CAVE RESEARCH FOUNDATION 1978

Annual Report

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Cave Research Foundation

1978 Annual Report

Cave Research Foundation
3678 Hollowcrest
Columbus, Ohio 43223

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.

EDITORS
Steve G. and Bethany J. Wells

Cover: Entrance to Indian Rockhouse, Buffalo National River, Arkansas. Buffalo National River is being studied by CRF for evaluation of karst and cave resources. Photo by C. Welbourn.

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January, 1979

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Acknowledgements

Many of the projects outlined in this report have been conducted within the National Park System. The support and encouragement of the Superintendents and staffs at Mammoth Cave National Park, Carlsbad Caverns National Park, Guadalupe Mountains National Park, King's Canyon National Park, Buffalo National River, and Grand Canyon National Park have contributed greatly to the success of these projects, and their assistance is gratefully appreciated.

Dr. Thomas L. Poulson's biological research was supported in part by The National Science Foundation.

Dr. Steve G. Wells's hydrologic research was supported in part by an RAC Grant, University of New Mexico. Field assistance from the Bureau of Land Management, Roswell District, personnel is acknowledged.

Dr. Patty Jo Watson's and Dr. Kenneth C. Carstens's archeological research was supported by a contract from the National Park Service.

Inventory of cave resources at Buffalo National River was supported by a National Park Service contract.

Highlights of 1978

This year was highlighted by the completion of three projects aimed at providing baseline research data necessary for the management of cave resources in Big Bend National Park, Texas; Buffalo National River, Arkansas; and Grand Canyon National Park, Arizona. The Foundation was the recipient of a contract from the National Park Service to do archeological testing and survey in Mammoth Cave National Park, with Dr. Patty Jo Watson and Dr. Kenneth C. Carstens as principal investigators.

A continued strengthening of the research program is expressed by the more than 50 contributors to this Annual Report. Also a significant number of scientific and interpretive publications appeared in 1978. These include 2 theses, 1 book, 28 scientific articles, 8 papers at professional meetings 3 special publications and more than 25 professional and interpretive talks. A complete list can be found later in the report.

In the area of interpretation, CRF personnel participated in the seasonal training at Carlsbad Caverns National Park and presented interpretive talks for the staff and visitors at Mammoth Cave National Park.

There were seven well-written research proposals submitted to the Foundation for the 1978 CRF Karst Research Fellowship. The 1978 Fellowship was not given, but rather three individual grants of $300 each were awarded:

"Form as an indicator of process in karst landscapes." Ardith K. Hansel. University of Illinois-Urbana.

"A hydrologic study of the Greenbrier limestone karst of Central Greenbrier County, West Virginia." Sara A. Heller. West Virginia University.

"A study of mammoth from a karst faunal trap, Hot Springs, South Dakota." Barbara Lee Dutro. Southern Methodist University.

In other research support the Foundation supported Dr. Paul Williams, University of Auckland, New Zealand during his research activities at Mammoth Cave National Park and Carlsbad Caverns National Park.

Exploration and survey continued in the Flint Mammoth Cave area, Guadalupe Escarpment and Lilburn Cave. Although we experienced no spectacular breakthroughs, substantial progress was made. A number of cartographic projects are nearing completion and should be published soon.

The Cave Research Foundation played an important role as a cosponsor of the Fourth National Cave Management Symposium in Carlsbad, New Mexico, along with the National Park Service, National Forest Service, Bureau of Land Management, National Speleological Society, and the National Caves Association. The Symposium attracted nearly 100 individuals concerned with cave management from across the country.

President's Report

In Mammoth Cave National Park there has been significant progress toward the eventual implementation of the Master Plan signed in 1977. The potential problems of water and sewage, noted by a CRF study team, have been vigorously acted upon by the National Park Service. A water line started nearly a year ago is complete and there has been considerable progress in the planning of regional sewage facilities through a 201 sewage study with surrounding communities. An archeological survey (under contract to CRF scientists) and a transportation study related to the Master Plan and proposed staging area are complete.

The continued presence of the Great Onyx Job Corps Center on Flint Ridge is a constant source of sewage pollution and alteration of the caves' natural environment. The Cave Research Foundation continues to press for its prompt removal.

Recently, CRF scientists initiated discussion with the U.S. Army Corps of Engineers concerning possible removal of Lock and Dam No. 6 on the Green River. The lock, built in 1906 and deactivated in 1951, floods portions of the Flint Mammoth Cave System, with serious effects on the aquatic cave communities. The removal of this structure would allow the water level in portions of the cave to return to its natural base level and allow the restoration of now altered aquatic cave communities near the Green River. Our workers are continuing to gather data on this matter.

The number of research projects supported by the Foundation has increased significantly as evidenced by the recent expansion of this report. Although the major ongoing research areas are in Guadalupe Escarpment, Kings Canyon National Park and Mammoth Cave National Park, there are numerous projects in other areas. Three recently completed in-house projects at Big Bend National Park, Grand Canyon National Park and Buffalo National River were designed to provide the Park Service with some of the basic data necessary to develop and implement management plans for their cave resources. At Buffalo National River the Foundation is continuing an assessment of the karst resources through a second contract with the Park Service. As people pressure continues to increase on the cave resources, the need for basic research in all aspects of speleology will be essential. The Cave Research Foundation, with more than 20 years of karst related research, will continue to support all aspects of karst research through fellowships, grants, field support and in-house studies.

In 1974 the Board of Directors established an endowment fund to earn money to support the Foundation's research grants and fellowship. Through the efforts of many people the endowment fund has doubled to more than $8,000 in the last year. Our goal is to have $25,000 by the year 1982. Donations are welcome.

The cartographers have been very busy in 1978 trying to finish the most complete map of Carlsbad Caverns ever produced. Publication is scheduled for early in 1979. Other projects include a map of Proctor Cave and the continuing work on the Flint Mammoth Cave System maps. The donation of an IBM 1620 to the Foundation will allow our cartographers to shorten the time from survey to finished map. We can expect to see some fine maps produced in the next two years.

In 1981 the National Speleological Society will sponsor the 8th International Congress of Speleology to be held at Western Kentucky University. The Cave Research Foundation will be cooperating closely with the NSS in the planning and operation of the Congress. Plans for CRF contributions to the program, including several pre- and post-camps, are being finalized.

W. Calvin Welbourn

W. Calvin Welbourn
President

SCIENTIFIC PROGRAMS

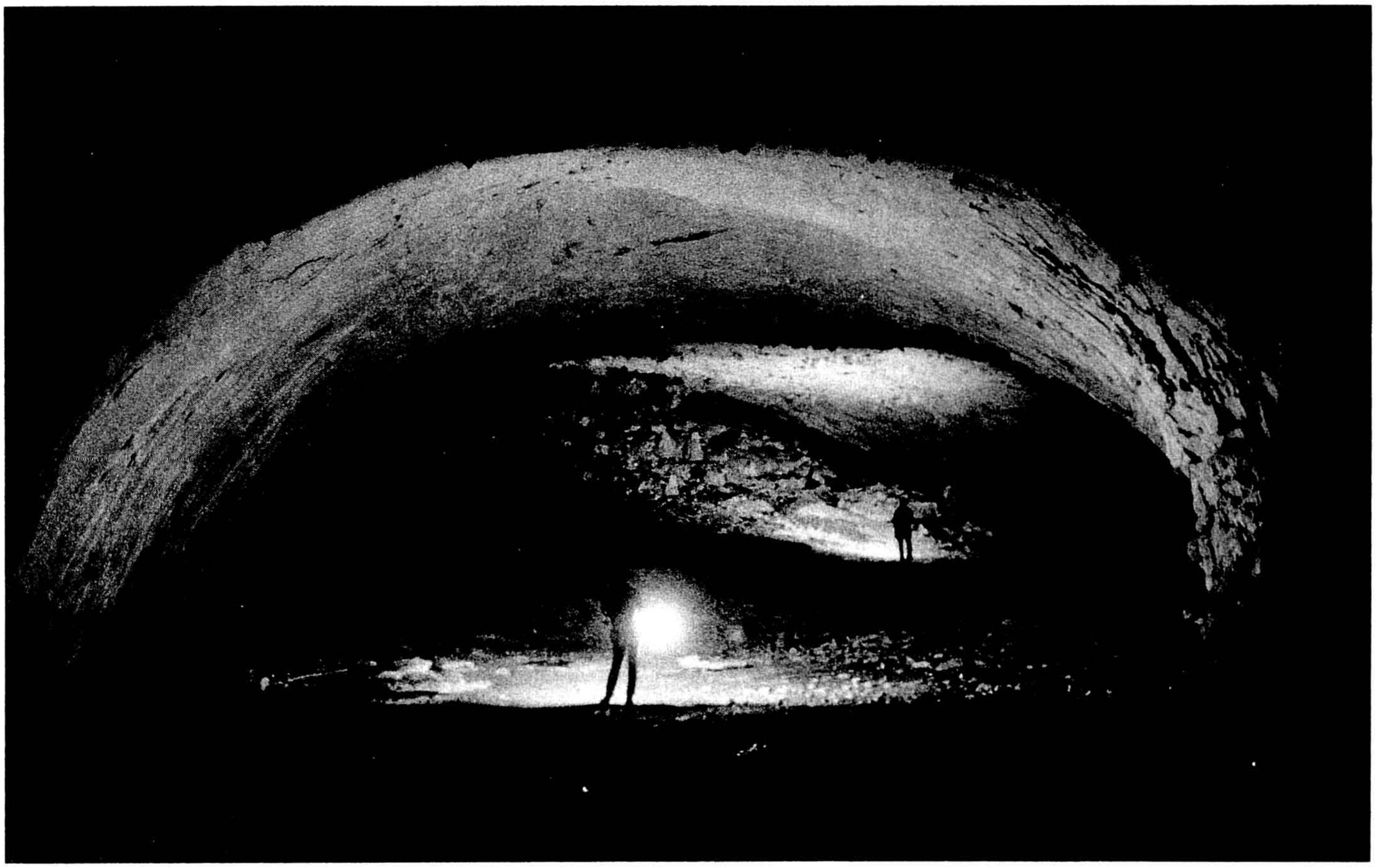

Figure 1. Illuminated cross-sectional profiles in Midnight Goat Cave, Carlsbad Caverns National Park, New Mexico. Photo by D. Jagnow.

Cartographic Program

Figure 2. Cave passage surveying in Carlsbad Caverns National Park, New Mexico. Photo by P. Lindsley.

Exploration and Cartography in the Central Kentucky Karst

Tomislav M. Gracanin, Richard B. Zopf, Thomas E. Cottrel, Roger W. Brucker, Lynn Weller and Patricia P. Wilcox

Introduction

During the 12-month period ending November 1, 1978, we surveyed 5.22 km (3.25 mi) of previously unmapped passageways in the Flint-Mammoth Cave system. The total surveyed length of the system increased to 312.24 km (194.02 mi) during that period.

The question may be asked, are we running out of cave to survey? The answer is no. However, the total amount of survey this year was considerably less than in past years (Fig. 3) for several reasons. A Buffalo National River expedition took the place of one Flint Mammoth expedition, and severe winter weather curtailed activities at another expedition. Attendance was well below anticipated levels at all expeditions. Furthermore, exploration is now conducted farther from entrances and in passages of smaller average dimensions than in past years.

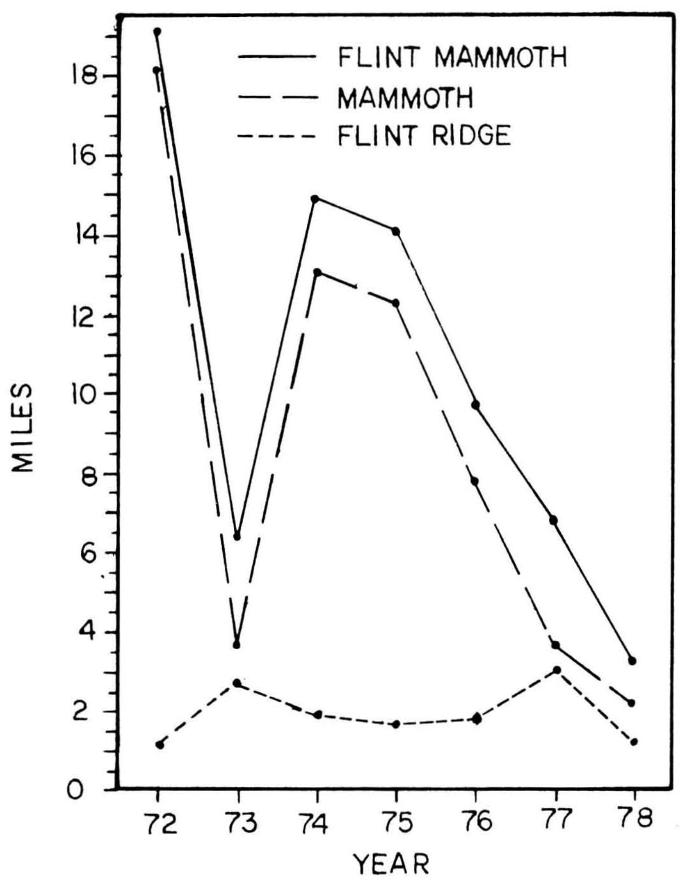

Figure 3. Annual new survey totals for the Mammoth Cave System since the connection in 1972.

Exploration in Flint Ridge

New surveys in the Flint Ridge portion of the system amounted to 1.9 km (1.18 mi) and brought the total length to 158.11 km (98.25 mi). The surveys were evenly distributed throughout the system. Major discoveries in Colossal Cave included 550 m (1800 ft) of tube-shaped passage that terminated near upstream Houchins River, and 150 m (500 ft) of large, high-level passage near the Belfry. Ongoing resurvey of the Ralph's River Trail yielded 365 m (1200 ft) of new survey in addition to 460 m (1500 ft) of resurvey. In lower Salts Cave explorers encountered rare, beautiful and delicate speleothems in a canyon passage. The survey was suspended in order to save the speleothems from possible damage. Bedquilt area and Floyd's Lost Passage also yielded noteworthy surveys.

Exploration in Mammoth Cave

Mammoth Cave again was the target of more survey activity than Flint Ridge during 1978, as has been the case every year since the connection in 1972 (Fig. 3, Table 1). The 3.34 km (2.07 mi) of new survey obtained in 1978 increased the surveyed length of the Mammoth Cave portion of the system to 154.14 km (95.78 mi). Exploration efforts were directed at more than 20 areas of the cave. Nearly 610 m (2000 ft) have been surveyed in complex underdrains beneath Black Kettle Avenue, and these have been pushed into the vicinity of the Mystic River Tributary. Mystic River Tributary yielded nearly 300 m (1000 ft) of survey, and many promising leads remain. A concentrated effort in Lucy's Dome produced 300 m (1000 ft). New surveys in Cathedral Domes, Woodburry's Pass and Bransford West totalled 250 m (820 ft) each. Bishop's Pit has been descended and surveyed.

Exploration in Marion and Emily's Avenues and Carlos Way also resulted in surveys. A major breakthrough in Miller Avenue at the close of the reporting year led into more segments of a trunk passage, perhaps truncated pieces of Kentucky Avenue. This most recent discovery has not yet been fully checked.

TABLE 1.

1978 Survey activity, Central Kentucky Karst

	New Survey		Resurvey		Length (11/78)	
	m	ft	m	ft	km	mi
Flint Mammoth	5234.5	17,173.7	733.7	2407.0	312.25	194.02
Flint Ridge	1897.0	6223.7	568.7	1865.9	158.11	98.25
Mammoth	3337.6	10,950.0	164.9	541.1	154.14*	95.78*
Proctor	481.9	1581.0	–	–	10.72	6.66
Great Onyx	–	–	191.1	627.1	4.49	2.79
Small Caves	164.6	540.1	61.8	202.9	–	–

Total survey from Nov. 1, 1977 through Oct. 31, 1978 is 6867.7 m (22,531.8 ft), or 6.87 km (4.27 mi).

* 844.2 m (2769.7 ft) of Mammoth Cave survey represents resurvey from the Kaemper and Nelson maps.

The "Small" Caves

Surveys in Proctor Cave in Joppa Ridge totalled 482 m (1581 ft) and increased the cave's length to 10.72 km (6.66 mi). Major accomplishments included tying in the hanging A-47 pit drain survey and recording over 275 m (900 ft) of survey near the P-16 pit.

Accurate resurvey of the major trunk passages in Great Onyx Cave has been completed. The cave yielded no new survey footage. Last year we reported that a stream passage departing from the Ralph's River Trail area in Flint Ridge was heading toward Great Onyx Cave. The explorers followed the stream passage as it crossed under Stairway Crawl in Great Onyx Cave, 40 ft above. To their disappointment, the passage terminated. From Great Onyx above, explorers were stopped by an impassable shaft drain, and no connection could be made between Flint Mammoth and Great Onyx caves.

Joppa Ridge Rebble Rubble Cave, discovered during the systematic walking reconnaissance effort, yielded 77.7 m (254.9 ft) of survey and generated much excitement because it is close to passages in Proctor Cave. Other exploration and survey took place in Cripple Creek Cave on Joppa Ridge and in Dickey Pit in Flint Ridge.

Cartography

The major cartographic goal set for 1978 was completion of the Proctor Cave manuscript map and its preparation for publication. A manuscript map is an accurate, detailed compilation of all surveys for a given cave area, and it provides a base for a final edited map that is published. Inking of the manuscript map is in progress. This includes inking of the topographic overlays as well as the cave passages. We did not meet our goal, but new plans call for a mid-1979 completion date for the inked map.

Other important work included beginning a field map of the Cathedral Domes section of Mammoth Cave and updating the Cleveland Avenue field map. These maps should greatly aid exploration.

A long-term, continuing project to bring the computer survey data base files up-to-date was carried on this year. Several marathon key punching sessions at Indiana University of Pennsylvania helped reduce the backlog but barely kept abreast of incoming surveys. All processed data are stored on magnetic tape. At present we have 1239 books of survey data entered and a backlog of 192 books. There were 1431 survey books on November 1.

During 1979 we will try to run the CRF cave data processing program in conjunction with the Surface II Graphics Package. The combination should greatly increase the capability of manipulating the cave data. For example, it will permit us to plot oblique view block diagrams of all parts of the cave system complete with topography.

Cartography Report—Guadalupe Escarpment Area

Robert H. Buecher

The thrust of work during 1978 was in support of the 1 inch = 200 feet map of Carlsbad Caverns. The theodolite control network was expanded into Lower Cave. Distance meter and theodolite ties were made from Lower Cave into the Big Room, Mabel's Room and the Mystery Room. Brunton compass surveys and theodolite work continued in the Main Corridor. Survey data reduction for Lower Cave has been initiated again, and Joe Repa is drafting the map of this area. Several rough drafts of different areas of Lower Cave have been finished. John McLean has finished the draft version of the Carlsbad Caverns map. The final version will be printed as a map card in early spring, 1979 and will be for sale to visitors.

Work continues in caves within Carlsbad Caverns National Park and other areas. Survey work is continuing in Deep Cave under the direction of Pete Lindsley. A working version of the map has been completed. Also completed this year is the draft version of Scout Cave by Joe Repa. In Lincoln National Forest, Alan and Carol Hill are continuing the survey of Three Fingers Cave and Jim Goodbar started a new survey of Virgin Cave. One expedition was made to Dry Cave on Bureau of Land Management lands. Additionally, work is continuing in Edgewood Caverns with no end in sight.

In April an entire expedition was devoted to teaching cave surveying. Use of a Brunton compass and notetaking were taught. A section of Left Hand Tunnel was sketched by all participants. This session has greatly improved the surveying skills of many of us.

Last winter a meeting was held in Las Cruces to review the status of our cartographic projects and to formulate future goals. As a result of this meeting we have changed our methods of handling cave survey information. To get a faster turn-around on data reduction for preliminary maps, we have reduced our dependence on computer processing. Survey reduction is now handled when possible during the expedition on small, programmable calculators. The job of reducing raw data and adding to the working map is now done by the original survey team. This increases the understanding of the mapping process and aids in detecting and correcting errors. Diana Northup and John McLean have filed and indexed a large quantity of original survey data. Xerox copies of the original survey data are now available to the map makers and expedition leaders. This should end our problems with losing survey books.

Our goals for the next year include: revisions to the 1 inch = 200 feet map of Carlsbad Caverns, completion of final maps of Lower Cave and the Big Room, and completion of the Deep Cave map and Scout Cave map. Joe Repa has been appointed Cartographer West and will be in charge of survey work in the Guadalupe Escarpment Area.

TABLE 2.
1978 Survey totals for the Guadalupe Escarpment

Carlsbad Caverns			
Big Room		11,448.10	feet
Main Corridor		5,859.46	
Lower Cave		5,296.68	
New Section		1,451.97	
New Mexico Room		35.69	
Surface		3,877.10	
	Total	27,969.00	feet
Carlsbad Caverns National Park			
Deep Cave		512.16	feet
Rock Slide Cave		360.33	
Scout Cave		252.20	
	Total	1,124.69	feet
BLM Caves			
Chosa Draw caves		1,716.70	feet
Chosa Draw surface		1,676.00	
Dry Cave		1,069.52	
	Total	4,462.22	feet
Forest Service caves			
Three Fingers		960.98	feet
Virgin		172.87	
	Total	1,133.85	feet

Total surveyed distance by CRF-West = 34,689.76 feet.

Cartography and Exploration at Lilburn Cave—1978

Ellis Hedlund, Lee Blackburn, Stan Ulfeldt and John Tinsley

The Lilburn Project's principal cartographic effort was the development of a new, computerized survey program to meet the needs of the research now underway at Lilburn Cave. The computer program uses an optimized method of assembling and adjusting loops that takes into account the topological rigidity of the survey net. This technique produces the most accurate map possible from the array of data and permits new or corrected survey data to be incorporated easily into the cartography. The program is now running on CRF's newly acquired IBM 1620 computer system. Conventional and stereo (3-D) plots can be drawn on an attached Calcomp plotter.

Surveying crews are conducting traverses on the surface in Redwood Canyon to locate the numerous karst features relative to USGS benchmarks and the subsurface survey network in Lilburn Cave. At present, only ¼ of these features have been surveyed. The 1977 surveys were confined to the area immediately above the mapped extent of Lilburn cave. The 1978 surveys have been conducted in the extensive karst area located in the northern portion of the marble. This area has an elevation of approximately 120 m above the cave and extends approximately 1.3 km north of the mapped northern limit of Lilburn Cave. The new traverses total about 4.42 km, thus doubling the length of above-ground survey. The area north of the cave includes 75% of the karst in Redwood Canyon. Although researchers have found no natural entrances, there are numerous sinkholes which take water, including a system of swallets which consumes the discharge of the second-largest sinking stream in Redwood Canyon. During 1979 we will attempt to complete the surface surveys in this area and locate entrances to the extensive karst system.

Surveying in Lilburn Cave proper included resurveys of traverses suspected of having errors, and exploration and mapping of the complex maze of passages in the east-central portion of the cave. To facilitate locating sampled sites within the Lilburn survey net, several short traverses were laid out and faded numbers at nearby stations were relabeled.

Cartography and Exploration: Uplands Research Laboratory

Don E. Coons

The Uplands Research Laboratory enjoyed a remarkably successful summer of cartography and exploration. Effort was concentrated in Hicks and Whigpistle Caves. Nearly six miles of new passage were surveyed, including one of the biggest finds since the Proctor Trunk.

Jim Quinlan employed the following personnel: Bob Taylor, Carol Conroy and Don Coons as full-time employees; Sherri Engler, Tom Ahlers, Phil O'dell and Dan Quinlan as part-time employees; and Sherri Engler, Gary Tinker, John Branstetter, Andy Lever and Tom Gracacin as volunteers.

