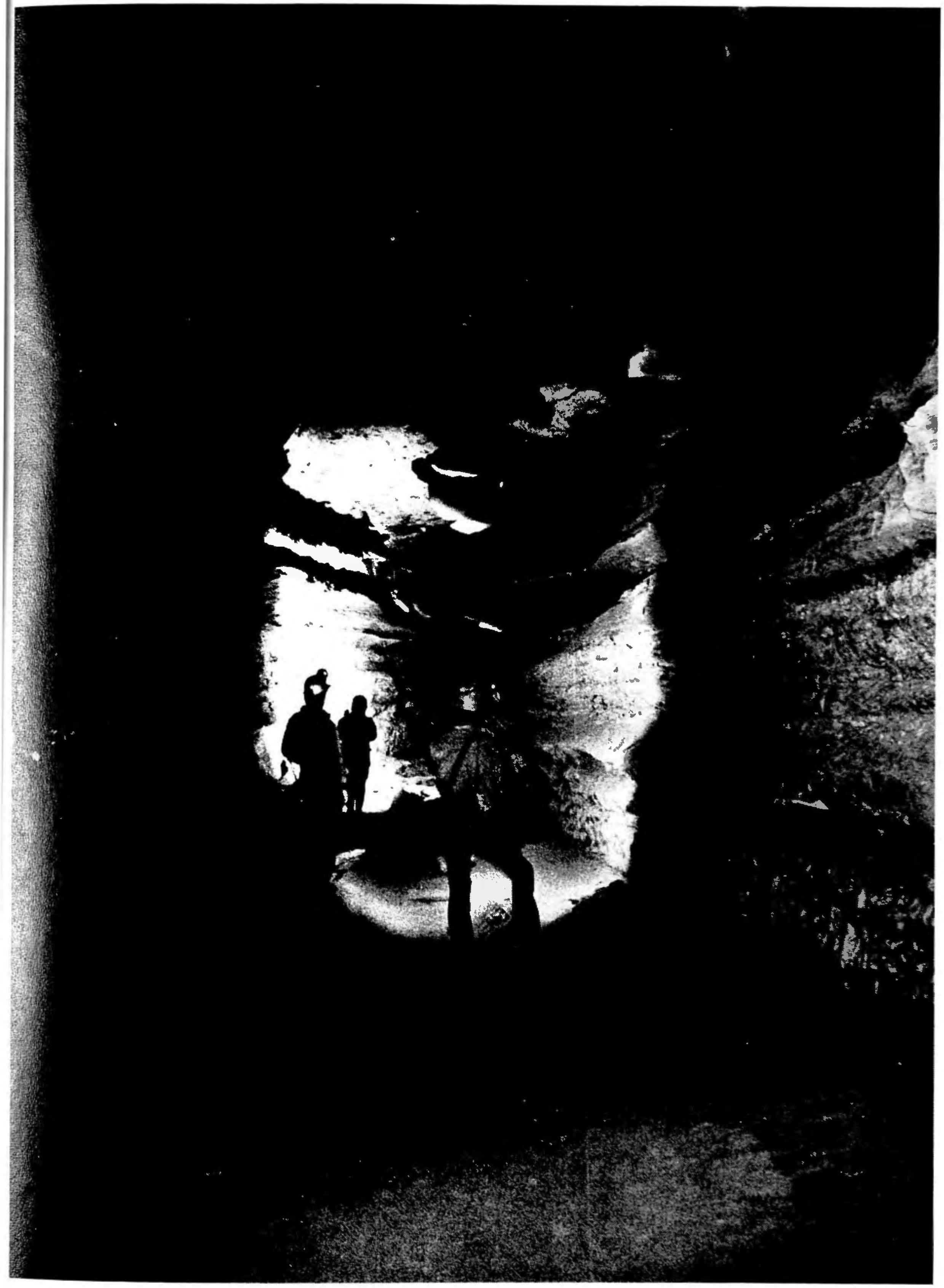

Figure 22: One of the most beautiful reaches of passage in the Flint-Mammoth Cave System is a 12-foot wide by 20-foot high sand-floored canyon along Mather Avenue. Mather Avenue was formed perhaps 500,000 years ago when water in an upper-level passage (Turner Avenue) changed course and eroded downward into the Aux Vases and Joppa members of the Ste. Genevieve Limestone. (Photo by Roger Brucker)

HISTORY PROGRAM

Figure 23: Ralph Stone Hall, Flint Ridge System. This area and adjacent Ralph's River Trail were named in honor of Dr. Ralph W. Stone, former State Geologist of the Commonwealth of Pennsylvania, editor of ***The Caves of Pennsylvania***, and past president of the then newly-formed National Speleological Society. Dr. Stone also participated as an advisor to geologists during the historic C-3 (Collins Crystal Cave) expedition undertaken in 1954. (Photo by Roger Brucker)

Saltpeter and Gunpowder Manufacturing in Kentucky

Angelo I. George

The manufacturing of saltpeter and gunpowder was a prominent early industry in the state of Kentucky. Its fame as a saltpeter producer extends prior to the time of her statehood. Thomas Jefferson (1787) in his *Notes on the State of Virginia*, makes reference to the saltpeter production centers along the Cumberland River. However, production in this locality is known to have been in operation as early as 1775 (Arnow, 1963).

Samuel Brown (1809), an early entrepreneur in the industry, is credited with producing one of the earliest inventories of saltpeter sites in Kentucky (George, 1975). His list consisted of 5 caves and 28 rockshelters. Roger Sperka and Angelo George (in manuscript, 1972) using data gathered from their cave files, produced a listing of 10 known saltpeter sites along with 40 possible sites. The majority of these possible sites became known sites with later investigation. By 1981, Carol Hill et al., had increased this number to 21 known sites. This was followed by an update with 35 known sites (Hill, 1982).

Present efforts center on site visitation, inventory of artifacts, cave mapping, collection of oral history, literature search, review and interpretation. This has produced 163 saltpeter and 31 gunpowder sites in Kentucky (Table 4). The data base can be broken down into three categories consisting of known sites, suspected sites, and place name sites. From this there are 103 known sites, 14 suspected sites, and 46 place name saltpeter sites. Of the known sites, 19 of them are rockshelters. Of the gunpowder sites, 21 are known powder installations and there are 10 place names which suggest this kind of activity (Table 5).

Table 4. Saltpeter sites in Kentucky. (Site types indicated are: CV for cave, and RS for rockshelter).

		Total	103	14	46	163
			Site Classification			
County	Site Name	Map No.	Known	Susp	Place Name	Site Type
Adair	Breeding Saltpeter Cave	68	X			CV
Adair	Saltpeter Cave	69			X	CV
Allen	Carpenter Cave No. 1	70	X			CV
Allen	Goodrum Cave	72	X			CV
Allen	Holland Cave	71	X			CV
Barren	Canoe Creek	73			X	
Barren	Duval Saltpeter Cave	75	X			CV
Barren	Payne Cave	76	X			CV
Barren	Saltpeter Cave	74	X			CV
Bath	Peter Cave	1			X	
Bath	Trough Lick Branch	2			X	
Bell	Cave in Pine Mountain	125	X			CV
Bell	Saltpeter Cave	126			X	CV
Breathitt	Alum Cave Branch	3			X	
Breckinridge	Stinnettsville Pit	78	X			CV
Breckinridge	Thornhill Cave	77	X			CV
Bullitt	Zonetown Saltpeter Cave	123	X			CV
Butler	Saltpeter Cave	130	X			CV
Caldwell	Lisanby Cave	79	X			CV
Carter	Laurel Cave	29	X			CV
Carter	Saltpeter Cave	5	X			CV
Carter	Saltpetre-Moon System	4	X			CV
Christian	Saltpeter Cave	80			X	CV
Clay	Saltpeter Hollow	7			X	
Clinton	Buffalo Saltpeter Cave	11	X			CV
Clinton	Copperas Cave	10	X			CV
Clinton	Copperas Saltpeter Cave	9			X	CV
Crittenden	Peter Cave	81			X	CV
Crittenden	Saltpetre Cave	82			X	RS
Cumberland	Saltpeter Cave	83			X	CV
Edmonson	Beckner Saltpeter Cave	91	X			CV
Edmonson	Dixon Cave	84	X			CV
Edmonson	Hundred Domes Cave	88	X			CV
Edmonson	James Cave	89	X			CV
Edmonson	Jim Cave	132	X			CV
Edmonson	Longs Cave	85	X			CV
Edmonson	Mammoth Cave	86	X			CV
Edmonson	Peter Branch	87			X	
Edmonson	Short Cave	90	X			CV
Edmonson	Wilson Cave	140	X			CV
Elliott	Peters Hill	12			X	
Estill	Moreland Saltpeter Cave	13	X			CV

Table 4 (continued). Saltpeter sites in Kentucky. (Site types indicated are: CV for cave, and RS for rockshelter.)