Hicks Cave lies 3 miles northwest of the town of Horse Cave. Its entrances are all within four vertical feet of Green River at its lowest flow, so that summer is the only practical time to enter. The cave is an extremely complex system of overflow passages between two parallel routes feeding springs on Green River. Over thirteen miles of tangled passage can be entered without ever penetrating more than two miles from the main entrance. From the back of this complex system, a single large passage (the J survey) leads away to the rest of the cave. At the beginning of the summer, this passage had been pushed just over 2.5 mi in 248 stations, making its total length from the original entrance 4.5 mi.

We had a new entrance, dug last summer, that bypassed the first quarter mile of the complex entrance area, but wetsuits were still necessary and parties spent six to seven hours reaching their survey points. Trip lengths ranged from twenty to twenty-four hours. Four parties yielded just over 1.5 mi of survey in this area. The J survey was pushed an additional 4200 ft through a tight flowstone squeeze and 2000 ft of crawl to a temporary end. J 389 resides in a forty-foot dome blowing large quantities of air from somewhere overhead.

The remaining survey was done in a complex area that opened up just beyond the previous end-point of the J survey. Dozens of leads opened in this area, so there is much more to be done. An additional half mile of survey in areas nearer the entrance puts the total length of the cave at 18.05 mi.

Jim Quinlan is presently drilling and blasting his way through fifty feet of solid rock to open a new entrance in the top of a dome near the end of the survey. It will eliminate most of our travel time and give us an all-weather entrance to fall back on should Green River give one of her unexpected surges.

Whigpistle's entrances lie about one mile south of the Park boundary near the town of Pig. The cave's length measured just under three miles at the beginning of the summer. Two trips to an area named Slackwater Creek yielded over 4500 ft of passage trending to the west and ending in breakdown. Active stream flow in this passage is to the east while mud scallops indicate flow to the west. Dye traces indicate that the stream resurges at Turnhole Bend to the north, but we are speculating that high-water conditions bring a flow reversal that may take water west across a drainage divide to Graham Springs. High flow dye traces will have to be completed to test this hypothesis.

Our third trip led to our best effort of the season and the biggest find in central Kentucky in several years. New entrances outside the Park were discovered. We decided to survey a lead near one of the entrances rather than push on into the cave. A pleasant crawl turned into a pool with about 5 in of air, then opened into walking canyon. This led to two miles of trunk passage comparable to Main Cave in Mammoth, and an enormous room 850 ft long with a flat breakdown and clay floor and cross sections ranging from 40 ft high by 95 ft wide to 60 ft high by 166 ft wide.

The entrances to the new cave are well protected by bathtubs, cobble crawls, chocolate baths and obscure routes. Only the most experienced wetsuit cavers with maps or perseverance will be able to enter. The cave now stands at 6.68 mi with numerous leads in the trunk and other areas.

Atmospheric Studies Program

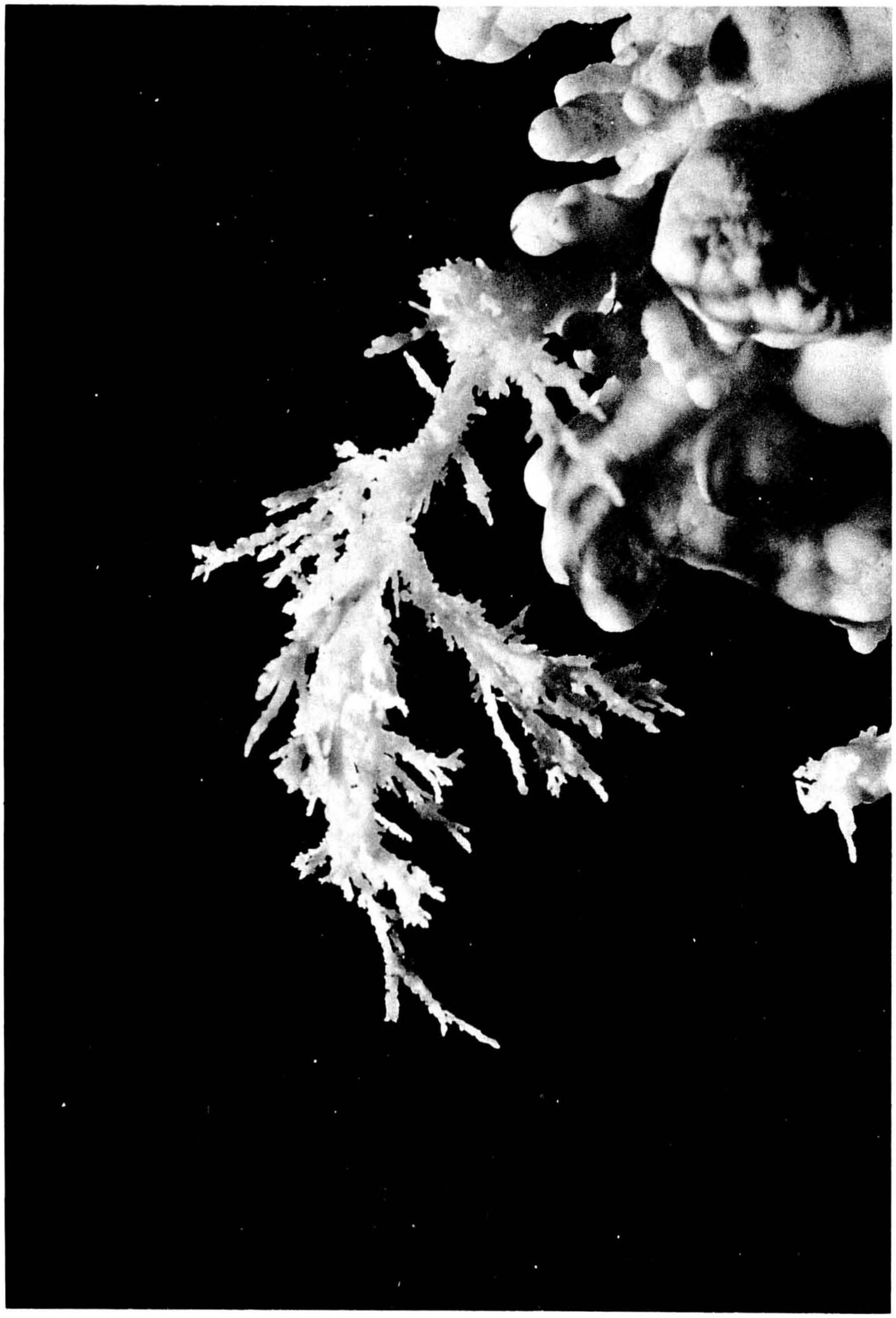

Figure 4. Crystal forms in Spider Cave, Carlsbad Caverns National Park, New Mexico. Photo by P. Lindsley.

Radon and Carbon Dioxide in the Air of Four Caves within Sequoia and Kings Canyon Parks, California

David J. DesMarais

Measurements of radon daughters and carbon dioxide were made in the air of Lilburn, Soldiers, Palmer and Deep Dig Caves. Data from Lilburn span a 13-month interval from April, 1977, to April, 1978. The abundances of these species in cave air reflect a balance between their formation (e.g., production of daughters from radon decay, evolution of carbon dioxide from soil biological activity) and their depletion (e.g., dilution of cave air by forest air, radioactive decay of the radon daughters). This study seeks to better understand these formation and depletion processes.

The four caves under study vary in size and geographic setting. Lilburn, an extensive, maze-type cave (12,000 m long) with small entrances, is in the lush Sequoia forest of Redwood Canyon. Soldiers (about 1000 m long) has a small entrance and is in a forest receiving less rainfall than Redwood Canyon. Deep Dig is an excavated cave (perhaps 100 to 200 m long) in Redwood Canyon with a small entrance and passages. Palmer Cave, essentially one large entrance and three large rooms, is at a higher elevation amidst sparser vegetation.

Several observations can be made from Figure 5 regarding the radon daughter working levels. The long caves have markedly higher levels (Lilburn—3.2 W. L., Soldiers—1.7 W. L.) than the short caves (Palmer—0.27 W. L., Deep Dig—0.5 W. L.) during the warm months. Lilburn's daughter levels were very constant between April and September, 1977, (about 3.2 W.L.) and, except for the anomalously high October, 1977, levels, were lower during the cold months (November, 1977, through April, 1978, averaged 2.6 W. L.). These patterns are consistent with those observed by Yarborough (1977) in other caves of the national park system.

The carbon dioxide (CO_2) concentrations also vary with cave size and season. On any specific day, though, CO_2 abundances are fairly uniform throughout much of Lilburn Cave. During the spring and summer of 1977, Lilburn and Soldiers Caves had appreciably higher concentrations (0.23 and 0.21 percent, respectively) than did Deep Dig Cave (0.13 percent). The CO_2 levels in Lilburn increase during spring and early summer and decrease during winter. Perhaps the seasonal CO_2 variations in Lilburn reflect variations in forest soil temperature. The following observations support this idea. Carbon isotope data tell us that the cave air CO_2 ($\delta^{13}C_{PDB}$ = -21.1 permil) derives from soil biological activity (soil CO_2 is -20.8 permil) and not the marble ($\delta^{13}C$ is about zero permil), the cave stream (dissolved carbon $\delta^{13}C$ = -12.5 permil) or forest air (CO_2 $\delta^{13}C$ = -10.5 permil during July, 1977). Furthermore, soil biological activity varies directly with soil temperature. April, 1978, soil temperatures were markedly lower than April, 1977, temperatures due to the drought-breaking record snowfalls of the 1977-1978 winter. Following these soil temperatures, cave CO_2 levels were correspondingly lower in April, 1978, than in April, 1977 (Fig. 5). The relationship between cave CO_2 and soil temperature will be examined more closely during the 1979 field season.

Judging from the few available data, a positive correlation apparently exists between CO_2 abundance and radon working level for the different caves in this study area. Dilution of cave air by forest air is the dominant process which balances CO_2 input from the soil. The correlation between radon and CO_2 suggests that this dilution process also limits radon daughter concentrations.

I am grateful to Howard Hurtt, Vance Nelson and Luther Perry for assistance in obtaining the radon measurements.

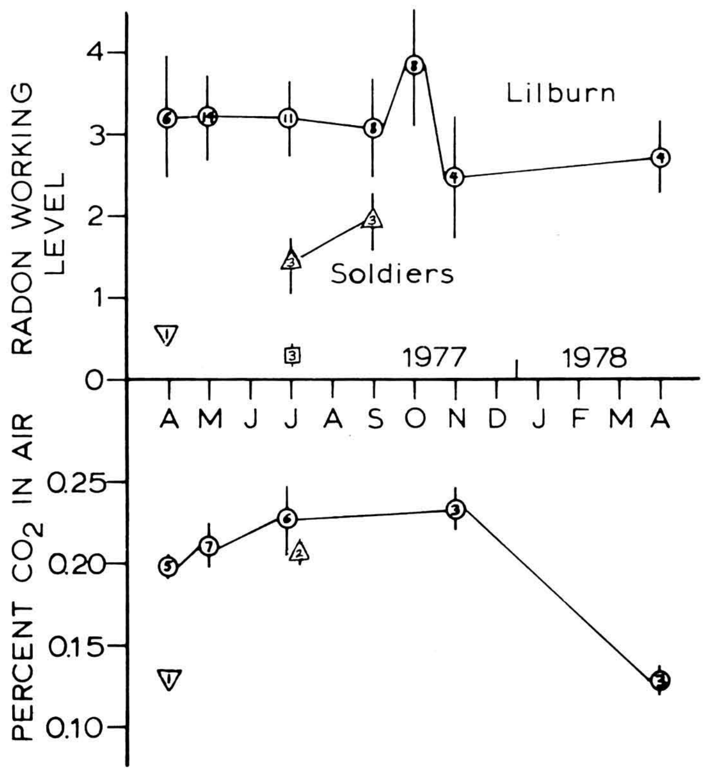

Figure 5. Plots of radon daughter and carbon dioxide abundances in cave air versus the month of their measurement during 1977 and early 1978. Data point symbols designate the caves as follows: ○ - Lilburn, △ - Soldiers, ▽ - Deep Dig, and □ - Palmer. Numbers inside symbols indicate the number of different stations at which replicate gas measurements were made. Vertical lines at each data point represent one standard deviation of all the measurements obtained in the particular cave on that date.

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The Use of Caves as a Laboratory for Air Particulate Deposition Studies

Thomas J. Murphy and Edwardine Nodzenski

The rate of deposition of particulates from the atmosphere in the absence of precipitation is not well understood. This is especially true of the particulates smaller than a few micrometers. It seems that the cave environment, free from precipitation, foliage and important sources of particulates might be a useful place to make some measurements to answer this question. It was also thought that information might be obtained on the composition of air particulates carried into the caves in the past. Some preliminary measurements and collections were made in 1978 to address these two problems. These included some high-volume air particulate measurements in Dyer Avenue in Crystal Cave, Kentucky, which showed concentrations of particulates less than 10 $\mu g/m^3$. This is a very low concentration and indicates that particulates in the air entering caves deposit quickly onto the cave walls.

Geoscience Program

Figure 6. Collapse sinkhole and sinkhole-fill stratigraphy in the Central Kentucky Karst. Photo by S. Wells.

Preliminary Report of Investigations: The Hot Springs Mammoth Site, 1978

Barbara Dutrow

Four weeks of field work during July and August at the Hot Springs Mammoth Site, South Dakota continued to produce abundant elephantine remains. An additional 173 faunal elements of *Mammuthus columbi* were recovered, mapped, and removed from the filled karst depression. This brings the total element count of mammoth to approximately 900. Screenwashing of the feeder spring conduit sands recovered many more invertebrates and microvertebrates. Approximately 220 m^3 of sediment were removed. The number of individual mammoths did not increase, holding steady at 22. However, the discovery of the first complete long bones (radius, ulna, femur, humerus) and a rare deciduous tusk were added to the inventory.

With continued excavations, additional mammoth footprints preserved in the laminated sinkhole fill were also located. Through excavation along time lines (bedding planes), we were able to isolate remains of one individual. This year's excavations aided in unravelling the stratigraphic history of the site. Trenches, excavations, and post-field season coring have unequivocally identified one main spring area which acted as a trap for numerous bones and probably destroyed many more by erosion. The original pond-fill depth at the shallow end was 45 ft, reaching a minimum of 65 ft in the conduit area. An asymmetric bottom to this sinkhole was proven, and the walls of the original sink were found to be vertical to overhanging. Recovery of fossil pollen and organics was disappointing, considering the area was deep and preservation seemed likely.

As envisioned now, the "cave" was originally overlain by gravel. Upon collapse, the gravels lensed out along the bottom, leaving a thicker veneer at the edges. Subsequent to collapse, the main spring, through fluidization and erosional reworking, deepened the main conduit area to 65 ft.

Work on this unusual and unique mammoth assemblage is continuing. The skeletal elements removed from the field are stored at Chadron State College (Nebraska), awaiting transportation to Dallas in the near future. Several of the long bones have been measured and a standardization of the measurements to be taken is complete. Compilation of the taphonic maps which show the spatial position and orientation of each fossil is underway. Work on the age-structure, taxonomy, mortality, longevity, ecology, and description of this local death assemblage of mammoth is continuing. These studies undoubtedly show the importance of karst terrains as natural traps for megafauna in the area.

Dr. Larry Agenbroad (Northern Arizona University) headed the field crew with four other permanent crew members and 19 Earthwatch participants. The research was supported by the National Geographic Society, The Center for Field Research (Earthwatch), Chadron State College-Research Institute, Cave Research Foundation, and Southern Methodist University-Institute for the Study of Earth and Man.

Geomorphology and Hydrology of the Gypsum Plain Karst, Eddy County, New Mexico

Alberto Gutierrez and Steve G. Wells

Field investigations were undertaken during 1978 to determine the general geomorphic and hydrologic setting of the Gypsum Plain Karst. The study area is located between the Black River and the Texas-New Mexico border. Field investigations during 1978 were reconnaissance in nature, and future studies include delineation of groundwater flow paths via mapping and dye tracing of groundwater. Additionally, surficial deposits in the Gypsum Plain Karst reflect Quaternary climatic history and dissolution history of the Delaware Basin (this region is being considered as a potential nuclear waste disposal site). Future work will include studies on the surficial deposits and their relationship to the dissolution history. Results of the 1977-78 field studies are summarized below.

Bedrock Geology

The study area is underlain almost exclusively by the Permian Castile Formation. Two other units have been recognized in the area, the Rustler Formation and the Ogalla Formation. The gravels of the Ogalla Formation are highly cemented by caliche or travertine, especially in the Black River area.

The Castile Formation is a thick ($\sim$600 m) sequence of nearly horizontal anhydrite, gypsum and limestone beds. The beds have a slight 1° dip to the northeast, although dips may vary locally due to flowage of gypsum. The Castile Formation has a uniform lithology, but varies from thinly laminated gypsum and dark grey limestone (exposed in Border Cave, Texas) to white massive gypsum characteristic of the Chosa Draw-Black River area (solutional features examined in this study are restricted to the Castile and overlying unconsolidated material). Very little work has been done on the structural geology of the Castile although a series of small, northeastward trending faults have been identified in the southwestward portion of the study area (Yeso Hills). A prominent series of joints are possibly associated with the same tectonic activity that created the small displacements in the Yeso Hills. Joints have been measured on the surface and in caves in the study area. These joints appear to coincide with the general trend of surface drainage in the study area and clearly exert a strong control over cave passage orientation and initial sink development.

Surficial Geology

Several episodes of erosion and deposition are visible in the surficial deposits of the study area. Paleochannels cut an erosion surface developed on the Castile and are exposed in arroyos and caves in the study area. C. B. Hunt has mapped many of these deposits as residual gypsiferous deposits on his 1977 map. Most of the deposits in the paleochannels are characterized by poorly-sorted clay and sand to angular gypsum gravels and cobbles. The geometry of these paleochannels appears similar to that of the existing channels cut in the Castile formation (deep and narrow arroyos characterized by low width-depth ratios).

Another, apparently older episode of deposition is recorded in sediments consisting of moderate to strongly cemented gravels which cap hills in the Chosa draw area and extend north and east beyond the Black River. These gravels are well rounded, moderate to poorly sorted and range in size from pebble to cobbles. The gravels consist of limestone, dolomite and chert clasts distinctly recognizable as part of the forereef facies of the Guadalupe-escarpment carbonates which crop out northwestward of the study area. Most of these deposits appear to rest above an old erosion surface on the Castile; however, near the Black River they have been identified in the fill of an apparent paleochannel in the Castile formation. The cementation of these gravels appears to be the result of groundwater movement rather than pedogenic processes.

Drainage and Karst Development

The most distinctive features of the gypsum plain result from dissolution and the creation of extensive karst topography. Two main types of sinks have been identified on the Gypsum Plain Karst. The classic solution-sink filled with unconsolidated material weathered in place has been observed in the south-central portion of the study area. These sinks are closed, approximately circular depressions usually less than 1.5 m deep, ranging from 10 to 80 m in diameter. All of these sinks contain a swallow hole which appears to take very little flow (most of the recharge occurs by infiltration through the unconsolidated fill). These sinks comprise approximately 3-5% of the recharge points to the subsurface drainage of the study area. The majority of the sinks on the gypsum plain are better described as sinking-stream sinks. These are elongate depressions containing a defined channel which terminate at a solutionally-widened fracture or joint. These sinks drain areas ranging from .1 to .5 km^2. Small sinking streams with well-defined drainage areas are especially common in the Yeso Hills and in the interfluves between Ben Slaughter Draw and the north fork of Hay Hollow. These features are easily recognized in the field and from the air, as they characteristically have dense vegetation growing on top of or near the swallow hole due to the increased available moisture. In areas where unconsolidated material overlies the bedrock, the streams are developed on the fill and sink into fractures in the bedrock at the contact between the fill and the bedrock surface. These sinking-stream sinks bear no apparent relationship to existing surface drainage patterns, draining only the area within each sink's small depression.

In contrast with the sinking-stream sinks described above, sinking streams with larger drainage areas (characteristic of the Chosa Draw region) are related to the surface drainage development of a basin. These sinking streams appear to be developed along pre-existing surface flow paths and do not sink into obvious fractures in the bedrock. It is not uncommon to find several of these sinking streams aligned along areas of past concentrated surface flow grading to the local baselevel of Chosa Draw.

Caves in the Yeso Hills, Ben Slaughter Draw area are developed below the small sinking stream sinks described above. There, caves typically consist of narrow, high, fracture passages which intersect at right angles. These passages usually lead to a small tubular passage (bedding plane controlled) that rapidly becomes impassable. These caves appear to be underdeveloped in comparison with the caves of Chosa Draw (possibly due to stage of development, catchment area or a combination of both).

Cave development is most extensive in the Chosa Draw area between the Yeso Hills and the Black River. Cave passage orientations in the Chosa Draw area are strongly controlled by joint patterns except in the lower portions of the cave. In this area the cave passages approach the groundwater table where passages widen along bedding planes. Base flow through the caves is normally very low; usually base flow discharge is less than 28 l/sec. In the lower levels of the caves of the Chosa Draw area, wide passages are developed along bedding planes and end in pools which fill the passages to the ceiling (apparently intersecting the local groundwater level). Calculated flood flow velocities and discharges are given in Table 3.

Table 3.

Flow Velocities and Discharges of Selected Caves in Gypsum Plain Karst

	Velocity	Discharge
Plunging Stream Cave	1.21 m/sec	.971 m^3/sec
Chosa Draw Sink	14.55 m/sec	15.87 m^3/sec
Blowhole Resurgence	9.39 m/sec	5.64 m^3/sec

There are four perennial resurgences in the study area: Jumping, Ben Slaughter, Terrace, and Cottonwood springs. These springs characteristically occur in the bottom of washes with well-developed, incised channels. The springs have small discharges usually less than 28 l/sec except during flood when flows rapidly increase significantly.

The karst features described above are not evenly distributed throughout the study area. Solution and small stream sinks are predominantly located in the southern part of the study area near the Yeso Hills and Ben Slaughter Draw. Their frequency decreases as one progresses north and northwest toward Chosa Draw and the Black River.

Major cave systems in the study area appear to be limited to the Chosa Draw area. These caves include the Parks Ranch Cave System, Chosa Draw Cave, Skylight Cave and Terrace Springs Cave (Fig. 7). No large cave systems have been found in the Yeso Hills, Ben Slaughter Draw area, although concentrations of sinks may indicate trunk passages that receive flow from several sinks.

General Hydrology of Gypsum Plain Karst

The hydrologic system of the Carlsbad gypsum plain is a complex interaction of both surface and subsurface processes that produce characteristic solutional features and channel morphology. The ratio of surface to subsurface drainage increases towards the Black River (baselevel). Large trunk passages in the Chosa Draw area enable flood discharges to be carried rapidly through the subsurface drainage systems. It is evident from field observation that the movement of the flood pulse is extremely rapid through the subsurface drainage. The recovery time to normal base flow ranges from several hours to one day, depending on the magnitude of the event. Specific conductance and salinity were measured in all the resurgences in the area and no appreciable seasonal variations are noted. Nine hours after a major flood event, the springs showed no significant

Figure 7. Entrance to Terrace Springs Cave in Chosa Draw Karst Drainage System, Gypsum Plain, New Mexico. Photo by S. Wells.

variations from mean specific conductance and salinity level. This is due to the rapid movement of the flood pulse through the subsurface drainage system.

Mineralogy of Three Fingers Cave, Lincoln National Forest, New Mexico

Carol A. Hill

The mineralogy of Three Fingers Cave is typical of that in many caves of the Guadalupe Mountains. Carbonate speleothems present in Three Fingers Cave are stalactites, stalagmites, columns, draperies, flowstone, shields, rimstone, helictites, spar and "popcorn." An especially well-developed bell-canopy occurs in the upper level (Big Room) near the entrance drop. The stalactites in the Big Room are small compared to their counterpart stalagmites. This size difference indicates a high drip rate for solutions depositing these speleothems. A rapid drip means slow growth for a stalactite because incoming solutions do not have time to equilibrate (CO_2 loss + evaporation) with the cave air before the drip falls to the floor (Allison, 1923); CO_2 loss occurs when the drip hits the floor and hence large stalagmites form. Petromorphic dogtooth spar is common in the cave limestone and occurs both in the Big Room and in the lower levels of the cave.

Speleothems in the lower levels of Three Fingers Cave are more actively growing than those in the upper levels. Also, many of the speleothems in the lower levels are stained red and orange (iron) and black (manganese). The "Fire Temple of the Cave God" is a beautiful display of a large, multi-colored, actively growing flowstone cascade. An unusual type of popcorn speleothem called a "calcite blade" occurs in a side passage off the Temple of the Cave God Room. "Normal" popcorn nodules are microcrystalline with a smooth texture. Calcite blades, on the other hand, consist of macrocrystalline rhombohedral calcite arranged in a rosette fashion on the popcorn nodule. In some instances the rhombohedrons of the calcite blades protrude outwards from the cave wall as little blocks stacked one upon the other.

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Mineralogy of Deep Cave, Carlsbad Caverns National Park

Carol A. Hill

The mineralogy of Deep Cave is reminiscent of the mineralogy of Ogle Cave, also in Carlsbad Caverns National Park (Hill, 1978). Massive, "dead" stalactites, stalagmites, bell canopies and columns occur in Deep Cave. Many of the columns have fallen to the floor and are cracked perpendicular to their length. Other carbonate speleothems in Deep Cave are flowstone, draperies, "popcorn," rimstone, helictites and shields. Two of the shields are noteworthy in that they have grown on a massive (17 m high) stalagmite rather than along the wall. The shields, 2 m and 0.3 m in diameter, are oriented perpendicular to each other and have formed along cracks in the desiccated stalagmite. "Antler" helictites, similar to those in Left Hand Tunnel of Carlsbad Caverns, also occur in Deep Cave. The Deep Cave helictites have many horizontally bifurcating branches which resemble deer antlers. Humidity in Deep Cave in May, 1978, measured 51% at the top of the entrance drop, 75% halfway down the drop, 75% at the bottom of the drop, and 78% at the back of the cave.

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Chiricahua Crystal Cave, Arizona

Carol A. Hill

Chiricahua Crystal Cave is located in Coronado National Forest, Arizona. The cave is developed in the Lower Cretaceous limestones of the Bisbee Formation (Cooper, 1959). Tertiary rhyolitic flows and tuffs unconformably overlie the Bisbee Formation in the vicinity of the cave. Chiricahua Crystal Cave is unique because of the euhedral quartz (SiO_2) crystals which line the walls and ceilings. Average crystal size is 4.5 cm in length and width (at the base); noted maximum crystal length is 8 cm (Harvey DuChene, personal communication). One already broken crystal exhibited three separate quartz growth layers, each approximately 1 cm thick (Fig. 8). Some of the quartz crystals are coated with a thin clay layer while others are covered by white to yellow calcite popcorn or flowstone. The quartz crystals always directly overlie limestone bedrock (Fig. 9) and never other secondary speleothems.

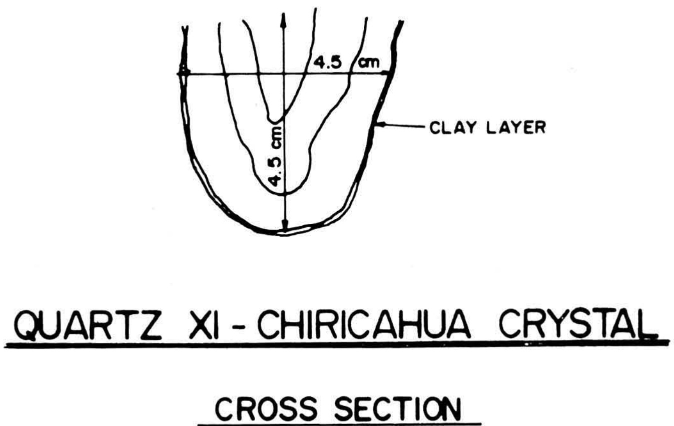

Figure 8. Cross-section of a quartz crystal from Chiricahua Crystal Cave showing three separate quartz growth episodes.

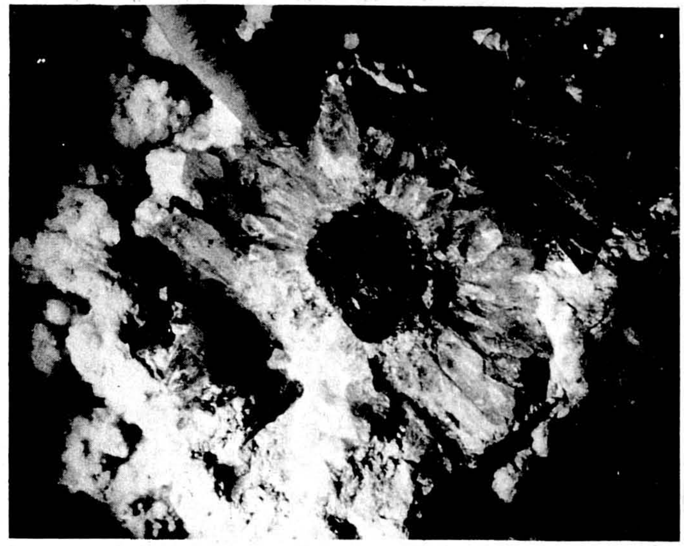

Figure 9. Quartz crystals (clear, white) lining limestone (dark, central core) and overlain by calcite popcorn (opaque, white), Chiricahua Crystal Cave. Cross-section resulted from vandalism.

Quartz is a mineral which has a very low solubility at ordinary temperatures (about 10 ppm SiO_2 at 25°C) but a much greater solubility at high temperatures (500 ppm at 300°C) (Krauskopf, 1967). The solubility of calcite ($CaCO_3$), on the other hand, decreases as the temperature rises (CO_2 is less soluble in hot water than in cold water). These facts relate to the history of quartz deposition in Chiricahua Crystal Cave. The quartz had to have been deposited from hot waters (most likely associated with various hydrothermal episodes of Tertiary volcanism); whereas, the limestone ($CaCO_3$) cave had to be dissolved by cold waters before the Tertiary hydrothermal episodes (the cave must predate the crystals which line the cave). The time span between these two events must either (1) have been of short duration since no subaerial secondary speleothems were deposited between the limestone and quartz crystals, or (2) of indeterminate length if one assumes that the cave remained underwater from the time of its genesis to the Tertiary when hydrothermal solutions deposited the quartz crystal linings. Later, after the hydrothermal solutions drained from the cave, subaerial calcite popcorn and flowstone coated the quartz crystals.

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Structural Analysis of Alabaster Cave, San Ysidro, New Mexico

Peter Hutchinson, Helene Warren, William D. White, Jerald Schultz and Sandra Anderson

Massive gypsum of the Jurassic Todilto Formation is exposed subareally, 6 km northwestward from the village of San Ysidro, New Mexico. Alabaster (Ojo del Diablo) Cave is developed in the Todilto Formation. The cave is situated between the eastern limb of an asymmetric, north-plunging anticline and the western limb of a north-plunging syncline (Fig. 10). The cave is a series of connecting, en echelon, rectilinear conduits which parallel the surface drainage of Arroyo Peñasco. The Arroyo Peñasco discharges into the Rio Salado, a tributary of the Rio Grande. The cave has a total length of 0.9 km and an orientation of N 15°E. Drainage in the cave, as indicated by scallop marks, is southwestward. Alabaster Cave is developed along the inflection of a conjugate fold set. The fold set resulted from the upthrust of the Nacimiento Mountains during the Laramide Orogeny (Late Cretaceous to early Tertiary). Axial-plane cleavage developed in the fold set and was subsequently exploited by groundwater in the late Quaternary.

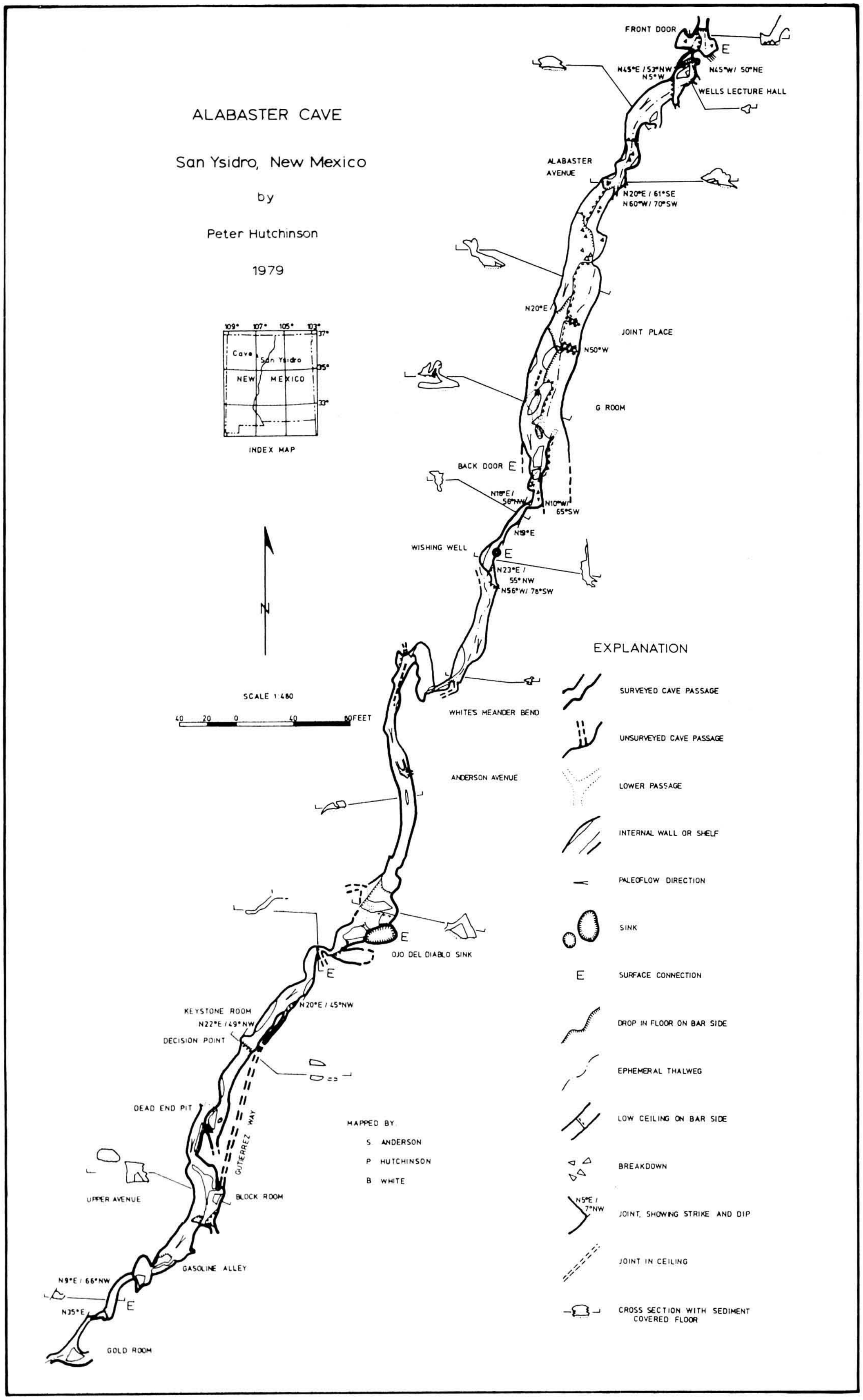

Figure 10. Map of Alabaster Cave near the Nacimiento Mountains, New Mexico.

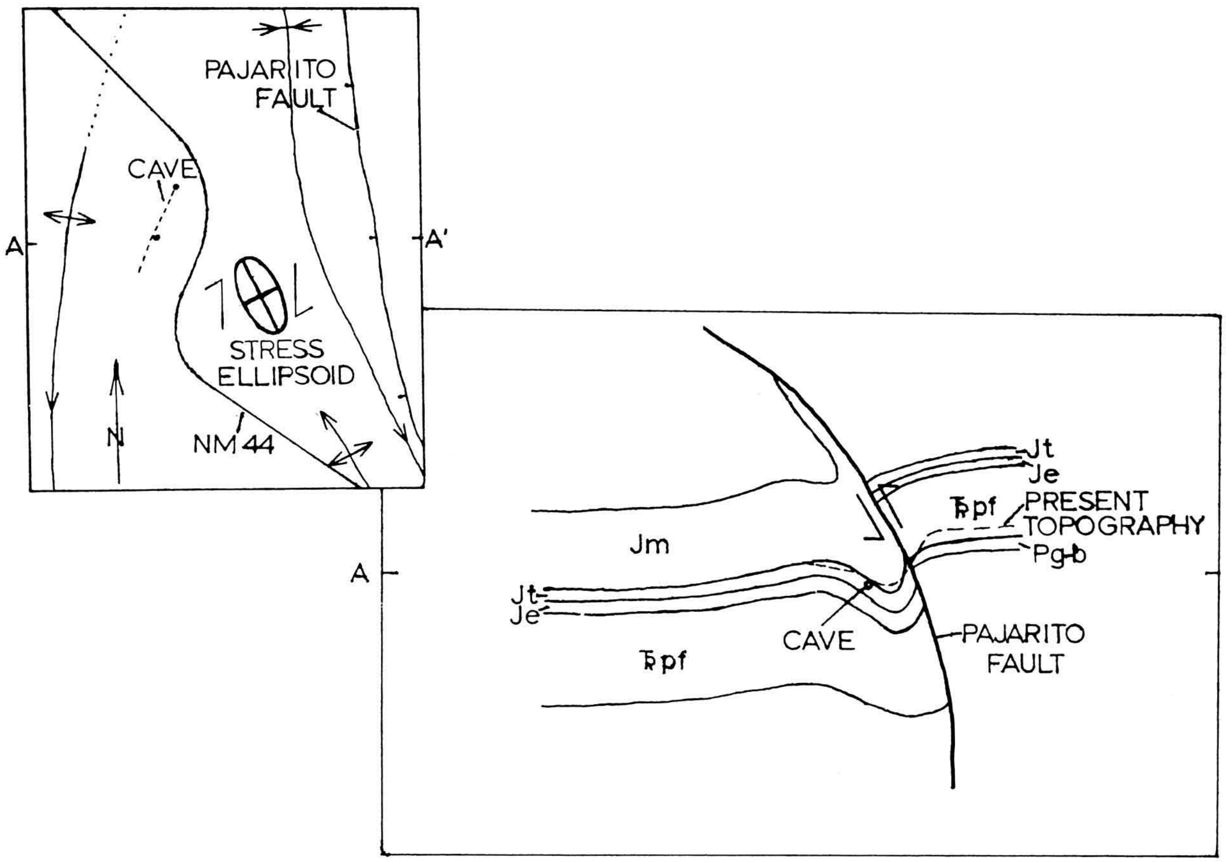

Figure 11. Cross-section through cave and Pajarito Fault showing east-west compression. Inset is a tectonic map with stress ellipsoid.

Structural Geology

Regional

The Nacimiento Uplift is the eastern boundary of the San Juan Basin (Kelley, 1960). The western border of this uplift is a westward yielding upthrust (Woodward, 1976). The upthrust propagated an east-west compressional environment which displays a right shift (Kelley, 1955). Drag folds and axial-plane cleavage developed from these compressional forces (Fig. 11).

Local

The cave passage orientation is controlled by joint orientations; whereas, the cross-sectional geometry is controlled both by the jointing and water-table elevation through time. The cave passages trend along two major joints. The dominant joint trend is parallel to the axis of the anticline with a mean bearing of N3°E (Fig. 12), and another joint trend has a bearing of N45°E (Table 4). An example can be seen in the Keystone Room where both passage walls are developed along joint surfaces (Fig. 10).

Cave Development

Early development of Alabaster Cave occurred by phreatic dissolution, creating the spongework formation observed in the Wishing Well chamber (Fig. 10). A drop in the water-table elevation produced vadose flow conditions and incision of the groundwater along joints. Labyrinthine passages developed primarily from breakdown and floodwater diversions around the collapse; an example is given by White's Meander Bend. The diverted groundwater exploited the minor joints, seeking alternate routes around the breakdown. This process forms many of the kinks in the rectilinear cave system. Transverse joints represent the other type of side passage orientations. South of Ojo del Diablo Sink is an example where the cave is cut by minor

TABLE 4.

Orientations of surficial joints and joints within Alabaster Cave

Surface Joints Above Alabaster Cave

N 5W/86SW	N25E /67NW	N55E /73NW	
N 3E /84NW	N25W/36SW	N75E /72NW	
N 0S /33E	N15E /64NW	N62E /62NW	MEAN = N06°E
N 0S /37W	N20E /76SW	N58W/89SW	
N65E /12SE	N25W/64SW	N55W/75NE	STANDARD
N 0S /36E	N25E /45NW	N70W/75SW	DEVIATION = 42°

Joints in Alabaster Cave

N45E /50NW	N 0S /90E	N75E /55NW	
N45E /53NW	N56W/78SW	N20E /45NW	
N67W	N24E /55NW	N75E /53NW	MEAN = N03°E
N 0S /90E	N18E /56SE	N21W/49SW	
N20E /61SE	N10W/65SW	N20W	
N60W/70SW	N13E	N25W/68SW	
N57W/74SW	N 7E	N10E	STANDARD
N50W	N22E /45SE	N70E /56NW	DEVIATION = 42°
N75W	N22E /56NW	N20E /49NW	
N50W	N25E /49NW	N35E /45NW	

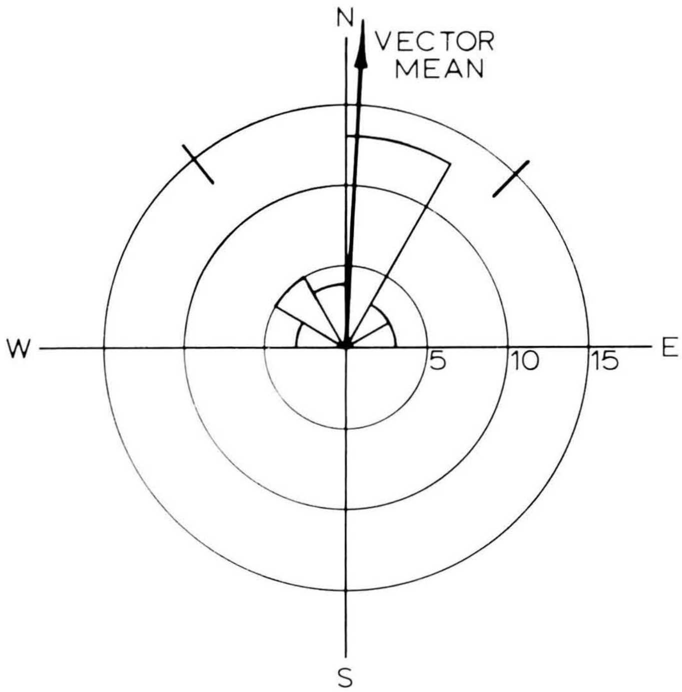

Figure 12. Rose diagram of cave joints showing vector mean and standard deviation. Note ancillary cave passages in an east-west orientation.

transverse joints giving rise to a 5 m kink in the passage (Fig. 10). Additionally, runoff from the anticline recharges the cave through these joint sets, accounting for the dissolutional enlargement of side passages.

Conclusions

Alabaster Cave forrned when groundwater exploited joint sets developed from drag of the upthrust of the Nacimiento Uplift. These joint sets developed parallel to the axial planes of the folds. The joint sets control the general orientation of Alabaster Cave which is N15°E. Minor joint sets were exploited during floodwater diversion and tributary recharge. The cross-sectional geometry of the cave passages is controlled by these joints and elevation of the water table during the Quaternary.

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Analysis of the Structural Control of Speleogenesis of Lilburn Cave, Kings Canyon National Park, California

Gail McCoy

Study of the structural control of speleogenesis in Lilburn Cave continued this year. Lilburn Cave has formed in a lens of distinctively foliated marble. The foliation is defined by alternating white to light gray and dark gray to black bands that vary from irregular, isolated patches to spectacular, even bands tens of feet wide. The grain size of the marble ranges from aphanitic to .3 in and often changes across a few inches of exposure.

Schist and quartzite also constitute part of the metasedimentary roof pendant that contains the cave. Weathering reddish-black biotite quartz schist with a variable degree of foliation and an aphanitic, resistant quartzite form the majority of this roof pendant.

Rocks of the Sierra Nevadan batholith that surround the metasedimentary rocks include the Big Baldy Granite on the east and the Giant Forest pluton of quartz dioritic to quartz monzonitic composition elsewhere (Ross, 1958).

Few marble outcrops show through the thick regolith in Redwood Canyon. The regolith mantling the karst and surrounding rocks consists of abundant soil with numerous granitic boulders and less common schist or quartzite cobbles. Streams flowing on the nonkarstic rocks sink at the contact with the marble. Sinkholes also help to define the minimum extent of the marble in this area.

Work within the cave included general study of major passages and detailed examination of selected areas. Major passages that have been looked at but not yet closely studied were checked for type of passage, presence of joints and faults, and the suitability of the passage for detailed work (structural importance, clean walls and accessibility).

Frequency of faulting varies through the cave. No solution has been noted along observed faults. Drag folds occur along some faults while other faults have cleanly defined fracture planes. No fault examined shows more than about three inches of separation.

Meyer Pit to the Telephone Pit and parts of Curl Passage and the East Stream have been closely examined. These major passages were chosen for their clean and accessible walls and ceiling, presence of fractures and reasonably simple plan. The orientation, extent and frequency of all fractures and the shape and general features (size, type of passage, special details) of the passage were determined. In one area, the dominant joints are subparallel and have variable dips. In places in the Curl Passage and the East Stream, the passages clearly follow the dominant joint-set. Where the dip of the joint-set steepens or shallows, the dip of the passage's ceiling changes at the same rate.

One common feature noted during the general studies is the secondary solution found in many areas. This solution typically forms random, meandering half-tubes a few feet in height without observable fractures. Greater amounts of secondary solution of less definite shape exist locally, often in areas with remnant fills. The irregular solution may have occurred while a passage was nearly filled with sediments, with streams forced into the area remaining between the marble ceiling and the insoluble fill. At a later time much of the sedimentary fill eroded away.

This research will continue next year. Field work on the surface is needed to locate contacts that were not found during this season's work. Subsurface study will include additional collection of fracture-orientations in major passages. After sufficient orientation data are obtained, patterns of jointing throughout the cave will be compared with patterns on the surface.

This research is part of a Master's degree in geology at San Jose State University, San Jose, California.

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Stratigraphic Variations in Mammoth Cave National Park

Arthur N. Palmer

Each of the rock units in the Girkin, Ste. Genevieve and St. Louis formations can be traced throughout the Flint Mammoth Cave System (Palmer, 1975). However, like everything else in nature, the stratigraphy appears to become more complex the more it is examined. This is to be expected, because the environmental conditions tended to vary a great deal over short distances in a shallow epi-continental sea like that in which the limestones of Mammoth Cave National Park were deposited. When mapped in detail, these variations in rock thickness and character should allow us to interpret the Mississippian paleoenvironments with unusual clarity. The Flint Mammoth Cave System is a three-dimensional rock exposure that is well suited to this kind of study.