County	Site Name	Map No.	Known	Susp	Place Name	Site Type
			Site Classification			
Estill	Salt Cave	14			X	CV
Estill	Saltpeter Cave	16	X			CV
Estill	Sparks Saltpeter Cave	15			X	CV
Grayson	Cave Creek Cave	92	X			CV
Grayson	Hayes Cave	141	X			CV
Green	Cushenberry Cave	94		X		CV
Green	Wickerville Saltpeter Cave	93	X			CV
Greenup	Peter Cave Branch	18			X	
Greenup	Peter Cave Branch	17			X	
Greenup	Petre Cave	139			X	RS
Hardin	Belt Cave	98	X			CV
Hardin	Cave	134	X			CV
Hardin	Cave No. 1	101	X			CV
Hardin	Cave No. 2	102	X			CV
Hardin	Constantine Saltpeter Cave	95	X			CV
Hardin	Flat Rock Cave	133	X			CV
Hardin	Given Maze Cave	96	X			CV
Hardin	Great Wonderland Cavern	99	X			CV
Hardin	John Hilth Cave	97		X		CV
Hardin	Peter Cave	100	X			CV
Hardin	V.O.C. Crystal Cave	135	X			CV
Hart	Barnes Smith Cave	103		X		CV
Hart	Forestville Saltpeter Cave	106	X			CV
Hart	Granny Puckett Cave	107	X			CV
Hart	Hatcher Valley Saltpeter Cave	104	X			CV
Hart	Logsdon Valley Cave	108	X			CV
Hart	Lone Star Saltpeter Cave	110	X			CV
Hart	Riders Mill Cave	111	X			CV
Hart	Saltpeter Cave	109	X			CV
Hart	Saltpetre Cave	105		X		CV
Jackson	Bowman Saltpeter Cave	21	X			CV
Jackson	Durham Saltpeter Cave	138	X			RS
Jackson	Hopper Cave	24			X	
Jackson	John Coffey Cave	22	X			CV
Jackson	John Griffin Cave	23		X		CV
Jackson	John Rogers Cave	19	X			CV
Jackson	Peter Branch	25			X	
Jackson	Peter Cave Branch	26			X	
Jackson	Tommy Cave	20	X			CV
Johnson	Peter Cave	163			X	
Knot	Alum Cave Branch	28			X	
Knot	Alum Cave Branch	27			X	
Lee	Cooperas Cave	30			X	
Lee	Fincastle Niter Mine	161	X			RS
Lee	Niter Mine	143	X			RS
Lee	Niter Mine	153	X			RS
Lee	Niter Mine	148	X			RS
Lee	Niter Mine	150	X			RS
Lee	Niter Mine	152	X			RS
Lee	Niter Mine	149	X			RS
Lee	Niter Mine	145	X			RS
Lee	Niter Mine	151	X			RS
Lee	Niter Mine	144	X			RS
Lee	Niter Mine	147	X			RS
Lee	Niter Mine	146	X			RS
Lee	Salt Rock Branch	6			X	
Letcher	Cave	129	X			CV
Letcher	Linefork Cavern	128	X			CV
Letcher	Water Cave	127	X			CV
Logan	Collier Saltpeter Cave	112	X			CV
Logan	Potato Cave	113	X			CV
Logan	Savage Cave	136	X			CV

Table 4 cont'd on p.42

Table 4 (cont'd). Saltpeter sites in Kentucky. (Site types indicated are: CV for cave, and RS for rockshelter.)

County	*Site Name*	*Map No.*	*Known*	*Susp*	*Place Name*	*Site Type*
			Site Classification			
Madison	Adams Cave	124	X			CV
Magoffin	Peter Cave Branch	31			X	
Martin	Little Peter Cave Branch	32			X	
Martin	Peter Cave Branch	34			X	
Martin	Peter Cave Fork	33			X	
Meade	Saltpeter Cave	114	X			CV
Metcalfe	Keltner No. 1	115		X		CV
Monroe	Salt Petre Cave	116	X			CV
Morgan	Peter Cave Branch	35			X	
Muhlenburg	Saltpeter Cave	162			X	CV
McCreary	Eureka Cave	131	X			CV
Powell	D. Boone Hut	36	X			RS
Powell	Old Nitre Mine	37	X			RS
Powell	Salt Cave	38			X	CV
Pulaski	Canoe Hollow	39			X	
Pulaski	Hail Cave	47		X		CV
Pulaski	Hargis Saltpeter Cave	48	X			CV
Pulaski	Kelley Saltpeter Cave	156	X			CV
Pulaski	Piney Grove Saltpeter Cave	44	X			CV
Pulaski	Pipeline Hollow	41			X	
Pulaski	Ranch Cave	52		X		CV
Pulaski	Salt Log Hollow	40			X	
Pulaski	Saltpeter Cave	50			X	CV
Pulaski	Saltpeter Cave	8	X			CV
Pulaski	Saltpeter Cave	45	X			CV
Pulaski	Saltpeter Knob	42			X	
Pulaski	Saltpeter Pit	51	X			CV
Pulaski	Sloans Valley Cave	43	X			CV
Rockcastle	Climax Cave	53	X			CV
Rockcastle	Great Saltpetre Cave	56	X			CV
Rockcastle	Ice Cave	57	X			CV
Rockcastle	Lloyd Mullins Cave	58	X			CV
Rockcastle	Owens Saltpeter Cave	54	X			CV
Rockcastle	Saltpeter Cave	55			X	CV
Rockcastle	Smokehole	46		X		CV
Rockcastle	Teamers Cave	59	X			CV
Russell	Peter Cave	117			X	
Taylor	Saltpeter Cave	118			X	CV
Taylor	Tampico Saltpeter Cave	119	X			CV
Todd	Saltpeter Cave	142			X	RS
Trigg	Cool Spring Cave	137	X			CV
Trigg	Kennedy Cave	120			X	CV
Warren	Plano Saltpeter Cave	122	X			CV
Warren	Pruitt Saltpeter Cave	121	X			CV
Wayne	?	65	X			RS
Wayne	Cooper Cave	60	X			CV
Wayne	Hines Cave	159	X			CV
Wayne	Peter Cave	62	X			CV
Wayne	Saltpeter Cave	63	X			CV
Wayne	Saltpeter Cave	61	X			CV
Wayne	Triple Saltpeter Cave	66	X			CV
Wayne	Wind Cave	64	X			CV
Whitley	Saltpeter Branch	67			X	

Saltpeter and gunpowder sites were plotted on a map of Kentucky (Figure 24) and the following important observations were made. Saltpeter and gunpowder sites occur in clusters and in close proximity with major wagon roads. There are no saltpeter sites known to occur within the Sinkhole Plain extending from Bowling Green to Brandenburg nor within the Inner Blue Grass Region. Sites only occur where the land was covered by forest or thick groves of trees. Hill (1981) has demonstrated the importance of forest cover over a saltpeter site in providing a nitrate source. Saltpeter site collection has strengthened her theory for the origin of nitrates in the cave environment. Powder factories also occur in or adjacent to

Table 5. Gunpowder Factories in Kentucky.