Perhaps the greatest stratigraphic variation observed so far in Mammoth Cave National Park occurs in massive bodies of coarse-grained sparite. Not only do they tend to thicken and thin over short distances, but where they are thin they tend to be finer in texture. The best examples can be seen in Mammoth Cave, where granular sparite banks progress toward the south with decreasing age. For instance, the sparite in the Fredonia Member (Ste. Genevieve Limestone) that forms the columns of the Ruins of Karnak is 7 m thick, but traced to the south its thickness decreases rapidly to 1.5-3m. The coarse-grained upper part of the Joppa Member that forms the walls of Kentucky Avenue for most of its length, with a thickness up to 15 m, thins both northward and southward to 4-6 m. Variations such as these account for many reversals of the overall northwesterly dip in Mammoth Cave Ridge and also may be responsible for the vertical divergence and convergence of passage levels that are concordant with the bedding.

As a first approximation, the variations in sparites described here seem to represent the southerly progression of a minor shelf edge, where oolites and skeletal fragments accumulate in thick, cross-bedded banks.

At Long Cave, the upper 5 m of the Paoli Member consist of a single bank of cross-bedded oolitic limestone (oosparite), in which the main passage of the cave is located. Despite the impressive size of this passage, its smooth-walled, tubular shape is undisturbed by breakdown because of the massive nature of the limestone. The smooth, undulant ceiling of the Frozen Niagara area of Mammoth Cave is formed by the lower part of the Levias Member, which is thin and incompetent elsewhere in Mammoth Cave Ridge. It is clear that stratigraphic variations can account for major differences in the character of cave passages from one place to another.

Table 5 shows how the major sparite units vary from north to south in the Mammoth Cave area.

Table 5

Rock Unit	Thickness (meters)				
	Historic Route	Cleaveland Ave. Area	lower Kentucky Ave.	Frozen Niagara	Long Cave
Paoli (lowest Girkin)	7	15	?	?	16.5
Levias (uppermost Ste. Genevieve)	1.2	0.6	?	5	3.6
upper Joppa	4	6	12-15	6.4	?
middle Fredonia	7	1.5-3	?	?	?

As the limestones in the cave walls are mapped in greater detail, a fairly clear picture of other spatial and temporal changes in the depositional environment can be obtained. This aspect of stratigraphic mapping has barely begun and will be expanded in the future.

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Weathering Features and Dissolutional Processes on Gypsum of the Todilto Formation, North-central New Mexico

Doris Rhodes, Susan Young, Helene Warren and Steve G. Wells

Weathering Features

A weathering zone, known as gypsite, forms on the gypsum outcrops of the Jurassic Todilto Formation in north-central New Mexico. The gypsite is of the cellular-crystalline variety and often occurs as fibrous-like crusts several centimeters in length. Additionally, gypsum has been deposited along interstices of massive gypsum breccia and joint planes by downward percolating water. Where fine grained clastic material is available, recrystallized gypsum combines with the fine quartz clasts to form an earthy gypsite. Weber and Kottlowski (1959) previously described these forms of gypsite:

> Brief mention should be made of the nature and origin of gypsite, that almost ubiquitous associate of gypsum outcrops. Gypsite is an earthy or cellular type of gypsum formed by the same processes as common caliche, and by leaching and recrystallization of the gypsum outcrops. The earthy type is soft, impure, and admixed with variable amounts of clay, silt, and carbonates. It forms in soils in semiarid regions by evaporation of calcium sulfate-rich waters drawn to or near the surface by capillary action. Gypsum is soluble to the extent of one part in 400 to 500 parts of water. As a consequence, leaching of outcrops by rainwater tends to produce a crust of spongy cellular gypsite, which is partly a residue of the gypsum bed, and partly reprecipated gypsum. Earthy gypsite coats gypsum outcrops, occurs in small lenses or surface crusts downslope from gypsum beds, and is part of the alkali crust of numerous depressions fed by gypsiferous waters. The cellular gypsite, which has a characteristic hollow sound when struck by a hammer, may indiscriminately cover thin beds of limestone and clastic rocks interbedded with gypsum, but does not appear to occur at any considerable distance from gypsum outcrops.

Our studies of weathering on the Todilto Formation yield the following results:

The surfaces of exposed gypsum have developed a brown-grey weathering rind which varies from .25-2 mm in thickness, depending on aspect (Table 6). Two forms of this rind appear, blocky and platey. On steep slopes, the gypsum weathers to angular and sub-angular blocks, with holes that are the result of dissolution. These slopes have a distinctly cavernous appearance. Less steep slopes are characterized by sub-rounded platey shields. These shields show recrystallization along the undersides. Superimposed on the weathering rind in many places are pinnacles of recrystallized gypsum. These pinnacles vary in height from 3-480 mm, depending on aspect (Table 6), and contain recrystallized sub-euhedral cyrstals.

Beneath the weathering rind is a layer of powdery gypsum. During periods of moisture, several ephemeral forms of bacteria and algae can be found. These show blue, black, red, and green colorations and are probably a mixed bag of chemo-autotrophs. Yellow colors in this layer are due to elemental sulfur (most probably bacterial oxidation from H_2S); black colors are caused by reduction by bacteria from $SO_4^{=}$; and blue, red and green colors are caused by photosynthetic bacteria and/or lichens. In those areas where the powdery layer does not underlie the weathering rind, a honeycomb texture is evident. This form is probably caused by dissolution during percolation events.

The following conclusions are based on field observation and data presented in Table 6:

1. Weathering features developed on the gypsite include angular blocks, platy shields, honeycomb textures and pinnacles. Honeycomb textures form by dissolution alone; whereas pinnacles and platy shields form by dissolution and recrystallization.
2. These different weathering features form under different slope and moisture conditions, rather than differences in lithology.
3. As gypsum bedrock weathers, it first forms a poorly indurated, powdery gypsum which is overlain by the weathering rind.
4. Chemical analyses indicate that the weathered, powdery gypsum and unweathered gypsum contain similar dissolved ion concentrations of calcium, magnesium, and sulfate; whereas, the weathering rind contains a greater percentage (by weight) of magnesium and less calcium and sulfate. The calcium and sulfate ions are removed during the transition from the powder to the rind. Thus, the change from bedrock to powder is mechanical, and the change from powder to rind is chemical.

Dissolution Process

Samples of unweathered gypsum bedrock were collected to examine the rate of dissolution of gypsum under varying flow conditions. Approximately 100 grams of gypsum were used in each of three experiments. The gypsum was placed in a 3.5 cm diameter tube and tap-water was discharged over the gypsum at a given rate of flow. The experiment was allowed to run 10 hours after which the sample was removed, dried at room temperature and weighed. Three different flow rates were used (2.5 ml/sec, 5.0 ml/sec, and 10.0 ml/sec), and the water temperature was held constant at 20.6°C for each flow rate. The results of the three experiments are given in Table 7. Figure 13 shows that the dissolution rate is proportional to the log of the flow rate. Additionally, after a flow rate of 0.5 cm/sec is obtained, the dissolution rate becomes constant at approximately 4.5 g/hr.

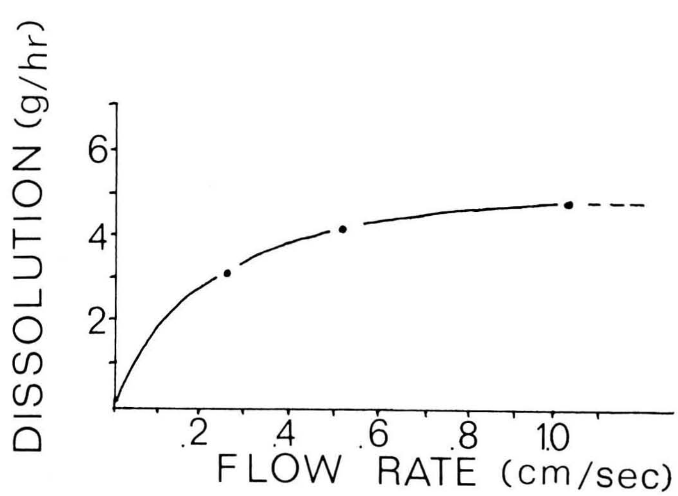

Figure 13. Dissolution rate of samples taken from the Todilto Formation under varying flow rates. Water temperature is constant.

TABLE 6.

Characteristics of weathering rinds on gypsum

	South Facing Slope	North Facing Slope	East Facing Slope
Pinnacle Measurements	4mm, 19mm, 10mm 6mm, 3mm, 4mm 6mm, 4mm, 12mm	17mm, 20mm, 12mm 7mm, 28mm, 17mm 7mm, 10mm, 20mm	480mm, 3mm, 4mm 10mm, 7mm, 406mm 50mm, 9mm, 72mm
Mean Pinnacle Size	7.55mm	15.55mm	115.66mm
Size Range	3mm to 19mm	7mm to 28mm	3mm to 480mm

Comparison of Surficial Features

South facing slope	*North facing slope*	*East facing slope*
1. cavernous, undercut erosion	1. less cavernous than south facing slope	1. non-cavernous
2. light grayish brown with red	2. medium to dark gray	2. light gray
3. prominent platey shields	3. plates not prominent	3. non-platey
4. slope less steep than north and east	4. steeper slope than east and south	4. slope less steep than north
5. not heavily lichenated	5. heavily lichenated	5. no lichens; bacteria, or moss present
6. sparse vegetation	6. insipient diverse vegetation	6. sparse vegetation

Chemical Analysis:

	Weathered Rind	White Powdery Gypsum	Unweathered Gypsum
Mg	.18%	.005%	.007%
Ca	33.5 %	36.4 %	36.8 %
SO_4	54.96%	61.34 %	61.07 %
Total %	88.64%	97.745%	97.877%

all values are weight %

TABLE 7.

Results from dissolution experiments on unweathered gypsum

	Experiments		
	#1	#2	#3
Initial Sample Weight	103.4 g	103.4 g	103.4 g
Final Sample Weight	55.5 g	61.9 g	71.6 g
Weight of Sample Dissolved	47.9 g	41.5 g	31.8 g
Dissolution Rate	4.79 g/hr	4.15 g/hr	3.18 g/hr
Sample Volume	48 ml	46 ml	46 ml
Flow Rate*	1.04 $cm^3/cm^2/sec$	.52 $cm^3/cm^2/sec$	.26 $cm^3/cm^2/sec$
Dissolution Interval	10 hr	10 hr	10 hr

Sedimentology and Stratigraphy of Clastic Deposits in Lilburn Cave King's Canyon National Park, California

John C. Tinsley

The sedimentary strata preserved in the northern and central parts of Lilburn Cave record at least three episodes of deposition and erosion. The oldest strata yet found are varve-like, clay-rich sediments, the fine textures of which markedly contrast with the coarse, cobbly and gravelly sands which comprise two successively younger deposits. The following paragraphs describe these three units and discuss the speleogenetic implications of the stratigraphy. An experiment is proposed based on basin geometry to further establish the credibility of paleomagnetic methods of correlation in Lilburn Cave. These results must be regarded as preliminary; the remarks herein pertain only to stratigraphic relationships in the northern and central parts of the cave.

Sedimentology and Stratigraphy

The stratigraphically lowest sediments have been informally designated the "banded clay." The banded clay mainly consists of distinctive, thinly laminated, varve-like deposits of clay, silty clay and clayey silt; the deposits are not known to contain material more coarse than fine to very fine sand. The banded clay is preserved as dissected remnants of deposits which formerly were much more extensive. The banded clay always rests on bedrock—either on floors or on ledges along the walls of passages. The maximum thickness exceeds two meters. The banded clay is overlain unconformably by the older of two coarse clastic deposits.

The old coarse clastic unit occupies an intermediate stratigraphic position and consists chiefly of isolated conglomeratic deposits commonly cemented with calcium carbonate. The matrix is quartzo-feldspathic sand; the clasts are stream-rounded and include phaneritic plutonics and metasedimentary lithologies typical of the Redwood Canyon drainage. This unit occurs as eroded remnants preserved in alcoves and fissures along walls and as fills in incised ceiling channels. These fills often are encrusted with speleothems. The old coarse clastic unit always exhibits cut-and-fill relations with, and/or overlies the banded clay. The advanced degree of cementation, the bleached appearance commonly exhibited by grains of biotite, and the pervasive stains of iron oxides throughout the matrix clearly distinguish the old coarse clastic unit from the texturally similar, young coarse clastic deposits.

The young coarse clastic deposits include all sediments in transport through the cave under the prevailing hydrologic conditions. These deposits have the same provenance and similar textures as the old coarse clastics. The young deposits occur along the courses of present-day streams and in passages known to have flooded historically. An absence of cementation or oxidation and/or weathering of grains, and the close spatial association with the modern hydrologic regime distinguish this unit from the old coarse clastic unit.

Basinal Analysis of Banded Clay

During 1978 much has been learned about the basin in which the banded clay was deposited. Twelve new localities have been found where banded clay underlies modern sediments. The distribution of the banded clay deposits now defines a basin which, when active, included at least the lower East Stream and Great Central passages, the Hexadendron Room, the Lake Room passage and their connectors. The four highest localities at which banded clays occur have been surveyed; the elevations of these localities are plotted on the cross-section in the lower half of Figure 14. The highest localities have identical elevations (within $\pm$ 0.3 m of the same elevation) despite their being rather widely separated in the cave. The areal locations are depicted in the partial sketch map of Lilburn Cave in the upper part of Figure 14. The banded clay apparently is also present in the Lake Room passage; however, a position correlation between banded clays in the Lake Room area and the higher localities in the Hex Room and in the East Stream areas awaits further detailed paleomagnetic sampling. Correlation seems likely and a hypothesis is presented below. If so, the banded clay occurs throughout a vertical range of at least 22 meters. Thus, the basin probably included at least the cave's two major trunk passages, the largest single room, plus passages in the Lake Room area.

Discussion

The implications posed by the contrast of the banded clay with the old coarse clastics are profound and become apparent from other field evidence. As a point of departure, consider the basic architecture of this portion of Lilburn Cave. The East Stream and Great Central passages are two high-gradient tubes which, at their upper (northern) ends, connect with a poorly understood system of vertical fissures; at their lower (southern) ends, the tubes connect with the Hex Room, the floor of which lies approximately 80 m subsurface. Stations 294, 295 and 300 are shown in the lower part of Figure 14 and depict the slope of the East Stream at slightly exaggerated vertical scale. The fissures often are choked with boulders and gravelly sands and cannot be entered. However, the fissures are the apparent source of much of the water and coarse sediment in these large trunk passages. It is probable that the fissures, in turn, connect reasonably directly to the surface, to Redwood Creek or its tributaries, but this connection has not been demonstrated. The fact is that the banded clays are situated within the trunk passages such that if *any* coarse clastics were being delivered to the basin (to the trunk passages) contemporaneously with deposition of the clays, there would be coarse material present in the clays. The coarse material simply is not present in the banded clays. This is best explained if the fissures did not function as conduits for coarse debris (as they do today) during deposition of the banded clay.

A conceptual model emerges in which the banded clay is a record of low-energy subaqueous deposition, a phase which persisted for at least 8,000 to 10,000 years, according to paleomagnetic studies by Ulfeldt and Packer (1977). Absolute dating of any of the deposits in the cave has yet to be done. However, there is excellent potential here for future work. The paleomagnetic studies do not enjoy independent time-control at present; thus, the onset and the cessation of deposition of banded clay cannot yet be fixed absolutely in time. It can be concluded, however, that a fine-textured phase of deposition was superceded by the influx of coarse clastics. It is noteworthy that banded clays interbedded with coarse clastics have not been found; therefore, contemporaneous deposition of coarse materials and banded clay did not occur in the banded clay basin. The accordant elevations of the highest occurrences of banded clay strongly suggest ponding or locally persistent, low-energy subaqueous conditions. Whether the ponding reflects regional controls ascribable to the water table or to a blockaded passage located somewhere downstream of the Lake Room is not established. The fact that the clays are not ubiquitous in the cave

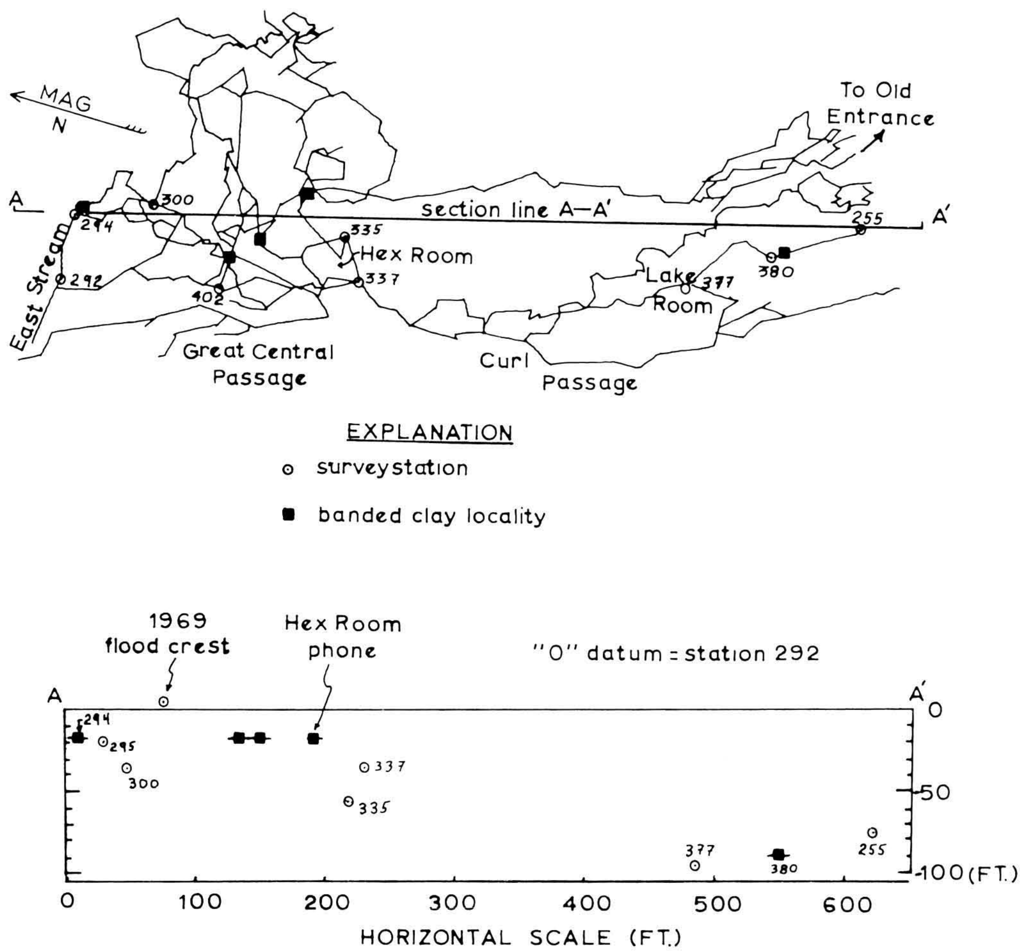

Figure 14. Plan view and vertical section depict areal and vertical positions of selected banded clay localities and nearby survey stations. Place names identify major elements in the banded clay basin. All occurrences of clay lie below the level attained by recent (1969?) episodes of flooding. The elevation of station 292 is assumed to be 0 for the vertical profile. Station 335 is approximately on the floor of the Hex Room.

indicates a fairly local phenomenon. When sedimentation rates and relative time spans are determined for different banded clay localities, more definitive models may be proposed.

The old coarse clastics are hypothesized to have entered this part of the cave when a downcutting Redwood Creek eroded into the system, or when sinkhole collapse dumped stream-transported detritus into the cave. Regardless of the mechanism by which the coarse detritus gained entry, the sedimentation probably was not synchronous throughout the cave. It is probable that the older coarse clastic deposits span an undetermined period of time and have as many sources as there are fissures. However, the deposits accumulated in sufficient volume and for a sufficient length of time to have totally filled major phreatic passages and perhaps to have triggered upward dissolution of roof rock to form anastomosing ceiling channels and roof pendants. Cemented, conglomeratic deposits herein assigned to the old coarse clastic phase of deposition are found preserved as fills in the ceiling channels and anastomoses. These deposits are probably the remnants of fills which aggraded and directed chemically aggressive ground water against the roof rock. An additional implication of this reconstruction of the sedimentologic history of Lilburn Cave is that the material filling the fissures cannot be older than the old, coarse clastic deposits and must in any event postdate the deposition of the banded clays.

Future Work

Future work will include: 1) downstream searches for additional banded clay deposits; 2) attempts to locate the spillway passage(s) in the banded clay basin; 3) mapping of old coarse clastic deposits in the northern and central sectors of the cave; 4) locating deposits suitable for absolute age dating of both the old clastics and the banded clay deposits; and 5) further paleomagnetic studies of the banded clay to refine understanding of sedimentation in the basin.

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Geomorphology of the Appalachian Karst

Elizabeth L. White and William B. White

The long-term study of karst landforms in the Appalachian Highlands continues. New results sketched below deal specifically with the properties and distribution of dolines in the 62 reference drainage basins used in previous work on the karst hydrology of the Appalachians.

A measure of the intensity of karstification is provided by the index of pitting, the number of dolines per square mile of carbonate rock outcrop. These numbers were determined for the 62 study basins, considering the Ordovician limestones and dolomites separately. The frequency of occurrence of basins with any given range in index of pitting is log-normally distributed with a mean index of 1-3 dolines/square mi (Fig. 15). There is no significant difference in distribution between basins or sub-basins on different rock types.

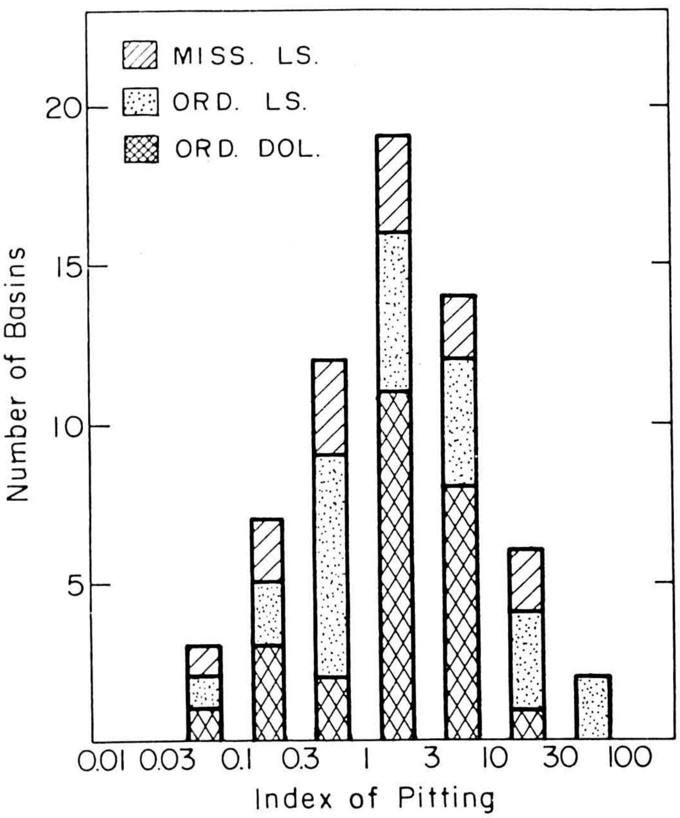

Figure 15. Log-normal distribution of index of pitting compared to number of basins.

Using those basins containing at least some dolines, the area of internal runoff into dolines, AD, was regressed against the number of dolines, N, without regard for rock type. The regression equation is

$$AD = 0.0135\, N^{1.17} \qquad r^2 = 0.75$$

The measured internal runoff area includes all areas shown on topographic maps, with internal drainage including areas drained into 10-foot contour, closed-depression features and areas which are internally drained without expression of dolines on topographic maps. There appears to be, nonetheless, a more or less direct proportionality, with considerable scatter, between the number of dolines and their drainage area. Assuming a direct proportionality, the mean doline size in the Appalachians has a diameter of 700 ft.