County	Site Name	Map No.	Known	Susp	Place Name
		Total	*21*		*10*
			Site Classification		
Adair	Powder Mill Branch	Q			X
Barren	Coon Creek Powder Factory	R	X		
Barren	Courts-Winn Powder Mill	X	X		
Barren	Nobob Powder Factory	W	X		
Boone	Gunpowder Creek	U			X
Clay	Powder Branch	A			X
Clay	Powder Horn Branch	B	X		
Edmonson	Floating Mill	S	X		
Elliott	Powder Mill Branch	C			X
Fayette	Eagle Powder Mills	I	X		
Fayette	Foley Powder Mill	K	X		
Fayette	O'Neil-McCoy Powder Mill	J	X		
Fayette	Powder Mill	N	X		
Fayette	Powder Mill	M	X		
Fayette	Samuel Trotter Powder Mill	L	X		
Fayette	Spencer Cooper's Powder Mfg.	O	X		
Greenup	Powder Mill Hollow	D			X
Hart	Lynn Camp Creek Powder Mill	T	X		
Jessmine	Anderson Miller Powder Mill	P	X		
Laurel	Powder Mill Creek	E			X
Lee	Pinnacle Rocks Powder Mill	W	X		
Lewis	Powder Lick Fork	V			X
Madison	Estill Station	Z	X		
Madison	Fort Boonesborough	Y	X		
Menifee	Powder Mill Branch	F	X		
Morgan	Powder Spring Branch	G			X
Pulaski	Kelley Powder Mill	AA	X		
Rockcastle	Powder Mill Hollow	H	X		
Scott	Johnston Powder Mill	BB	X		

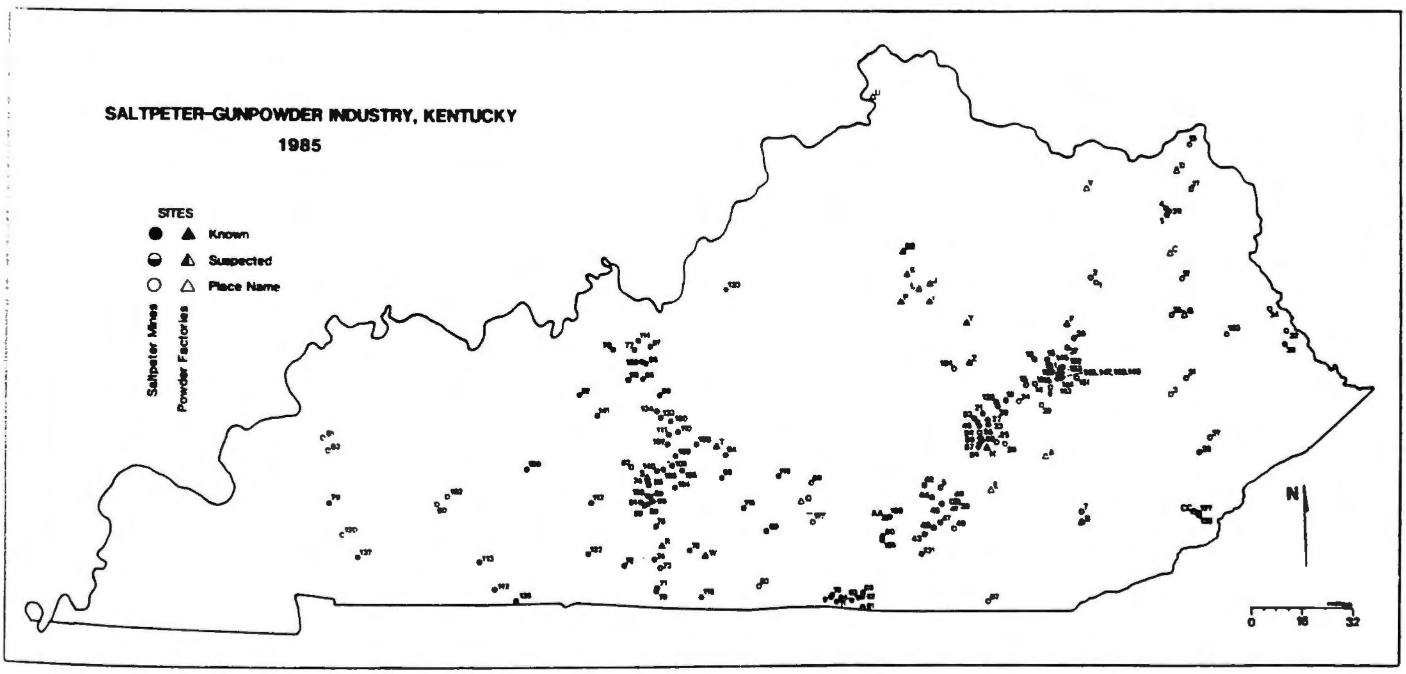

Figure 24: Historical saltpeter and gunpowder sites in Kentucky.

forested areas due to their reliance on timber to keep the operation going. And most important of all, the major saltpeter sites were the rockshelters (Brown, 1809; George, in press).