The regression equations were calculated separately for the dolines of the Valley and Ridge province (Ordovician limestones and dolomites) and the Appalachian Plateaus Province (Mississippian limestones). The results are:

Valley and Ridge: $AD = 0.011\, N^{1.15}$ $r^2 = 0.77$ (34 basins)

Plateaus: $AD = 0.035\, N^{1.09}$ $r^2 = 0.73$ (13 basins)

There appears to be a substantial difference in doline size between the two provinces. Valley and Ridge dolines have a mean diameter of 600 ft; whereas, the Plateau dolines have a mean diameter of 1100 ft. These diameters are calculated as an effective circle of internal drainage and are not represented by the highest closed depression contour which would encompass a considerably smaller area.

The distribution of dolines with respect to depth is shown in Figure 16 in comparison with a similar study made by Wells (1973) in the Central Kentucky Karst. This figure was obtained by counting the entire number of dolines with a given number of closed depression contours that occur in all 62 study basins. Omitted only are those basins for which the maps have only 40 to 50 ft contour intervals. There are 5,160 dolines that are at least 20 ft deep, but only 16 dolines 120 ft deep or greater. The frequency depth relations can be fitted to a simple exponential curve over the depth interval of 20 to 120 ft. The results show that the distribution of doline depths is independent of rock type and physiographic setting. The exponential coefficient is essentially the same for both the Appalachian and Kentucky doline populations. However, there is a fairly obvious deviation from simple exponential behavior visible in the distinct curvature of the points in Figure 16. It seems more likely that the doline depth statistics actually follow some more complicated distribution function.

The role of rock type and physiographic setting can be analyzed by comparing the internal runoff parameters summed over the entire set of drainage basins and normalized to the total area of carbonate rocks.

Table 8 compares the area of sinking stream basins, AB, and

TABLE 8.

Intensity of karstification measured by internal runoff

	Outcrop Area (Mi^2)	AB (Mi^2)	AD (Mi^2)	AB/Area	AD/Area
Appalachian Plateaus	637	96	159	0.15	0.25
Valley and Ridge	1098	74	70	0.07	0.06

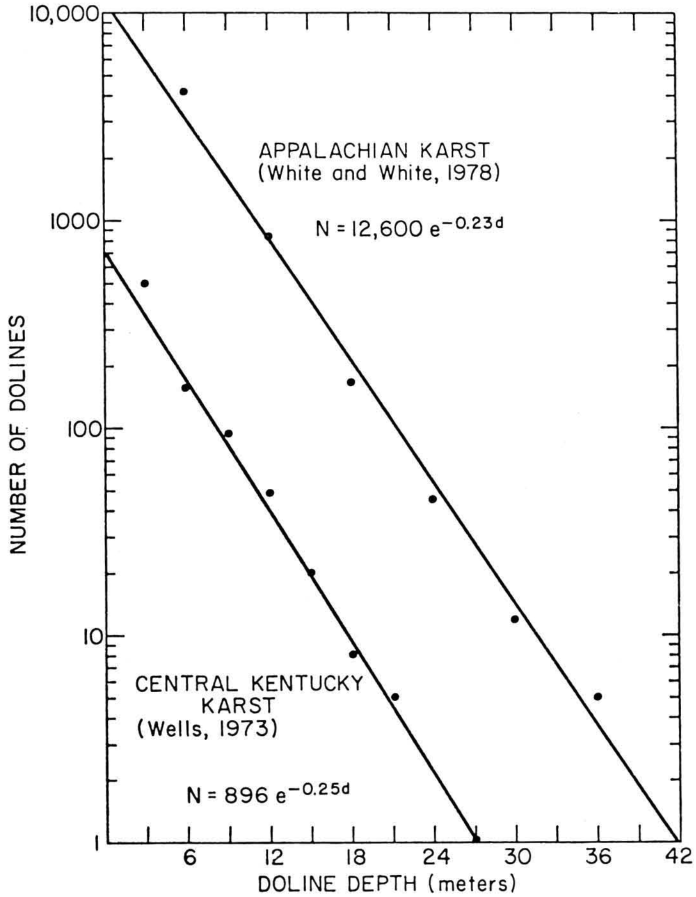

Figure 16. Distribution of dolines with respect to doline depth.

the area of internal runoff through dolines, AD. It is seen that in the Valley and Ridge Province there are only 0.07 square mi of sinking stream basin per square miles of drainage basin, while on the Plateaus there is twice this number. 6% of the carbonate rock area of the Valley and Ridge Province drains through dolines; whereas, on the Mississippian limestones of the Appalachian Plateaus the number is 25%. It is not possible to subdivide the dolomites and the limestones in the Valley and Ridge because the catchment areas, particularly the sinking stream catchments, span both rock types and some clastic rock areas as well.

TABLE 9.

Index of Pitting by Carbonate Rock Type

Rock Type	Outcrop Area	Total Number of Dolines	Index of Pitting (# /Mi^2)
Mississippian Limestone	583	2182	3.74
Ordovician Limestones	444	1506	3.39
Ordovician Dolomites	569	1472	2.58

Index of pitting can be separated by rock type, since it depends only on doline counts. Table 9 shows the results. The number of dolines per unit area is smallest on the Ordovician dolomites and largest on the Mississippian limestones. However, comparison with the internal runoff area shows that the Mississippian limestone dolines are also larger than the dolines on the Ordovician carbonate rocks. Thus it appears that the massive, flat-lying Mississippian carbonates support a more highly-developed karst than do the mixed sequence of folded and faulted Ordovician limestones and dolomites of the Valley and Ridge. However, the contrast is not so extreme as field observations of the two karst areas first indicated.

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Investigations of Semi-arid Karsts in the Carlsbad Caverns Area, New Mexico

Paul W. Williams

Two separate lines of research are being followed in the Carlsbad region. The first deals with water storage in the vadose zone of carbonate rocks above Carlsbad Caverns and the second involves a reconnaissance investigation of karst systems in the evaporite rocks of the Black River-Pecos River region.

(1) Storage of water in the vadose zone is almost always underestimated. Thus, an analysis of rainfall and percolation water data from Carlsbad Caverns is being undertaken in order to gain an insight into the role of the vadose zone in storage and transmission of rainwater.

(2) The world literature on karst developed in sulfate rocks is very slight by comparison to that on carbonate karsts. Since the very extensive evaporite deposits of the Delaware basin, that extends from New Mexico into Texas, must provide the basis for one of the major sulfate karsts of the world, part of this region in the Black River and Pecos River valleys was investigated in order to obtain more basic information on the nature of sulfate karst systems. This research is therefore of a broad-scale reconnaissance level, that may help to supplement the detailed information being obtained by Steve Wells at Chosa Draw (to whom grateful acknowledgement is given for an introduction to the area).

Morphometry of the Sinkhole Plain in the Mammoth Cave District, Kentucky

Paul W. Williams

This research was undertaken as a joint project with Jim Quinlan of the National Park Service. Quinlan's hydrologic work (Quinlan and Rowe, 1978) has shown that many streams sinking in the Park City-Glasgow upland area flow beneath the Mammoth Cave National Park to resurge in the Green River. The hydrology and geomorphology of the sinkhole plain in the Park City region is therefore of interest both for national park management purposes as well as for purely scientific reasons, as one of the "classical" karst topographies of North America. The region is also of particular interest as a previously unrecognized temperate *polygonal karst,* as defined by Williams (1972a), i.e., a terrain where closed depressions completely pit the land surface, occupying all the available space, such that their adjoining topographic divides form a cellular network. Such a relief might previously have been more associated with the humid tropics, but polygonal karst is now widely known in Europe and New Zealand, as well as in North America. The close-packed depressions act as competing centripetal sinks, draining incoming precipitation and delivering it to subterranean conduit systems. The first stage in understanding the operation of polygonal karst sinks in the karst hydrologic system is to describe their form. Hence, research was begun to analyze the morphometry of a transect across the sinkhole plain from the edge of the Glasgow upland, across Parker Cave where there is good subsurface information, to Park City and into the National Park, where limestones give way to more frequent occurrences of sandstone caprock.

The research to-date has included field inspection of the terrain followed by detailed air photo analysis and further field checking of interpretation. The next steps will involve morphometric measurements from the produced maps, followed by computer analysis to define morphometric characteristics of the sinkhole plain. The procedure being followed is based on Williams (1972b).

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Hydrology Program

Figure 17. Elk Spring Karst Window serves as a water supply system for farm in Central Kentucky Karst. Photo by S. Wells.

Recession Hydrographs for Karst Springs

Bruce E. Gaither and William B. White

The major discharge from carbonate aquifers is commonly through large springs. Fluctuation in discharge is due, in part, to variability in precipitation and other meteorological conditions. The nature of discharge variability, however, is also affected by such factors as the size and relief of the catchment, structure of the bedrock, and rock type which control the size, geometry, and three-dimensional distribution of the openings through which the ground water passes.

Analysis of hydrographs from 26 springs which emerge from carbonate aquifers in four distinct hydrogeologic regions of the United States demonstrates that the shape of the long-term hydrograph is closely related to the regional hydrogeologic setting and to aquifer flow type. Karst conduit aquifers are common in the Missouri Ozarks and in the Appalachian Highlands. These aquifers characteristically produce fast-response hydrographs. Slow, and sometimes low-response hydrographs are produced by the artesian aquifers which occur in the Coastal Plain carbonates of Florida and the Cretaceous limestones of Texas. The restricted flow of the diffuse (fracture) flow aquifers of northeastern Alabama results in mixed-response hydrographs which display strong seasonal trends.

All available water records from the springs that showed fast-response transient events were key-punched. The computer searched through the data for the recession limbs of single event hydrographs, reproduced them in semi-log form and calculated the slopes of individual line segments. The hydrograph recession limbs of most springs were found to be composed of two or more separate exponential components (see Fig. 18, a typical example). The multi-segment hydrographs can be interpreted as arising from nonhomogeneous permeability. The short-response time segments represent the fast flow of water through the conduit system; whereas, the longer-response time part of the event comes from the slow discharge of water through the fracture and pore system. The recession limbs can be fitted to an equation of the form

$$Q = \frac{Q_0}{1+f}\left[e^{-\frac{t}{t_{r(1)}}} + f\,e^{-\frac{t}{t_{r(2)}}}\right]$$

and the individual response times evaluated. In the above equation Q is discharge, Q_0 is the discharge at the beginning of the recession limb, t_R is the characteristic response time, and f is the fraction of the total discharge moving through the fracture and pore system.

In addition to the distinct populations of response times due to two (or more) kinds of permeability, response times are shortened by high hydraulic gradients as measured by high peak discharges. This factor is illustrated in Fig. 19. The regression equation is

$$Q_0 = 33\,t_R^{-0.88} \qquad r^2 = 0.66$$

In a large aquifer the response time is related to many factors. This study has identified two of them.

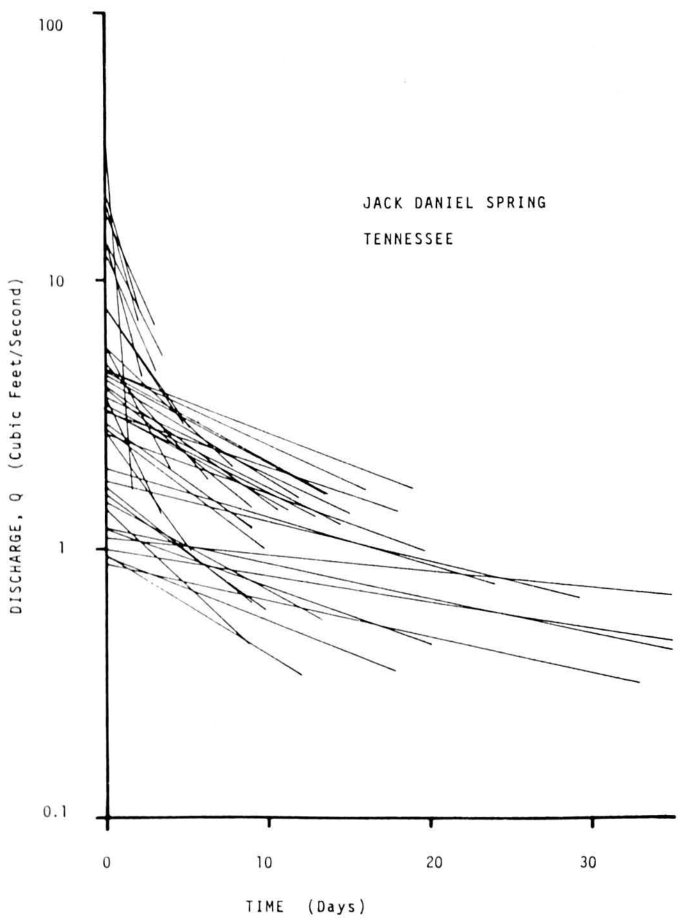

Figure 18. Hydrograph recession limbs for Jack Daniel Spring, Tennessee.

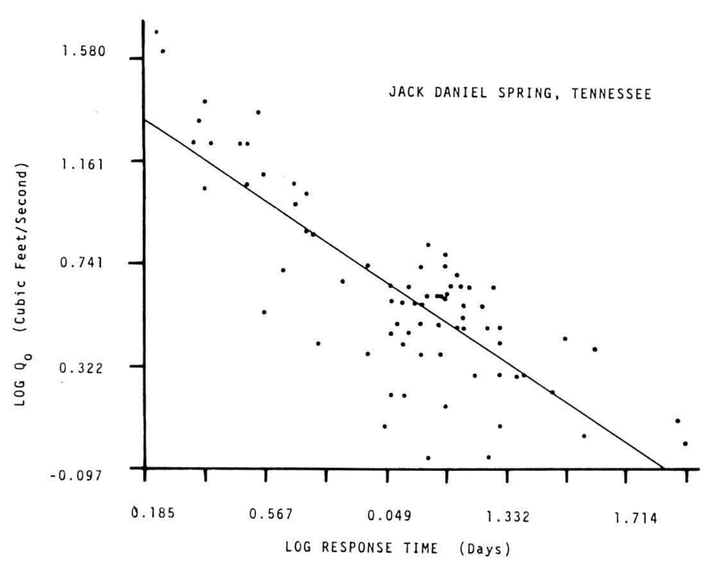

Figure 19. Comparison of response time to the discharge at the beginning of the recession limb.

Hydrogeology and Dissolution History of Alabaster Cave, North-central New Mexico

Kathy Hannaford, Alberto Gutierrez, Robert Lowy, Gassoway Brown III and Steve G. Wells

Alabaster Cave is located in north-central New Mexico near the junction of two major physiographic units, the Colorado Plateau and the Rio Grande Rift. The boundary between these two physiographic units is the Nacimiento Uplift. Early Cenozoic deformation produced north-south trending faults and folds along the Nacimiento Uplift and exposed the Jurassic Todilto Formation. The Todilto Formation is composed of laminated limestone overlain by bedded gypsum. Alabaster Cave is developed in the gypsum member of the Todilto Formation. The climate of this region is semi-arid. The flow conditions of Alabaster Cave are ephemeral with no permanent discharge.

Investigation of the present and past hydrogeologic conditions of Alabaster Cave consisted of 3 aspects: 1) analysis of scallops and flow conditions, 2) examination of dissolution features and cave passage morphology at various levels within the cave, and 3) examination of stream terraces and cave passage elevations.

Scallops and Flow Conditions

Scallop length and conduit dimensions were measured at 5 stations within Alabaster Cave. These measurements were used to determine past discharge conditions since the cave receives very little recharge at present. Sauter-means and resulting average flow velocities are given for the five stations in Table 10. Sauter-means ranged from 0.73 to 1.11 m/sec with a mean velocity for these stations of 0.85 m/sec. The calculation of average flow velocities does not imply that the groundwater was flowing at a constant velocity to produce the observed scallop morphology; rather, these were probably average maximum values since most preserved scallop development appears to have occurred at high velocities.

The conduit cross-section area and deduced velocities were used to estimate discharge for each station, assuming that the observed conduit was completely filled at some time. This is probably a reasonable assumption since scallops were observed on both the ceilings and walls of the conduit. Discharge estimates range from 0.268 to 0.445 m^3/sec with a mean of 0.384 m^3/sec. Such discharges were not constant but analogous to the flow of an ephemeral stream. The surface drainage area available to supply recharge to the cave is quite small and phreatic flow would not be in the range of the velocities deduced; thus, we infer that the water which formed Alabaster Cave came from a surface stream, the Arroyo Peñasco. Recharge occurred either as a sinking stream or as overflow events on the Arroyo Peñasco. Flow direction throughout the cave is southwesterly and parallels the flow direction of the Arroyo Peñasco.

Dissolution Features and Passage Morphology

Evidence for both phreatic and vadose flow conditions can be observed in Alabaster Cave. Evidence for phreatic dissolution consists of honeycomb passages which indicate undirected and saturated flow conditions. These phreatic features are found almost exclusively in the upper elevations of the cave. Features characteristic of vadose flow, such as meandering channels, occur in the lower levels of the cave.

Width-depth ratios of the cave passages were calculated for stations throughout the cave. Table 11 lists the width-depth

TABLE 11.

Width-to-depth ratios of cave passages

Distance from Main Entrance (m)	W/D Ratio
16.5	7.20
20.3	3.40
36.1	5.00
46.8	3.50
57.2	5.33
77.6	4.50
104.5	2.00
114.2	4.80
118.3	2.33
119.7	2.16
125.6	1.00
135.7	1.25
252.1	1.00
255.1	1.00
259.2	0.16
263.0	0.36

TABLE 10.

Summary of scallop parameters and flow conditions

Channel #	Sauter-mean L_{32}	Ave. Velocity $\overline{u}$	Flow Dir.	Diameter D	Area	Discharge
*3	4.68	.75		93	0.57 m^2	0.428 m^3/sec
*7	3.94	.905	S65W	73	0.39	0.353
*8	4.77	.725	S13W	76	0.37	0.268
*9	3.35	1.113	S40W	78	0.40	0.445
*10	4.74	.779	S12W	105	0.55	0.428

$\overline{Q}_{rel}$ = 0.384 m^3/sec

$\overline{V}_{rel}$ = 0.854 m/sec

ratios as a function of distance from the main entrance of the cave (or the recharge point). The data is plotted on a scatter diagram and a least squares regression is fitted to the data (Fig. 20). The correlation coefficient of this regression analysis is

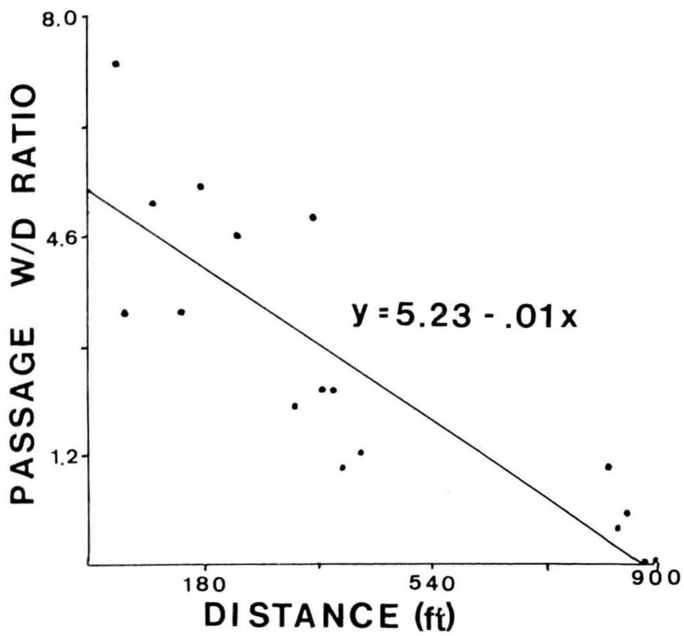

Figure 20. Comparison of width-depth ratios (W/D) to distance from the entrance of Alabaster Cave, New Mexico.

-0.814. Because of the small sample size, this correlation was tested for significance using an F-test (ANOVA) with degrees of freedom equal to 1 and 14. The regression F-value is significant at the 0.01 confidence level.

Width-depth ratios consistently decrease downstream. This consistent decrease suggests a falling baselevel and synchronous lowering of the karst groundwater. A critical problem in examining Alabaster Cave is that the majority of the cave has been extensively modified by collapse, making it difficult to visualize pre-existing conditions.

Stream Terraces and Cave Passage Elevations

Three terraces above the present stream level of the Arroyo Peñasco occur along the valley parallel to Alabaster Cave. Their longitudinal profiles are constructed by means of a plane table survey. The oldest terrace (Q1) is approximately 33.5 m above the present stream. Successive terraces, Q2 and Q3, are approximately 8.8 and 5.2 m above Arroyo Peñasco, respectively. The profiles of these terraces and the present stream level (Q4) are shown in Figure 21. The slopes of these terraces decrease with decreasing age from a slope of 0.0271 for Q1 to 0.004 for the present stream level. Two cave profiles are shown in Figure 21: one from the main entrance to the lowest outlet and one from the main entrance to a cave entrance on terrace Q3. We interpret the data in Figure 21 to mean that the northern portion of the cave was graded to the Q3 terrace during the past, and subsequent stream incision resulted in cave passage incision. This incision produced a steeper gradient in the southern portion of the cave (0.015 for the northern half and 0.020 for the southern half). Our interpretation of a lowering baselevel (based on stream and cave gradients) is supported by the width-depth ratios of the cave passage).

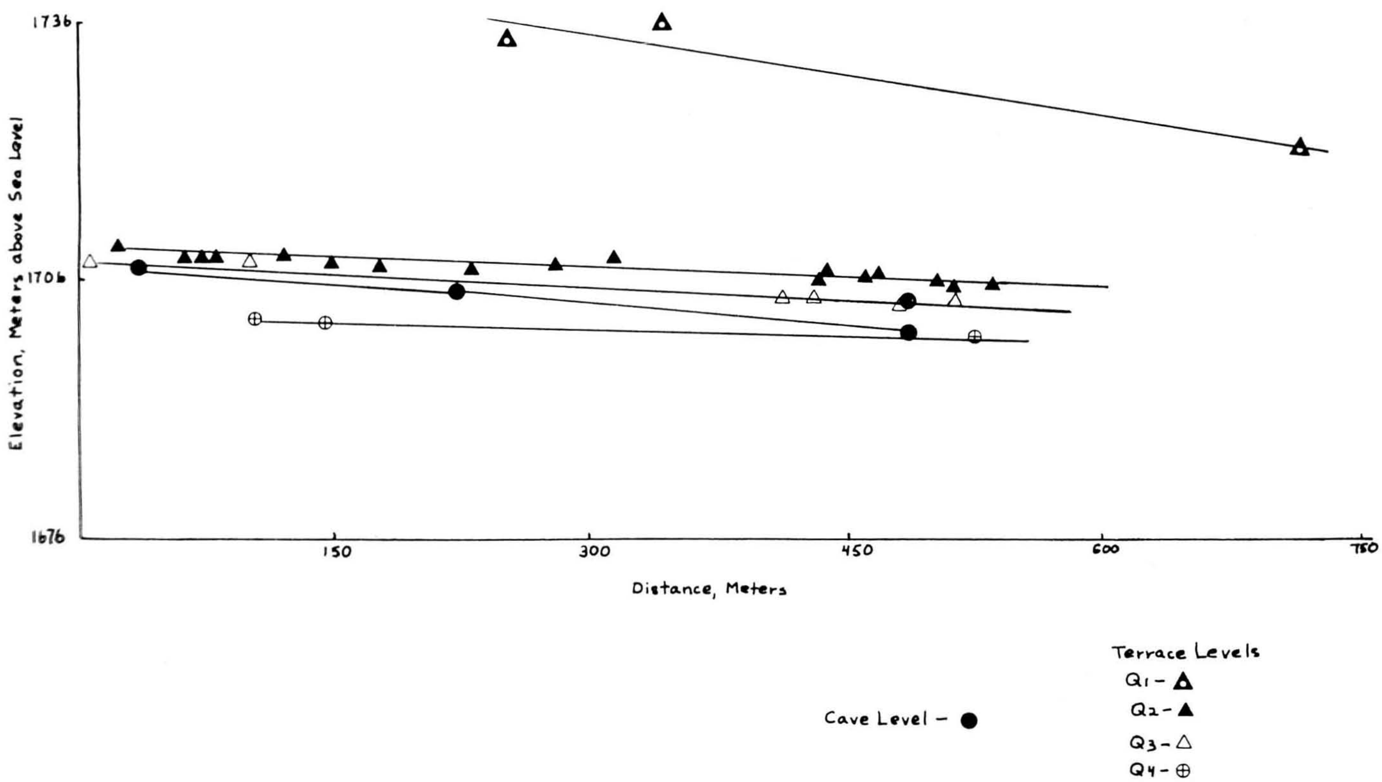

Figure 21. Longitudinal profiles measured on stream terraces along Arroyo Peñasco and on cave passage segments in Alabaster Cave.

Dissolution History of Alabaster Cave

A preliminary interpretation of the hydrogeologic history of Alabaster Cave can be presented from the data gathered so far. Passage morphology, dissolution features, and cave profiles reveal a complex history that includes both phreatic and vadose dissolution. Upper levels of the cave were dissolved under predominantly phreatic conditions of undirected flow. At this time the Arroyo Peñasco appears to have been at the Q1 level. Later, as the baselevel lowered and the arroyo began to incise, upper levels of the cave drained and collapse occurred within the phreatic passages. At a later time, when the arroyo was at the Q3 level, the majority of dissolution appears to have been under vadose conditions. There are two possible origins for this flow: an ephemeral sinking stream, entering at the main entrance sinkhole, or overflow from the Arroyo Peñasco during flood events. The absence of evidence for a sinking stream favors the overflow hypothesis. The collapsed upper passages were further modified to their present form and additional passages were formed at lower levels under this flow regime. Evidence for this regime includes the agreement of the upper cave gradient (dotted line in Fig. 21) with the Q3 surface, the estimated velocities and discharges that formed the observed scallops, and the observed passage morphology and dissolution features. As the arroyo has continued incision to its present level, the cave level has been adjusting to the Q4 surface in a manner similar to headward erosion in streams. The break-in-slope at approximately 180 m from the main entrance and the decreasing width-depth ratios of the passages in the downstream direction are the primary evidence for this phase of the dissolution history.

The existence of a pool at the Q4 level entrance (water entrance) and of laminated clay deposits at the Q3 level within the cave indicate that water backing up into the cave after flood events in the arroyo has played a part in the dissolution history of the cave and may be a contemporary cave-forming process. However, the extent of this effect is unknown at this time. Vadose dissolution features on breakdown blocks at the Q3 level and higher in the cave indicate that water levels may have fluctuated widely inside the cave; more detailed investigation of cave and valley features is needed to determine the importance and timing of these events.

Geomorphic Adjustments of Fluvial Systems to Groundwater Hydrology in Semiarid and Humid Karst

Steve G. Wells and Alberto A. Gutierrez

Low relief karst, which is characterized by integrated surface and subsurface drainage systems, occurs on Mississippian carbonate bedrock in central Kentucky and on Permian evaporite bedrock in southeastern New Mexico. In these two study areas, sinking streams recharge karst aquifers at the terminus of blind valleys. Temporal and spatial adjustments of these fluvial systems are complicated by groundwater responses to recent precipitation-runoff events and to Pleistocene climatic fluctuations.

The surface-runoff and groundwater-recharge relationships differ between fluviokarst systems in semiarid and humid climates. In the humid karst of Kentucky, sinking streams provide continuous recharge to karst aquifers; whereas, in the semiarid karst of New Mexico, flash floods provide discontinuous recharge to the aquifers. Hydrograph analyses of runoff events in humid fluviokarst systems indicate groundwater recovery times ranging from 10 to 20 days and sinking stream recovery times ranging from 3 to 5 days. Flow data obtained from field measurements and solutional-scallop studies in semiarid karst illustrate groundwater recovery times of 9 to 24 hours and sinking stream recovery times of 6 to 8 hours after a single precipitation event. In both areas, limited volume of the karst aquifers and rapid recharge from sinking streams increase the hydraulic head in the distal reaches of blind valleys. This ponding of groundwater increases the magnitude and frequency of overbank stage on sinking streams. Overbank sedimentation in humid karst develops wide alluvial valleys near sinking streams' termini. In semiarid karst, minor overbank sedimentation occurs, in part, because the rapid transmission of floodwaters prevents extensive ponding of water in blind valleys. The rapid increase in hydraulic head in semiarid fluviokarst produces groundwater flow velocities exceeding 1 m/sec. Alluviated surface drainages in semiarid karst display discontinuous runoff throughout a watershed for a given precipitation event.

Late Quaternary geomorphic history of both study areas involves successive lowering of base level. Periods of base-level stability are recorded as strath terraces on base-level rivers and as large, integrated cave systems sloping toward base-level rivers. Pleistocene base-level lowering resulted in capture of surface-subsurface drainages, shifts in groundwater and subaerial drainage divides, and abandonment of topographically higher groundwater levels.

Preservation of these geomorphic adjustments is not common in alluvial-fill sequences of blind valleys in humid karst; rather, the longitudinal profiles of sinking streams record these late Quaternary changes. Longitudinal profiles of sinking streams can be described mathematically and extrapolated beyond their terminus. The sinking streams grade to both active and abandoned groundwater levels beneath the present karst surface. Sinking streams near the base-level rivers have regraded their longitudinal profiles to the active groundwater level. Sinking streams farthest from base-level rivers have not adjusted and remain graded to an abandoned Pleistocene groundwater level.

In semiarid karst, arroyo incision and terrace development result from base-level lowering and subterranean capture. Sinking streams above blind valleys' termini are characterized by single, paired terraces, but below the spring outlets, fluvial systems are characterized by several unpaired terraces. Correlation of terraces in semiarid karst is complicated by the interdependence of surface and subsurface drainage.

Theory of Cave Origin and Karst Aquifer Development

William B. White

The work reported under this title is a continuing struggle for better, more encompassing, and more fundamental understanding of the processes that lead to the formation of caves, karst landforms, and the special permeability that characterizes karst aquifers. The analysis this year begins with some simple mass-balance considerations.

It is assumed that the carbonate rocks that support a suite of karst landforms and network of caves are of limited extent, horizontally. The boundaries within which mass balance is to be achieved are the watershed boundaries of a drainage basin. An observation point is assumed to be far enough downstream that no water or sediment sneaks by the gage by underground routes. It is further assumed that above the carbonate rock lie rocks of other lithologies and that a normal fluvial drainage was developed on these rocks before erosion cut down into the carbonate rock strata. If karstic drainage has developed to the point where much of the flow is underground, but surface streams flow during part of the year, a simple water balance can be written as sketched in Figure 22. Water flowing onto the karst from borderlands under-

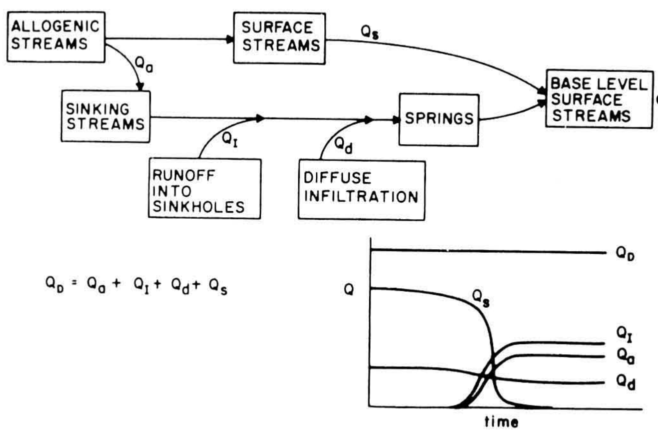

Figure 22. Water balance for a karstic drainage system.

lain by noncarbonate rocks will divide. Some will be lost in sinking streams forming one input to the underground system. The remainder will find its way to the gage by surface routes. Further contributions to the subsurface are derived by internal runoff into sinkholes and a diffuse infiltration component through the soils. All discharge returns to the surface drainage through springs upstream from the gage. The total discharge from the basin, Q_D, then is merely the sum of the individual components if the balance is done on long-term averages. Obviously, the rate of flow varies greatly among the different routes and the equation is not a valid instantaneous balance.

The relative contributions of the different flow routes to the total discharge as they vary with time are shown on the graph. The total discharge is assumed constant, which is equivalent to ignoring changes in climate over long periods of time. Initially there is only the surface flow and a diffuse groundwater flow component. As the karst develops, more and more water is lost to the subsurface. Q_S, the surface flow, eventually goes to zero and the internal drainage becomes responsible for the total discharge.

Throughput of water, mostly in surface drainage channels, carries away weathered rock material so that the land surface is gradually sculptured and lowered. There is sediment flow as well as the water flow and a mass balance can be written for the sediments (Fig. 23). One sediment stream follows the surface

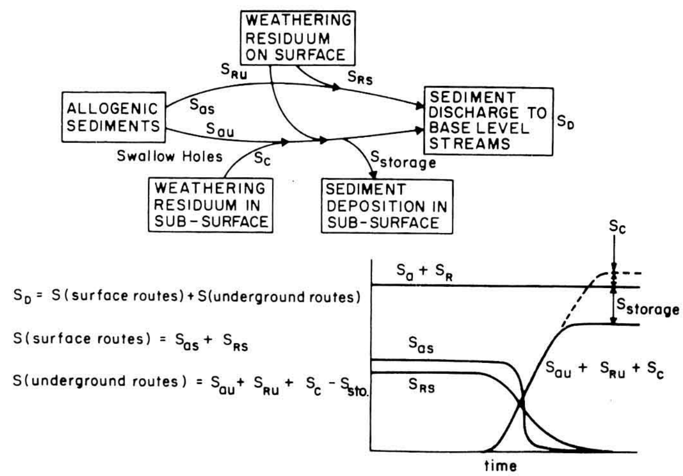

Figure 23. Mass balance for sediment transport in karstic drainage system.

channel as long as surface streams contain water. A second sediment stream follows the subsurface routes as soon as the water in the solution conduits is moving fast enough to transport it. The surface sediment stream contains material washed into the karst area from the nonkarstic borderlands and the weathered residuum left behind during the formation of the surface landforms. Allogenic sediments are also washed into the subsurface by sinking streams, and the subsurface sediment stream is augmented by surface material carried underground through dolines and by the weathering residuum from limestone dissolved during the formation of the conduit system. It is assumed here that no sediments are transported by the water moving through the diffuse flow system. The overall sediment balance also has a sink term: the possibility of silting up of pre-existing solution cavities so that sediments are placed in long-term storage within the rock mass and do not reappear at the observation point during the time scale of observation (e.g. a few tens of years). The sediment budget, as seen at the gage point, can contain either a surplus derived from the sediments added during weathering of the subsurface, or a deficit caused by sediment deposition in the subsurface.

Analysis of the evolution of a conduit system through the removal of bedrock by moving groundwater must therefore take into account three kinds of factors: the hydraulics of the moving water, the rate of chemical reaction between the water and the limestone, and the rate of mechanical transport of clastic sediment. Each of these has certain thresholds or triggers which are reached as the conduit system enlarges. By coincidence, it appears that all of these triggers are reached at about the same time.

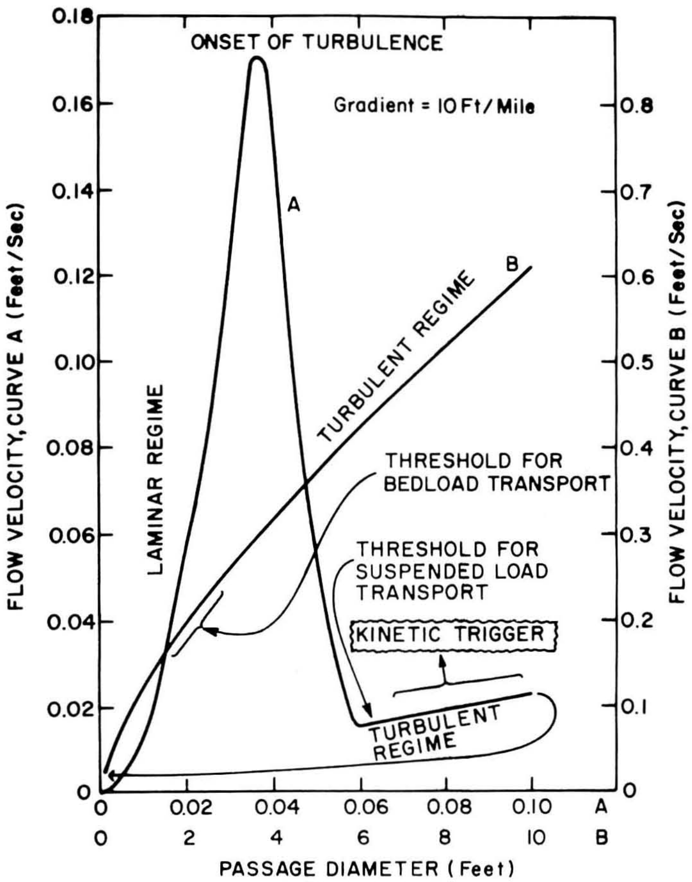

Figure 24. Threshold conditions in karst drainage indicated by flow velocity and passage diameter comparisons.

Figure 24 illustrates the situation. If a hydraulic gradient is assumed, the flow velocity through a "conduit" of specified diameter can be calculated. When passage diameters are less than 0.03 ft (about 1 cm), the flow regime is laminar, there is no sediment transport, and the solution kinetics are sluggish. As the passage grows, velocity increases until turbulence sets in, at which time there is a momentary decrease in velocity (shown in somewhat exaggerated form in Figure 24 because of the choice of scales). Then the velocity increases again, but at a slower rate with the water in a turbulent regime. With the onset of turbulence, it is possible for underground waters to carry suspended sediments. The threshold for the movement of sediment as bedload comes at somewhat higher velocities because of the critical boundary/shear needed to tumble the sediments along the bed. The flow regimes and sediment transport regimes suggest that openings in carbonate rock less than 0.1 cm in size behave as fracture permeability; whereas, openings greater than 1.0 cm in size behave as conduit permeability.

Recent laboratory investigations show that the kinetics of calcite solution increase very rapidly as the solution into which the calcite is dissolving becomes more undersaturated. There is a competition between the rate at which water moves through the carbonate rock mass and the rate at which limestone is taken into solution. Slow-moving water reacts to near-saturation before it penetrates very deeply into the aquifer, and the overall enlargement of the conduit is slow. As the conduit enlarges, water moves faster and penetrates farther before becoming saturated. It is argued that there is a critical conduit size that will permit water to flow entirely through the aquifer and remain below the critical level of undersaturation to permit rapid solution of the limestone (White, 1976). This is, in effect, a kinetic trigger which allows the favored conduit to enlarge at a more rapid rate than its neighbors, resulting in single conduit caves. For a given geologic setting it should be possible to calculate the rate of passage enlargement as a function of time. One such calculation has been completed. It begins with an open joint through which water at an initial CO_2 partial pressure of $10^{-2.6}$ atm is driven under a gradient of 10 feet/mile. Roughly 3000 years is required to enlarge the joint to the kinetic and sediment transport trigger dimensions. The rate of passage enlargement then increases by a factor of 100 over a relatively narrow time interval and only 10,000 years are required to produce a conduit of 10 feet in diameter. This time scale was calculated from an optimal set of conditions and is probably in the upper range of passage development rate, although it is not inconsistent with geological observations of cave formation since the withdrawal of the Wisconsin ice.

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Ecology Program

Figure 25. Grotto salamander in a cave, Buffalo National River, Arkansas. Photo by C. Welbourn.

Biosurvey Preliminary Report—Lilburn Cave, Kings Canyon National Park, California

Tom G. Campbell and Stephen M. Juarez

Preliminary floral and faunal surveys of Lilburn Cave were initiated in October, 1977, and are continuing at the present. The investigations have included collection and identification of vertebrate remains, stratified sampling of sedimentary deposits in the bottoms of vertical shafts near the entrances, and a survey of stream passages and lakes within the cave for troglobitic aquatic invertebrates.

There is a paucity of troglobitic and troglophilic organisms, but we have recovered some vertebrate material. It appears that the animals collected either became trapped after falling into the cave or were deposited in the cave by mud and water flowing into the entrance passages. All vertebrate material collected has been extant rodent genera with the exception of a Sierra Salamander. The salamander was collected upon death three months after its initial discovery.

A grid system has been established in the bottom of Telephone Pit. Exact location, depth, and orientation of fossilized plant and animal remains are being investigated in an attempt to determine a chronological record of the flora and fauna of the west slope of the Sierras. This should be possible if the sediments prove to be of significant depth and have remained undisturbed by hydrological events.

Two specimens of a troglobitic amphipod (Crustacea) have been collected from the underside of small rocks in a slow moving stream (lake) passage. One of the specimens collected is gravid. Both specimens lack eyes and pigmentation, and both exhibit iridescent spots on the side of the abdomen (see Fig 26). Difficulties encountered in obtaining pertinent literature have prevented comparison of these specimens with a previously described crustacean from another area of the cave. Future studies will attempt to determine the distribution and abundance of these amphipods.

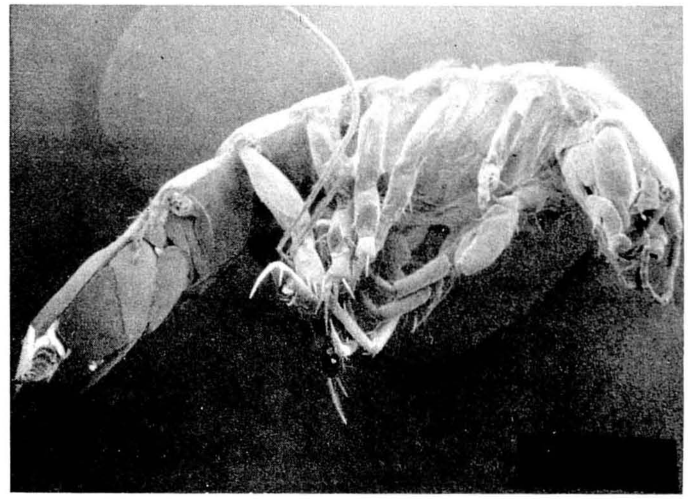

Figure 26. Troglobitic amphipod (Crustacea) collected in Lilburn Cave, California.

The presence of amphipods in the cave indicates a potential for the discovery of turbellarian platyhelminthes and other invertebrates. Continued sampling, including plankton net filtration of clear streams and downstream from stirred sediments, baiting, and direct observation are being conducted at this time.

Future studies will be directed towards various aspects of microbial and invertebrate ecology. The simplified trophic structure of this detritus fueled ecosystem lends itself well to studies of this nature. Resource availability and utilization will be studied, with special emphasis being given to diversity, competition, predation, and genetics. Similar considerations should be given to the troglophilic spiders and insects inhabiting the "twilight zone."

With standard techniques we have attempted to examine and sample throughout the Lilburn ecosystem in the hopes of turning up items that may be of interest to specialists in each area. Dr. William Akersten, curator of the Rancho La Brea Natural History Museum and a prominent researcher of rodent paleontology, has agreed to help. Drs. Lynda Harding and Bert Tribbey (both from California State University, Fresno) have also agreed to help with the microbial ecology and aquatic biology, respectively. Dr. David Zellmer (also at C.S.U.F.) has been kind enough to perform gamma ray spectroscopy using techniques similar to those he used in an analysis of Apollo 14 lunar samples. We are presently looking for a palynologist interested in examining soil samples from the Meyer Pit entrance. We are eager to turn over projects to workers who have skills that exceed ours.

The authors gratefully acknowledge the assistance given by numerous faculty and other persons at California State University, Fresno, especially Dr. David E. Grubbs and Peter Woodman. We would also like to thank the Cave Research Foundation for their patience and support.

Note: Any literature concerning previously described crustaceans from this cave would be greatly appreciated. See the authors' addresses in "Contributors to this Report."

Fossil Packrat Middens from Caves in the Eastern Grand Canyon, Arizona

Kenneth Cole

Fossil packrat middens, the debris left by several species of packrats (*Neotoma* sp.), can be used to date cave features and to examine the past vegetation from the vicinity of the caves.

Seventeen middens have been analyzed from the eastern Grand Canyon thus far. The ages of these middens range from 2,300 years to 18,630 years before present (Y.B.P.) as determined by twenty radiocarbon dates.

Ages of Cave Features

Packrat middens can be used in several ways to determine the ages of cave features. The age of a *Neotoma* deposit must not only postdate the feature upon which it is deposited but can also be used as a minimum date for the last deposition of speleothems in that vicinity. Packrat middens can be preserved for greater than 50,000 years in the absence of moisture, but speleothem deposition, or high humidity, will lead to the decomposition of the deposit within a relatively short time.

Pleistocene packrat middens are distinctive in that they are more well-indurated (harder), contain distinctive plant fossils, and are less odoriferous than younger middens. Using these criteria it is possible to distinguish between a Pleistocene and Holocene age midden (between 8,000 and 11,000 YBP the distinction is difficult).

Several caves in the Redwall Limestone along the South Rim of the eastern Grand Canyon have been surveyed for amberat. Three caves, Tse'an Cho, Tuning Fork Cave, and Crystal Forest Cave contain no Pleistocene amberat. The first two caves have entrances close to the surface of Horseshoe Mesa and have probably received runoff in the recent past. Crystal Forest Cave is directly underneath Tuning Fork Cave (Robert Buecher, pers. comm.) and has probably received moisture draining from Tuning Fork Cave.

Babylon Cave has several Pleistocene packrat middens, two of which have been radiocarbon dated at 13,540 ± 170 (A-1805) and 18,630 ± 310 (A-1798). The abundant speleothems in this cave probably date from well before this 18,630 year date since this time period was near the maximum of the Wisconsin Glacial Period and deposits would have been most likely to occur at 18,000 years than at any other time during the Wisconsin.

Cave of the Domes has few Pleistocene deposits for a cave of its size, but one has been dated at 13,865 ± 796 (A-1780). The entrance room where this deposit was found has been dry since this date, although decomposing deposits in most of the cave suggest moisture.

Tse' an Bida Cave is the most extensive cave in the area. The lower 700 feet of passage have been dry at least since the deposition of packrat middens at 13,780 ± 240 (A-1790) and 13,340 ± 150 (A-1806) YBP. The upper 250 feet of passage were probably subjected to periodic flooding from a wash near the upper entrance in the late Pleistocene. Two middens near the upper entrance were dated at 8,470 ± 100 (wk-145) and 10,150 ± 120 (wk-146) but older middens were not found in the upper rooms.

Vegetational Changes

The packrat middens record dramatic changes in the vegetation since the late Pleistocene. The four dated middens in Tse'an Bida Cave show a progression from a Fir Forest community (*Pseudotsuga menziesii* and *Abies concolor*) to a Pinyon-Juniper (*Pinus edulis* and *Juniperus osteosperma/monosperma*) community sometime between 13,000 and 10,000 YBP. By 8,400 YBP the community was dominated by Juniper, Prickley Pear cactus (*Opuntia erinacea*), and Agave (*Agave utahensis*), similar to the vegetation present today. This series suggests a progression toward a warmer and/or dryer climate.

The Fir Forest fossils are examined through time with respect to the variables of elevation and insolation (slope aspect and protection) in Figure 27. The lower boundary of Fir Forest was 2600 ft below its present distribution at 13,500 YBP. At 8,500 YBP the boundary had moved up considerably but was still 1200 ft below its present distribution as indicated by two fossils from 6200 ft in Bass Canyon, one of which was dated at 8,590 ± 110 YBP on *Juniperus* (wk-147) and 8,430 ± 300 on *Pseudotsuga* (wk-149).