Eastern Kentucky contains the real heart of the saltpeter industry; the rockshelters under production probably outnumbered the cave saltpeter sites by about 100 to 1. This is at variance with conclusions offered by Burton Faust in that the entire 1810 saltpeter production came from caves (1967, p. 68). There are hundreds of saltpeter-operated rockshelters within the Red River Gorge (Coy, et al., 1984; Fig and Knudsen, in manuscript). And these are the same saltpeter sites that Samuel Brown makes reference to in his saltpeter monograph. Coy et al., have established the importance of preference of rockshelters for the same reasons that Brown favored the sites.

Rockshelters produced 20 lbs. of saltpeter per bushel of sandstone whereas the cave sites only produced 1 lb. per bushel of cave earth. The reason is chemical; i.e., rockshelter saltpeter is pure potassium nitrate whereas cave saltpeter is calcium nitrate and requires the wood ash conversion process to yield potassium nitrate. Montgomery County for the year of 1812 may be used to give an idea as to the quantity of saltpeter produced from rockshelters. Present-day counties of Lee and Powell were part of Montgomery County during this time period. Production figures in Mongomery County yielded 44,575 lbs. whereas Warren County (which included Mammoth Cave) produced only 22, 850 lbs. per year (Niles, 1812). Still at that time, Wayne County with its satellite of caves and rockshelters, out-produced all of the other counties in Kentucky, topping the list with 51,785 lbs. per year.

Aside from the presence of saltpeter in a cave or rockshelter, there appears to be some physical characteristics associated with caves that helped the entrepreneur in his selection process, based upon on-site investigations and the review of 58 available saltpeter cave maps. The cave maps were divided into three different geomorphic classifications: dendritic; crudely dendritic with maze-like features; and network caves (after the classification of Palmer, 1984). It was found that the dendritic cave population yielded 34.48% (20 caves). 62.07% (36 maps) were crudely dendritic caves with maze-like features, and only 3.45% (2 caves) were network caves. The saltpeter works are found in or in the immediate vicinity of the maze-like features. It is probable that there is a greater amount of air circulation in these parts of the cave environment. This aids in the dessication of cave soils. Surprisingly, almost half of the saltpeter cave map population contain more than one entrance. Single entrance caves account for 53.45% (31 caves) while 46.5% (27 caves) had two or more entrances. Although more research needs to be done, a number of multi-entrance cave saltpeter sites have evidence of large bat colonies that are no longer present in the caves.

There are more than 3700 caves inventoried in this state; saltpeter caves account for 3.9% of the total cave population. This is a very small percentage and helps to strengthen the idea that the saltpeter entrepreneurs were even more site selective when singling out representative caves for a mining venture.

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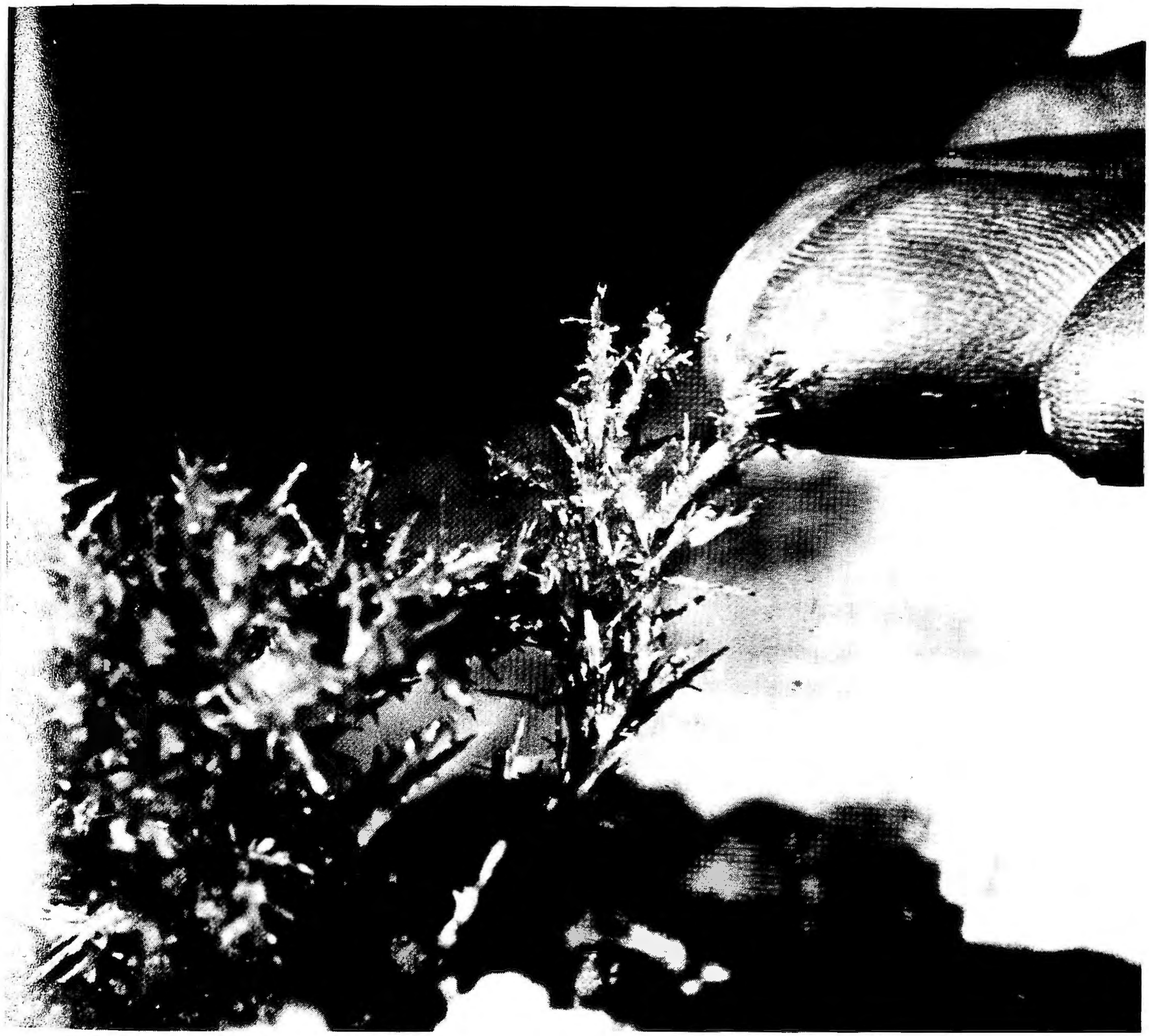

Figure 25: Delicate aragonite crystals found along the route to the Guadalupe Room, Carlsbad Cavern. The formation of aragonite in caves has been something of an enigma to mineralogists. Aragonite and calcite are polymorphs; that is, they both have the same chemical composition, Ca CO_3, but crystallize into different crystal systems (aragonite crystallizes into the orthorhombic system and calcite into the rhombehedral system). Calcite should be the only stable form of $CaCO_3$ at cave temperatures and pressures, but aragonite, which should require a much higher pressure to form, does form in caves. (Photo by R. Pete Lindsley)

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———, 1984, Volcanoes, Volcanic Ash Deposits and Erosion Rates in the Redwood Canyon Karst, Sequoia and Kings Canyon National Parks, CA: Presented to the Diablo Grotto, Natl. Speleol. Soc., Walnut Creek, CA, September.

History

Sides, Stan, 1984, Historical geography of Mammoth Cave: Course taught as part of Western Kentucky University's Karst Field Studies at Mammoth Cave, Mammoth Cave National Park, June 24-30.

FIELD TRIPS

Hill, Carol A., 1984, Field trip to Carlsbad Cavern and New Cave: conducted for the New Mexico Museum of Natural History, March.

Kennedy, Mary, Pat Watson, Ron Wilson, 1984, Guided a group of Kentucky archaeologists through parts of the Flint Ridge cave system in conjunction with a cave conservation conference sponsored by the Univ. of Louisville Archaeological Survey, November 29.

SERVICE

Poulson, Thomas L., 1984, Served on the Research Advisory Committee of the National Speleological Society.

———, 1984, Served on the Advisory Board of the *International Journal of Speleology.*

———, 1984, Served as an Advisor to the National Park Service, Interpretive and Design Center at Harpers Ferry, VA, on exhibits for Mammoth Cave and Carlsbad Caverns National Parks, April.