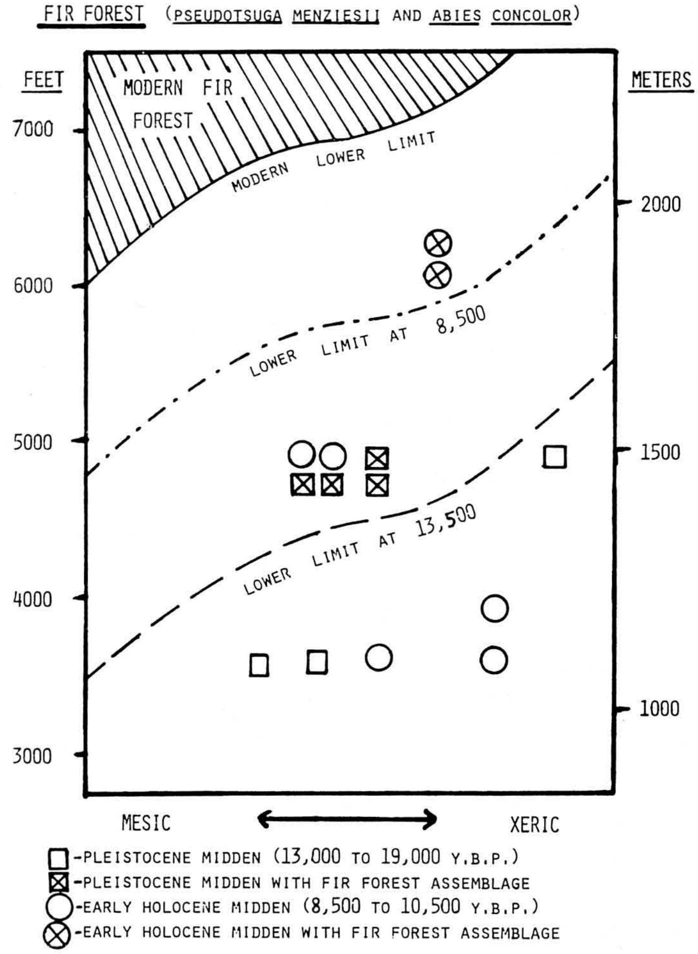

Figure 27. Shifts in fir forest assemblage on rim of Grand Canyon, Arizona.

This data indicate that although the climate of the area had become considerably warmer and/or dryer by the close of the Pleistocene (10,000 YBP), the vegetation (and hence, climate) did not approach its present state until after 8,500 YBP.

Further work is continuing on this project and has recently included the discovery of amberat in several higher-elevation caves in the Redwall Limestone in the Nankoweap and Clear Creek areas. These deposits indicate that a forest dominated by Limber Pine (*Pinus flexilis*), Spruce (*Picea engelmanii* and *Picea pungens*), and Common Juniper (*Juniperus communis*) occupied the higher elevations during the late Pleistocene in the Grand Canyon. These deposits are of special interest because Common Juniper and Spruce do not occur within the Canyon today, while the closest locality for modern Limber Pine is 50 miles from the Canyon.

Community Organization

Thomas L. Poulson

The continuing thrust of my research is to understand how systems constraints constitute selection pressures that shape species biologies which, in turn, constrain community organization. In other words, how do rigor, variability, and predictability of nutrient resources and abiotic factors affect life history, foraging, energetics, and genotypic and/or phenotypic flexibility in organisms? And, how in turn does the suite of species biologies favored locally affect the dominance-diversity patterns and guild organization in local component communities? Table 12 illustrates how I apply these ideas to the general differences between high and low energy availability of food types in caves. An article in the *Cave Research Foundation 1977 Annual Report* entitled "A Tale of Two Spiders" showed that the high food energy specialist *Phanetta* is time efficient with highly flexible rates of reproduction, development, and growth; whereas, the low-energy specialist *Anthrobia* is resource efficient with low and relatively inflexible rates of reproduction, development, and growth and shows clear habitat selection.

In this and past reports the following sets of terms are equivalent: 1) For energy and caloric availability, high = hot = high payoff = low rigor, and conversely low = cold = low payoff = high rigor; and, 2) for species life history patterns, high r (compound interest rate of population growth) = r^+ = live fast, die soon = time efficient, and conversely low r = r^- = live

TABLE 12.

Systems Constraints — natural selection — Species Biology — indirect constraints — Community Organization

I. "Hot" vs "cold" foods in general

A. High calories/m^2/month 1. Average value = "hot" 2. Seasonality (near entrances) a. Pulsed every year b. Abiotic risk = flood and/or dry-cold air (predictable) 3. Heterogeneity of food a. In time. Hot ephemeral and cool, longer lasting b. Little in space. Small, discrete patches and high gradient at edges	Fast growth = short life Time efficient = resource inefficient fast to find food, reproduce, grow, and enter resting stage until good times return in next season Physiological flexibility Developmental flexibility (time and size) Sedentary immatures *and* migratory or phoretic stage Many, small young (density-independent risks most important) and multiple reproductions per season Specialization to food (within and between species) but not habitat Specialization and/or to patch size by body size-lifespan (precedent in carrion and dung use outside of caves)	Within patch diversity low at one time Monopolization of hot part Even-aged cohorts so different sized species within and between patch size High densities so key predator might reduce monopolist and so allow more species to coexist? Successionally get less dominance as hot food used and more resource-efficient species arrive and/or use cooler portions Between patch diversity may be high With primacy have different colonists If no early colonist monopolization get different later species Different successional stages Between habitat diversity low since food patch buffers any microclimate-substrate effects
B. Low calories/m^2/month 1. Average value = "cold" 2. Low level of seasonality a. Gradual input and not every year or every place b. Little or no abiotic risk and that is predictable 3. Little food heterogeneity a. None in time. Cold and persistent b. Spatial. Large and diffuse patches, low gradients of density, and diffuse patch edges	Slow growth = long life Resource efficient = time inefficient efficient searchers but slow rates due to constraints of low energy foods; no resting stages Little physiological flexibility to abiotic risks Developmental flexibility in time but not in size Mobile at all ages Few, large young (density dependent energetic bottleneck for young) and single reproduction per season (but not every year): long life spreads risk of reproductive failure No food specialization (components resistant to decomposition similar regardless of type) Microclimate-substrate specialization	Within patch diversity relatively high No monopolization possible All size-age classes so different sized species of a guild impossible at a local level Always low densities Little or no succession; equilibrial Species separate by density of food within a patch Between patch diversity low Between habitat diversity moderate since no buffering of microclimate-substrate effects by dispersed food

slowly, die late = resource efficient. It will be useful to follow the evolution of my thinking on these matters in the 1971-1972 Cave Research Foundation annual reports. This 1978 report reflects the current state of my understanding and is especially explicit about whether there are distinct component communities and/or whether there are indirect constraints of systems properties on community organization by way of species biologies.

It is important to consider whether there really are component communities based on species specialization to characteristics of a food type, or whether the differences in species association are partly due to the discrete nature of food type patches in caves. It may be that the specializations are due to adaptation to level of energy availability irrespective of food type. I believe that there is evidence for both alternatives, but a definitive answer awaits the results of field food manipulations in which an unnatural food type, horse manure, is used as bait in forms that mimic natural food types in caves. To do this I will homogenize horse manure and then shape, size, and disperse it in patterns like raccoon, cave rat, cricket, and beetle feces (see right panel of Figure 29). My earlier studies showed that addition of a natural food type, leaf litter, to an open area attracts the expected specialists. The addition of unnatural horse manure repels cave fecal specialists, attracts different species than any of those associated with any cave fecal food type, and allows otherwise rare cave generalists to become highly dominant. However, these results are not conclusive proof of specialization to fecal types in caves since horse feces have consistency and size characteristics that do not even come close to matching those of cave fecal types.

With the above caveats in mind, let us consider evidence which bears on the hypothesis that there are component communities in the Flint Mammoth Cave System based primarily on species specialization to constraints of average energy avail-

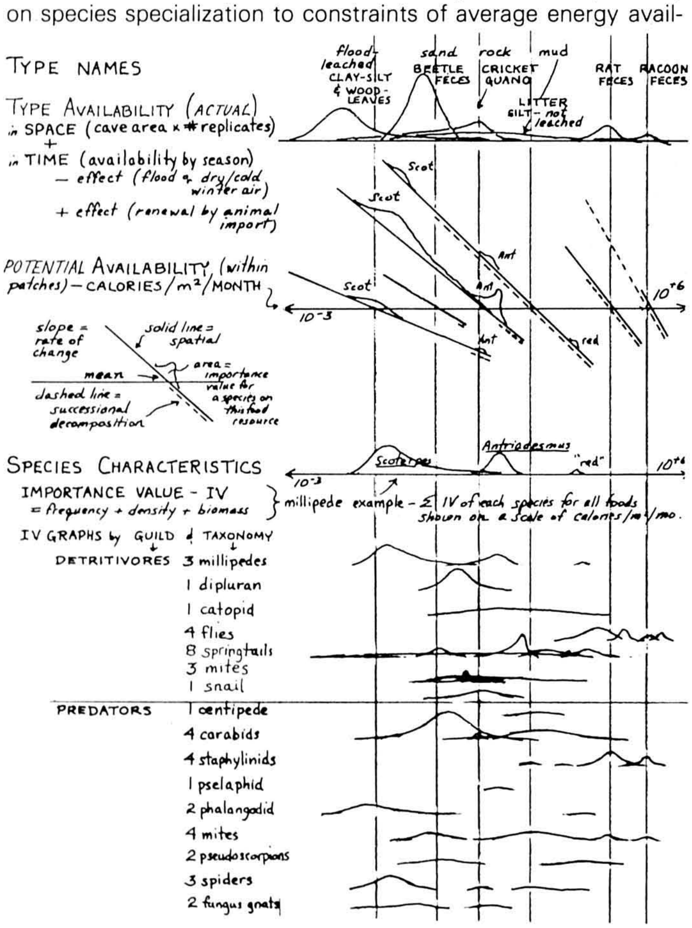

Figure 28. Potential energy availability of ecosystems.

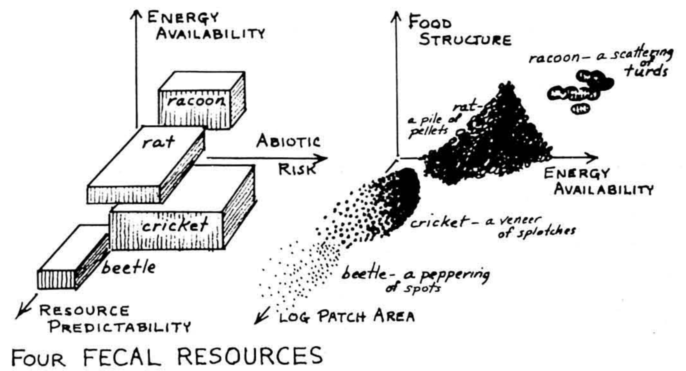

Figure 29. Four fecal resources in cave ecosystems.

ability of food types (Figure 28, and Table 12), and secondarily on structure, heterogeneity, predictability, and risk differences among food types (Figure 29 and Table 13). First refer to Figure 28 where all graphs are on a common scale from 10^{-3} to 10^{+6} calories/m^2/month. The top graph gives semi-quantitative values for the actual availability, as areas under the food type curves, for each food based on total occurrence in space throughout the cave. The second graph shows that the potential energy availabilities for the same and/or different patches of one food type overlap greatly with energy availabilities of adjacent food types. This overlap is either in successional = decompositional time (mainly the "hot" foods at the high energy availability end of the spectrum to the right), and/or in seasonal time and in space = dispersion (mainly the "cold" foods to the left). However, the overlap of actual availabilities is less since the cold and hot ends of each food type spectrum are less common than the mid ranges and since patches of some of the food types are relatively rare, small, and not usable because of high abiotic risk. Using data only for pure patches of each food type, we see that species importance values, as given by areas under each species curves on the bottom half of Figure 28, tend to be separated enough to suggest that there is specialization to food type as well as to energy availability per se. In fact, of the 44 species, 30 have 95%+ of their total importance value on one, 7 on two, 5 on three, and 2 on four of the seven food types. Let us now see how these figures are derived.

The importance value criterion for species specialization is a composite value based on distribution + abundance + biomass. Distribution is measured on a frequency basis by monthly samples over two years for at least two pure patches of each food type. Abundance is measured as density in number/m^2 for the same patches. And biomass is the best index of productivity, that is, rate of energy turnover, lacking comparable data for each species on generation times, growth rate, and metabolic rate.

Specialization is least clear for unleached litter and organic silt. This is the least available food type, the most heterogeneous, and the most often mixed with rat, cricket, and beetle feces in a compound community setting at cave entrances (in fact the I.V. data are for three m^2 patches artificially established to avoid the confounding problem of mixing). Furthermore, this food type occurs on a variety of substrates—including rock, sand, and clay-silt—which modify the litter-substrate interface accumulation of leachate and modify microclimatic factors such as moisture. It cannot be coincidence that a high proportion of the litter community in caves are facultative cave species, that is, troglophiles which also occur near the litter-soil interface outside of caves. They seem to maintain themselves in the cave by reinvasion from the surface, possibly every season in areas where abiotic risks of cold-dry winter air and flooding are prevalent. Paradoxically, the most available food type outside of caves is litter, and it may be

TABLE 13.

Systems Constraints—natural selection—Species Biology—indirect constraints—Community Organization

II. Fecal types (caves): All near entrances with some risks due to cold-dry winter air

II. Fecal types (caves): All near entrances with some risks due to cold-dry winter air

A. "Hot" = Raccoon feces 1. Seasonal. Unpredictable pulses in time and space 2. Heterogeneity a. Most hot but different dietary items (meat, fruit, nuts) + cool (keratin = fur of raccoon) b. large unit, folds, soft c. single unit = one stage of decomposition each unit	No dung burying guild Mobile, wide searching adults with alternative food sources? Fly maggot burrowers = colonists with group behavior in decomposition Late succession generalists from other component communities	Within patch diversity low → mod primacy = monopolization by first colonist → high density with intra- and inter-specific competition especially early in succession Between patch diversity high (see Table 12) also fungi dominate in cold-dry winter when flies not active
B. "Warm" = Pack rat feces 1. Seasonal. Predictable highs in time and place 2. Heterogeneity a. Continuum hot → cool based on diet (fruit, seeds, buds, leaves, grass, bark) b. small unit, hard c. pile with different units at different stages of decomposition d. top, central, edge + leachate trapped on rocks = food heterogeneity within pile	Specialization. Adults lose specialized dispersal mechanisms Species and life history stage separation by place in pile Hot-early and cool-late successional specialists Fungi important (not animal burrowers)	Within patch diversity high separation by space = stage of decomposition low local density so little competitive interactions (3-d nature of pile also mitigates competitive effects) coevolved interactions? —fungi with rat —consumers with fungi Little between patch diversity except at edges of pile where leaching differences etc. may affect species from adjacent communities
C. "Cool" = Cave cricket feces 1. Seasonal. Predictable highs in time and place 2. Heterogeneity a. All cool. Saprovore-scavenger feces have little undigested residues b. tiny unit, soft — veneers c. spatial differences in dispersion	Some sedentary specialists when food density is high but more mobile and longer lived species in areas of high dispersion Saprovores when rock retards leaching but grazers where fecal unit loses the moist portion quickly	Within patch diversity high separation in space = dispersion of feces over gradients in meters sedentary grazers + low density allows local differences with little competitive interaction Between habitat diversity based on substrate and amount of leaching and microclimate

the ancestral food resource for many troglobite species. These species are now specialized to fecal resources that are not common on the forest floor but are common and discretely distributed in the caves. It is in this context that I have maintained that cave decomposer communities can be studied more easily than those on the forest floor only because the forest has more food types, more mixing of food types, and more topographic, microclimatic, soil, and seasonal differences which affect availability of each food type.

The millipede species illustrate the general pattern for troglobites which occur on several foods but encounter similar energy availabilities on each. These species pick different times in successional decomposition or different places along a gradient of food concentration, and have most of their importance value and reproduction on a single food type. For *Scoterpes*, as shown by the areas under the curves along the sloped lines of potential energy availability in Figure 28, most of the importance value is centered on the cold = dispersed areas of cricket guano. *Scoterpes* has a low importance value on very dispersed, unleached litter that has completed any successional decomposition, and on fresh bits of leached twigs and leaves washed in through vertical shafts in occasional years and then deposited by gentle backflooding as veneers on cave passage walls and ceilings. Beetle feces are in the range of energy availabilities used by *Scoterpes*, but the sand where most beetles occur, associated with high densities of beetles' preferred food of cricket eggs, seems to be problematic for millipede locomotion and they avoid sand. Like *Scoterpes*, the troglobite *Antriadesmus* is an obligate cave millipede and specializes on cricket guano. However, compared to *Scoterpes*, *Antriadesmus* occurs on a narrower and hotter range of energy availabilities and has a higher percentage of its total importance on cricket guano. The rarity of the "red" flat-scuted millipede and its restriction to fresh litter are typical of troglophiles that regularly colonize entrance areas. These troglophiles may not persist there without seasonal renewal of litter by gravity or as imported by cave rats that use fresh litter as nest material. In summary the total I.V. for each millipede species is obtained by projecting the species I.V. curves for each food on line 2 onto a single line and summing the areas to give the overall curves shown on the graph of line 3. A similar procedure is used to obtain the overall curves for all the other species at the bottom half of Figure 28. It now remains to consider the mechanisms that result in the low overlap of I.V.s for related species and clustering of each species I.V. around a narrow range of energy availabilities of energy availabilities for single food types.

The low overlap values for the millipedes and other pairs, triplets, or quadruplets of potentially competing species could be due to species being preadapted to different food types before their invasion of caves, and/or to accentuation of ecological differences due to competition with species in the same guild that invaded caves at later geological times. In the case of the millipedes, the spiders reported on last year, and catopid vs dipluran reported on in 1975 and 1976, the specializations to differing energy availabilities are not the result of ongoing competitive exclusion. This is because 1) the colder food specialist of each pair grows more slowly on hot rather than cold food when alone and given no choice, and the opposite is the case for the hotter food specialist of the pair; and, 2) there is no change in patterns of growth or microdistribution, either in the field or laboratory with a spectrum of food dispersions available, when the putative competitors are alone vs together. However, neither of these results in itself precludes the possibility of specialization due to competitive interaction in the evolutionary past.

In the case of the millipedes, there is indirect evidence that *Scoterpes* and *Antriadesmus* can coexist on cricket guano because they were preadapted to differing energy availabilities by their ancestral habitats and because cricket guano occurs over many meters of lateral extent with clear gradients of energy availability based on dispersion of feces. There is a similar codistribution of an *Antriadesmus* and *Scoterpes* species in Tumbling Creek Cave in Missouri, but the codistribution is based instead on dispersion of bat feces. The foraging and life history differences that account for this Missouri-Kentucky convergence in different species are consistent with the hypothesis that *Scoterpes* invaded caves from a litter-soil interface habitat, and *Antriadesmus* invaded from a deep litter-endogeic habitat with more locally predictable and hot food. *Scoterpes* is a highly mobile searcher and reproduces on an irregular basis as adults find a patch of food slightly hotter than the level of energy availability required by adults. It may live 3-5 years and reproduce several times after the 3-4 year period of immaturity. In contrast, *Antriadesmus* is nearly sedentary and the entire population of adults mate in synchrony in spring. The adults die, and the young grow quickly, mature, and mate the next spring in the same place. Interestingly, the snail *Carychium* and pselaphid beetle *Batrisodes* are, like *Antriadesmus*, nearly sedentary, specialized to cricket guano, and have relatives in deep litter outside of caves.

To gain further insight into organization of component communities, let us consider not only general energy availability (Figure 28 and Table 12) but also food structure, dispersion pattern, predictability, and risk (Figure 29 and Table 13). To illustrate let us examine the differences among raccoon, rat, and cricket feces beyond their similarities of occurring near entrances where they are potentially subject to abiotic risk of cold-dry winter air. The cold air restricts usability and, along with seasonal differences in renewal, results in a seasonal cycle of availability.

The important systems constraints for cricket guano are homogeneity of cool and tiny fecal units which have gradients of dispersion under cricket roosts and are predictably renewed in time and space. Cave cricket diets mainly include rotting animal and vegetable matter, so there is little undigested residue in their feces and thus no successional decomposition. However, the community shows a seasonal succession with a late summer zenith in species diversity due to species that break dormancy late and/or reproduce slowly after the spring onset of renewal when crickets begin foraging outside again after their winter dormancy. One species, a saprovore springtail *Hypogastrura*, attains high densities on single fecal splotches if the splotches remain wet with little leaching, but densities of other cricket guano specialists are low, even on a local level, so there seem to be no possibilities for direct competitive interaction or important predator control. There are both tiny sedentary species on dense, thick guano veneers and small searchers where the feces are dispersed as single droppings. Searchers include the millipede *Scoterpes*, the dipluran *Plusiocampa*, and the phalangodid *Phalangodes*. Sedentary species include the millipede *Antriadesmus*, an oribatid mite, the catopid *Ptomaphagus*, the snail *Carychium*, and the pselaphid beetle *Batrisodes* that separate by local feces differences in thickness and moisture along centimeter distances. Thus the cricket guano community is structured horizontally by density of feces, moisture, and amount of leaching. The great differences between path diversity are based on: 1) the few cricket roosts which are both well buffered from rigorous microclimate change and protected from winter-spring drip and sheet wash on the entrance formations over which most cricket roosts occur; and, 2) the few cave entrance areas overlain by deep forest litter which seems to be the source now and/or in the past for deep litter-endogeic species like the millipede *Antriadesmus* and the pselaphid *Batrisodes*.

In contrast to cricket feces, both raccoon and rat feces are hot and heterogeneous. This results in successional decomposition, and a patch is dense with sharp mm to cm gradients in microclimate and state of decomposition. Thus, there are often high densities of organisms with few species in one patch and so predation, competition, and mutualism may be important in explaining community organization. Despite these common attributes, raccoon and rat fecal component communities differ greatly inter alia because of differences in food structure and predictability of renewal (Figure 29 and Table 13).

The important systems constraints for raccoon feces in caves are unpredictable renewal, and single, large, and soft fecal pellets that have a variable but mostly hot energy availability. On the forest floor rain and warm temperatures are constraints that select for fast utilization of various fecal types by a dung-burying scarabid beetle guild. However, in caves there is not enough dung for this guild and no risks of fast disappearance due to rain or extreme temperature, so troglophilic flies with mobile adults and burrowing maggot larvae are the only primary consumer specialists on raccoon feces. A large species of heliomyzid, *Amoebelaria*, dominate fresh feces as even-aged cohorts of maggots monopolize local regions of a fecal pellet. It may be that their collective activity keeps the feces liquid enough to facilitate a pharyngeal filter feeding mechanism that is known to allow other maggots to extract bacteria from the liquid feces. The heliomyzid maggots may be fed on by adults of a black staphylinid beetle whose larvae prey on maggots of psychodids or sphaerocerids that follow the heliomyzid in succession. It might be that predation allows coexistence of different maggots since the heliomyzids virtually destroy a fecal pellet when no staphylinids are present and then the psychodid or pshaerocerid stage of succession is much reduced or skipped. Instead, succession proceeds directly to generalist detritivores like the catopid beetle *Ptomaphagus*, the oribatid mite *Ceratozetes*, and occasionally with the pseudoscorpion predator *Hesperochernes*. Overlapping with this stage and continuing until decomposition is complete there are, depending on substrate and moisture, *Arrhopalites* or *Tomocerus* or *Hypogastrura* or *Sinella* as springtails and either a mesostigmatid or rhagidid mite as micropredators. Thus, there is less dominance with time since, as with other decompositional successions, the availability of any one nutrient type decreases due to incorporation in organisms, and interspersion with other types and with the inorganic substrate. Also, the last components to decompose are recalcitrant and cannot be monopolized by any species. This decrease in dominance also holds when raccoon feces are deposited in cold-dry conditions in winter when fungi are virtually the only decomposer organisms in and on the dung. In summary there are many between-feces differences in community composition locally and in between seasons due to differences in decompositional stage, the identity of the first and second fly colonist species, the mix of other food types in the immediate area, and the substrate, microclimate, and seasonal contexts in which the raccoon defecates. In contrast almost none of these considerations apply to the rat fecal component community (Table 13).