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 newly-formed Publishing function.

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

Claire B. Wood, Sales Manager and Retail Sales
Rich Wolfert, Retail Sales (for western areas)
Thomas A. Brucker, Wholesale
Roger E. McClure, Business Manager
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
Claire B. Wood, Sales Manager
Thomas A. Brucker Wholesale Distributor

Initial funding for publishing was provided by $10,000 in donations from 30 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. A new book, *Yochib: The River Cave* by William Steele, should be in print by the summer of 1985.

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 ISBN9 prefix-0-939-748-) are now listed in *Books in Print*, and Cave Books is listed in the standard directories as a publishing house with interests in nonfiction and fiction having to do with caves, karst, and speleology. The general address for Cave Books is 756 Harvard Ave., St. Louis, MO 63130 USA. A complete listing of books and maps available through Cave Books may be obtained by writing to this address.

Bibliography of Cave Books Publications to Date

Conn, Herb and Jan, 1981, *The Jewel Cave Adventure*: Cave Books, St. Louis, MO, (illus.), 240 pp.

Crowther, P. P., C. F. Pinnix, R. B. Zopf, T. A. Brucker, P. G. Eller, S. G. Wells, J. F. Wilcox, 1984, *The Grand Kentucky Junction*: Cave Books, St. Louis, MO, 96 pp.

Daunt-Mergens, Diano O. (ed.), 1981, *Cave Research Foundation Personnel Manual*: Cave Books, St. Louis, MO, 3d ed., (illus.), 155 pp.

Lavoie, Kathleen H. (ed.), 1984, *Cave Research Foundation Annual Report—1983*: Cave Books, St. Louis, MO, (illus.), 45 pp.

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———, (ed.) *Cave Research Foundation Annual Report—1984*: Cave Books, St. Louis, MO, (illus.).

Moore, George W. and G. Nicholas Sullivan, 1981, *Speleology: The Study of Caves*: Cave Books, St. Louis, MO, (revised ed., illus.), 163 pp.

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Palmer, Margaret V. (ed.), 1981, *Cave Research Foundation Annual Report—1980*: Cave Books, St. Louis, MO, (illus.), 51 pp.

——— and Arthur N. Palmer (eds.), 1983, *Cave Research Foundation Annual Report—1982*: Cave Books, St. Louis, MO (illus.), 45 pp.

Poulson, Thomas L. and Bethany J. Wells (eds.), 1981, *Cave Research Foundation Annual Report—1979*: Cave Books, St. Louis, MO (illus.), 74 pp.

Steele, William, (in press), *Yochib: The River Cave*: Cave Books, St. Louis, MO.

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———, (ed.), 1984, *Cave Research Foundation: 1969-1973*: Cave Books, St. Louis, MO, (illus.), 290 pp.

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Figure 26: Main passage of Ogle Cave, Carlsbad Caverns National Park, New Mexico. This and other caves in the Guadalupe Mountains were apparently formed by sulfuric acid from the oxidation of H_2S coming from oil-field brines. (The stalagmites and stalactites were formed in the usual way). (Photo by Arthur N. Palmer)

Management Structure

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Personnel Officer:	Ronald C. Wilson
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Finance and Supply Coord.:	Linda Starr
Field Station Maintenance:	Ron Kerbo

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Operations Manager:	Paul Blore
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Newsletter Editor:	Mike Warshauer
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OPERATING COMMITTEES

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

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

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Conservation Committee: Identifies conservation issues of concern to the Foundation and maintains liaison with conservation organizations.

Sarah G. Bishop, Chairman

Finance Committee: Drafts Foundation budgets, provides advice to treasurer and seeks sources of funds to support Foundation programs.

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. This stability allows us to offer increasing support to the CRF Fellowship/Grant Program. We invite your continued support and contributions in behalf of our efforts.

Roger E. McClure, Chairman/Treasurer
Roger W. Brucker
L. Kay Sides
Linda Starr
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Publications Committee: Provides policy guidance and direction on all Foundation publication matters; proposes publications initiatives; assists individuals/groups in accomplishing their publication goals; reviews/coordinates on all proposed publications; insures all publications meet desired quality/format standards and represent the Foundation in a favorable manner.

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Roger W. Brucker
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Claire B. Wood

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.

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