The diet of cave rats, *Neotoma*, and thus energy availability in the feces, is a greater mix of energy availabilities than for raccoons. There is more opportunity for decomposer specialization in rat feces, but the major constraint that makes this community different is the near absolute predictability of the fecal dumps in space, thus allowing equilibrial communities and potentially coevolved biotic interactions. Cave rats may use the same fecal dump for hundreds if not thousands of years, so each pile has all stages of decomposition. Many are large enough to provide microclimatic and structural refuges when feces are not being continuously renewed and/or are not as usable due to cold-dry winter microclimates near cave entrances. Thus for old, large piles there is no between-pile heterogeneity; every pile has the staphylinid *Quedius* and the small sciarid fly with apparently the same coprophilous fungi. Small, newly started fecal piles have the expected fungi but are a bit like raccoon scats in their animal composition; there are none of the large sciarid fly larva but there are often the small black staphylinid beetles, the catopid *Ptomaphagus*, and the springtail *Tomocerus*. The later successional rat fecal specialists, the large staphylinid *Quedius* and the small sciarid, arrive within a month and the flies associated with raccoon feces never occur. Apparently the maggots cannot burrow into the small, hard fecal pellets, and even the early successional coprophilous fungi have most of their hyphae on the outside of the pellets where they are grazed by larvae of the large sciarid fly, which are in turn preyed on by staphylinid beetles.

The species specializing on rat feces ensure success either by having resting stages and/or dispersal stages to move among piles. For the sciarid flies a winged adult is the dispersal stage; the staphylinid *Quedius* has lost its wings evolutionarily but its mobility seems to ensure colonization of new piles as long as they are in the same general area. For the fungi I presume that the rat disperses the spores and that they may even require gut passage for germination. This is true for coprophilous fungal spores in rabbits, which, like rats, have latrines that are predictable in space and so allow transfer of the spores from feces to the animal.

Deep within large fecal piles the 3-dimensional structure of spaces among the pellets provides refuge, especially for larvae of *Quedius* and the small sciarid fly, against the more severe microclimate and the more intense competition and predation at early successional stages at the surface of the pile. Thus the central parts of large piles have the most simple and predictable species composition, with no between-pile differences. Any between-pile species diversity is for species in dispersed fecal pellets and decomposed feces at the periphery of a pile or where the pile contacts a hard clay or rock substrate. A hard substrate allows local accumulation of leachate from decomposing feces and so favors a saprovore springtail and its tiny mite predator. On drier sites of loose sand-silt and under nearby rocks, a grazing springtail, *Sinella*, is locally abundant along with occasional individuals of two large predators, a pseudoscorpion *Hesperochernes* and/or a carabid beetle *Pseudanophthalmus*. These peripheral areas have interspersion of other food types and are thus a compound community. As is usual, more species occur and specialist importance values decrease when food types are mixed in a compound community setting.

Archeology and Anthropology Program

Figure 30. Prehistoric cane flute near proposed self-guided Mammoth Cave tour (thumb hole on opposite side not shown).

Cave Research Foundation Archeological Project and Shellmound Archeological Project, 1978

Patty Jo Watson and Kenneth C. Carstens

In April, 1978, CRF President Cal Welbourn and members of the CRF Archeological Project signed a contract with the National Park Service for archeological survey and testing of areas to be affected by implementation of the Park Master Plan. Field supervisor for this work was Ken Carstens.

During the past year we also completed the NEH grant (National Endowment for the Humanities grant #RO-26228-77-371) awarded in the spring of 1977 for archeological work in the Mammoth Cave National Park area and for our related research (the Shellmound Archeological Project) in the Big Bend of the Green River, 40 miles west of the Park (Watson, 1977). In March, 1978, we received a National Science Foundation grant to the Shellmound Archeological Project for fieldwork and subsequent analyses in the Big Bend region. Hence, while Ken Carstens' crew was working in the Park on the NPS contract in June and July, another crew supervised by Bill Marquardt was carrying out a variety of archeological and geoarcheological tasks in the Big Bend. The relationship of our work in these two places has been described in earlier annual reports, but may be summarized here as follows:

Ethnobotanist Dick Yarnell conducted a study of the prehistoric botanical remains that are well preserved in Mammoth Cave and Salts Cave. Evidence indicated that the aboriginal spelunkers were eating an unexpectedly large percentage of cultivated or semi-cultivated plants, as well as even larger quantities of hickory nuts, probably a staple diet item much of the year. The cultivated plants included squash and gourd, sunflower, sumpweed (a relative of sunflower), and possibly goosefoot weed (*Chenopodium*). The thick-walled fruits of squash and gourd were probably used primarily as containers, although squash seeds—nutritious and tasty if parched—were at least sometimes eaten. The squash and gourd are tropical plants, first cultivated somewhere south of the Mexican border several thousand years before they appear in the archeological record in North America, but the other species are native to North America. Yarnell's analysis of stratified plant remains recovered from our excavations in Salts Cave Vestibule suggested further that the native North American plants were being used in the early first millennium B.C., before the tropical plants were introduced (Yarnell, 1974). The intriguing possibility of a native North American horticultural pattern developing independently of the beginning of food-production in Mexico led us to the nearest archeological sites that would enable us to test that proposition: the Archaic shellmounds along Green River downstream from the Park. These mounds, long known to interested persons and partially excavated in the 1930s by WPA workers, overlap in age with the Indian activity in the big caves of Mammoth Cave National Park. However, the lower levels of the shellmounds were thought to be older than the remains in Salts and Mammoth Caves; therefore, stratified botanical materials from them should provide an excellent check on the MCNP subsistence pattern. In 1972 and 1974 we dug test pits at two of the mounds (the Carlston Annis site and the Bowles site, Bt 5 and Oh 13, respectively). Detailed examination of the botanical remains by Gary Crawford, a student of Yarnell's, documented a pattern quite different from that evidenced at Salts and Mammoth Caves (Chomko and Crawford, 1978). Squash was present before 2000 B.C. together with large quantities of hickory nuts and some other forest foods, but no cultigens or suspected cultigens (Watson, 1977). Since that discovery, we have continued our investigation of the cultural history of each region so we can eventually understand the origins of plant-cultivation in each, as well as the highly unusual expertise the central Kentucky aborigines had in exploring and mining parts of the Flint Mammoth Cave System.

Archeological activities during 1978 in both the Mammoth Cave National Park and Big Bend research areas are briefly summarized below.

I. Fieldwork in Mammoth Cave National Park

Most of the fieldwork done in the Park was in fulfillment of the NPS contract (section II below), but during the February 17-19 weekend, Washington University archeobotanist Gail Wagner led a tree-coring expedition to Blue Spring Hollow. She wanted to see whether the relict hemlocks that grow there show enough climatic sensitivity to enable use of their rings as climatic indicators, at least for the recent past. Two recently dead trees were cored, and the rings do show some promise of the required sensitivity.

During the same weekend, an archeological crew recorded some of the relatively abundant aboriginal debris (paleofecal fragments, occasional gourd and squash fragments, and quantities of torch and campfire remains) in the P and Q surveys near the Chapman Entrance in Upper Salts. A third group made a photo trip to Rider Haggard's Flight in Lower Mammoth Cave so that Roger Brucker could photograph the passages (complex, superimposed canyons like those of the S survey area in Lower Salts) and scattered Indian remains (charcoal fragments and torch smudges) there. The Indians probably went from the Wooden Bowl Room out Ganter Avenue to reach this passage and doubtless continued at least to Henry's Dome, but we lose their trail where the E survey becomes wet as it approaches the pit.

II. National Park Service Archeological Contract

A contract for archeological survey and testing in Mammoth Cave National Park in connection with implementing portions of the Park Master Plan was awarded to the CRF Archeological Project on April 15, 1978, in the amount of $9,015.50. After studying the Master Plan document, Patty Jo Watson and Kenneth Carstens prepared a proposal calling for archeological survey and testing in 8 areas of the Park as follows:

- Houchins Ferry
- Mammoth Cave Ferry
- Brooks Knob/Mouth of Buffalo Creek
- First Creek Hollow-Ollie-Wet Prong Complex
- Dennison Ferry
- Maple Springs Ranger Station
- Union City
- Colossal Cave

An intensive survey of the proposed self-guided tour from Violet City to Star Chamber portion of Mammoth Cave was also conducted in addition to the above surface areas.

All the field work was carried out between May 28, 1978, and July 3, 1978, as was the necessary cleaning and cataloging of finds, and preliminary analyses. The field supervisor for all these activities was Kenneth Carstens who worked with a crew of 4 archeological students. The fieldwork consisted primarily of surface survey, i.e., a search for archeological sites in the areas scheduled for development. However, test excavations (5 days) were made at a cave near the proposed Union City staging area (Fig. 31). A summary of results from the surveys and testing is provided below. The full and final report on this work is due to the National Park Service's Tallahassee Archeological Center by March, 1979. Carstens is writing this report.

Figure 31. Test excavations at site 15Ed49 (Charles McNutt, foreground; Darwin Horn, background).

Summary of Results

A total of 36 archeological sites were located during the surface reconnaissance. Eight of these sites may be affected to varying degrees when the Master Plan is implemented; however, only one site (15 Ed 79), located within the area slated for the Union City Staging grounds, will be affected directly (the site will be destroyed during the construction of the Staging Area). The remaining seven sites are located either within the vicinity of Union City (15 Ed 49 and 15 Ed 66), or are adjacent to proposed hiking trails in the northwest area of the Park (15 Ed 52 and 53; 15 Ed 72 and 73; and 15 Ed 76). Secondary impact to these sites could occur when "tourist-hikers" leave the immediate vicinity of the Staging Area or go off the foot trails for additional exploration (Fig. 32).

Test excavations occurred at one of the peripheral rockshelter/cave vestibule sites near Union City (15 Ed 49). An archeological

Figure 32. Large rockshelter site north of Green River that has been destroyed by relic hunters.

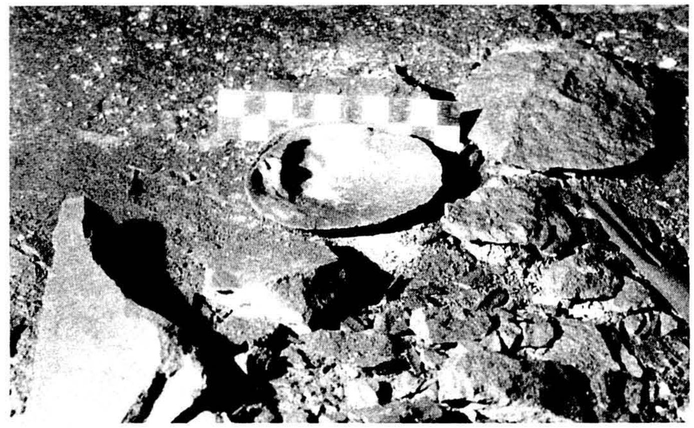

Figure 33. Unionid shell scraper *insitu* near proposed self-guided Mammoth Cave tour. Shell may have been used for removing various minerals from cave walls.

record preceding and consequent to the use of Salts and Mammoth caves is contained within the stratigraphy of this site. Of major importance at this site is a thick stratigraphical level of Middle Woodland cultural material (ca., 300 B.C. to A.D. 300). This level could provide information necessary for the understanding of post-Late Archaic-Early Woodland cultural dynamics in the Central Kentucky Karst for that time interval immediately following the use of the Flint Mammoth Cave System.

Finally, the area inside Mammoth Cave proposed for a self-guided tour (Violet City to Star Chamber, where an elevator was supposed to be put in) was found to contain sufficient aboriginal debris so that we recommend simply cancelling the self-guided tour proposal. There is significant prehistoric material in abundance, in and around the breakdown on the passage floor [mostly campfire fuel, but also paleo-fecal fragments, occasional big pieces of squash and gourd, cane torch bundles, textile fragments, unionid gypsum scrapers (Fig. 33), a cane flute (Fig. 30), and several possible aboriginal drawings (Fig. 34) on many of the higher ledges above the passage floor.

In sum, our recommendation will be to go ahead with all proposed developments where neither primary or secondary impacts to archeological sites may result (i.e., at Maple Springs, Dennison, Mammoth, and Houchin's Ferries, and the Buffalo-Brooks Knob area). Where impacts may result, additional site excavation and/or testing will be suggested (i.e., rockshelters within the First Creek Hollow-Ollie area and sites within or peripheral to the Union City Staging area). Construction of the Union City Staging area should not occur prior to extensive excavations at site 15 Ed 79. Further, an archeologist should be present whenever the ground is broken in any of the above proposed Master Plan developments.

III. Termination of the NEH Grant

Work supported by the NEH grant during the past year includes 1) analysis by Dick Yarnell of another series of charred plant remains from Salts Cave Vestibule; 2) completion of Gary Crawford's analysis of the charred botanical remains from the Bt 5 and Oh 13 shellmounds; 3) analysis by Gail Wagner of charred plant remains from five rock shelter and cave sites in and near Mammoth Cave National Park; 4) completion of a detailed catalog by biologist Ron Wilson of 113 fragments of prehistoric squash and gourd fruits from Mammoth Cave and Salts Cave, stored in various museums in the Midwest and eastern U.S.; 5) search by parasitologist Sharon Patton for parasites in human paleofecal specimens from Salts Cave (none found so far);

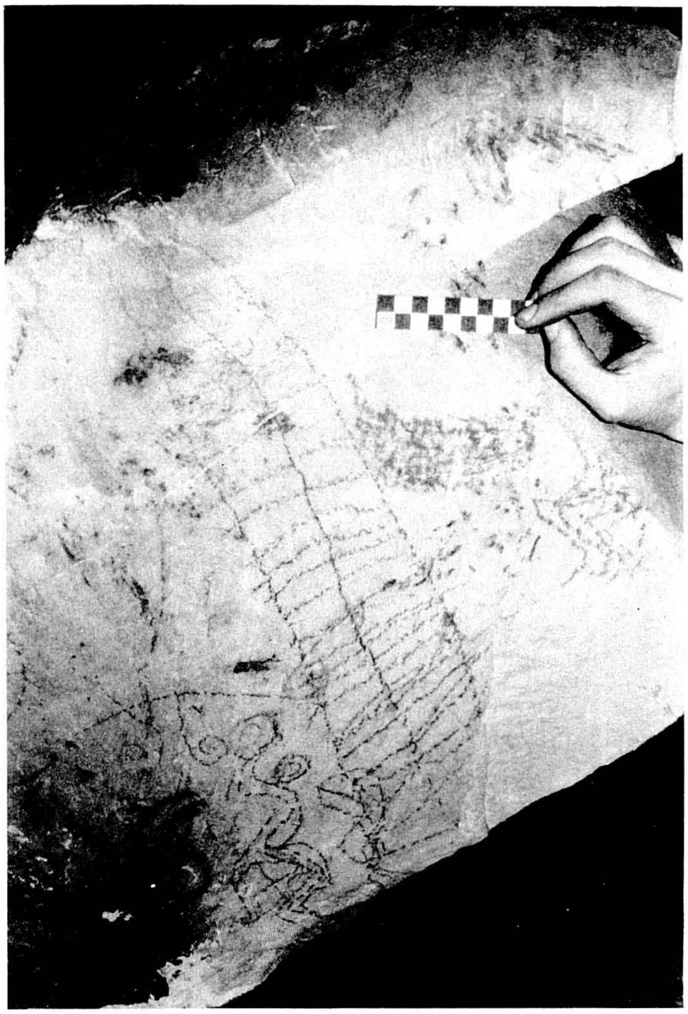

Figure 34. Probable aboriginal drawing near proposed self-guided Mammoth Cave tour.

6) pollen analyses by Vaughn Bryant and Jim Schoenwetter; 7) faunal analysis by Lathel Duffield and Greg Waselkov; 8) malacological analyses by David Baerreis and Diana Patch; 9) analyses of human skeletal remains by Louise Robbins and of the dentitions by Steve Ward; 9) completion of soil-augering transects at Bt 5 (the Carlston Annis shellmound) under the direction of geoarcheologist Julie Stein, who is preparing paleotopographic and isopach maps of the deposits (Stein 1978); and 10) flotation, water-screening, and microstratigraphic work at Bt 5 during June, 1978 (see section IV below). In addition, we received a preliminary report on the age of the pollen cores taken during October, 1977 (Watson, 1977). The ox-bow lake we cored was apparently cut off from Green River nearly 2000 years ago.

IV. The Shellmound Archeological Project

Activities carried out in the Big Bend were largely supported by the NEH and NSF grants mentioned above and include the soil-augering referred to in this section as well as a 7-week field season (late May to early July) centered on the Carlston Annis mound. During that field season we excavated four shallow trenches on the mound summit and one very long and deep trench at the mound edge, as well as carrying out geomorphological and botanical reconnaissance over the region between the Big Bend and the mouth of the Green River near Henderson, Kentucky. The excavated shellmidden deposit was either water-screened or floated, except for samples saved from each layer for David Baerreis's gastropod studies. Trench profiles were sprayed and recorded by University of Missouri graduate student, Linda Gorski, using a technique developed at the Ozette site in western Washington State by microstratigraphers Madge and Paul Gleeson. NEH funds enabled Madge Gleeson to spend three days at our camp early in June to aid Gorski in applying the technique at Bt 5.

Meanwhile, painstaking recording (large-scale mapping of all objects 2 cm or larger on trench floors dug at intervals of 5 cm) was done in the shallow trenches. This mapping included recording of dip and strike on all objects for which such data were obtainable. These data are being collated and manipulated statistically at the University of Missouri by Bill Marquardt and his student Alan May. The object is to enable as detailed an understanding as possible of the manner in which the midden was formed by both natural and cultural processes.

Acknowledgments

We are very grateful to Superintendent Amos Hawkins, Chief Interpreter Steven Smith, Chief Guide Lewis Cutliffe, and the other officials and personnel of Mammoth Cave National Park for their cooperation and their interest in our research within the Park. In the Big Bend, we are deeply indebted to Mr. and Mrs. Waldemar Annis, not only for permission to work at the Carlston Annis site but also for their very hospitable provision of a fine field headquarters; to Mr. John L. Thomas for his never-failing and invaluable aid in all logistical matters; and to the people of Logansport for their kindness and hospitality.

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HISTORY PROGRAM

Figure 35. Tributary cave passage to Hanson's Lost River, the Flint-Mammoth Connection. Photo by D. DesMarais.

Cultural Resources in Cedar Spring Saltpetre Cave, Edmonson County, Kentucky

Duane De Paepe

The saltpetre cave near Cedar Spring contains circa 1812 mining features similar to those in other regional nitre extractive operations (Fig. 36). Intensive mining activity is noted in the first 900 feet of the main cave trunk passage. A sandstone contact dripping spring at the entrance once percolated leachwater into the vat gallery. Stone causeways, ramps and trails probably originate at least in part from nitre mining, although it is not possible to separate these features from a later commercial attempt.

Of particular interest are hundreds of tally marks found inscribed on walls and ceilings in intensively mined areas. Such features have been reported in several eastern United States saltpetre caves, where they have been interpreted as quantification attempts by the miners at dig sites. Tally marks are uncommon in the Mammoth Cave region and have not been found in Mammoth Cave.

Mattock imprints are displayed in abundance throughout the mined area. Blade imprints are curved, approximately 2½ inches wide, and identical to those seen in Long Cave (Mammoth Cave National Park) and Wyandotte and Summer's Saltpetre Caves in Indiana. A mattock handle was noted in the air chamber of one of the hoppers, as was a paddle and torch material from the vat gallery. Rock sifting and shallow pit mining took place in floor breakdown, in addition to direct extraction from massive clay deposits. The shallow pit mining sites are identical to those in Blue Spring Branch in Mammoth Cave. In Cedar Spring Saltpetre Cave there is an association with rock sorting sites and tally marks displays. There are two distinct clay types found in the cave, and both were mined. Samples of each were collected during the current field investigation, and were processed under similar circa 1812 solutional parameters. An abundant nitrate precipitation was obtained.

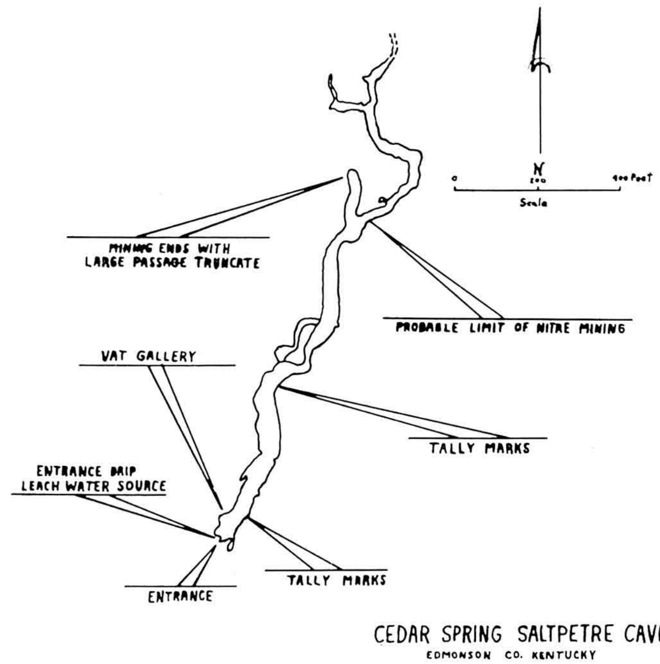

Figure 36. Map of saltpetre mining operations in Cedar Spring Saltpeter Cave, Kentucky.

Central Kentucky Circa 1812 Saltpetre Mining Investigations

Duane De Paepe

Progress continues in several aspects of the interpretation of circa 1812 saltpetre mining features in and around Mammoth Cave National Park. A particular highlight of the year was the first identification of a saltpetre artifact assemblage from Jim Cave, located in the park in close proximity to Long Cave. Fragments of a "V" notched log pipeline and dig site techniques suggest that this cave was mined under the same management as that of Long Cave. A preliminary evaluation has been sent to the park superintendent along with a recommendation that provisions be made for protection of these historic features. Field reconnaissance was also made in Short Cave and Hatcher Valley Saltpetre Caves, outside the national park.

In Mammoth Cave, studies interpreting the vat-pumping-pipeline system have been concluded. This effort has been integrated with available historic documentation describing the surface boiling furnace-crystallization works and has taken maximum advantage of recorded site specifics without archeological excavation.

Also completed is a literature and records search which has reconstructed an historical overview, placing the Mammoth Cave saltpetre operation in proper economic, transportation and technological context in the development of this widespread industry from Colonial America until the death of the last Confederate saltpetre miner in 1959.

Field work in Mammoth Cave has continued with the recording of ox cart route vestiges and nitre mining sites along the Historic Route. A section of well-preserved mattock imprints has been identified in the breakdown alcove at Methodist Church. Floor breakdown sifting sites in the Black Chambers are being compared with similar excavations in Blue Spring Branch and Harvey's Avenue to determine origin.

The Saga of Floyd Collins

Robert K. Murray and Roger W. Brucker

Floyd Collins, a Kentucky explorer, became trapped while crawling out of Sand Cave in January, 1925. A dislodged rock blocked his left ankle in a V-shaped groove in such a way that he could not pull loose. Rescue workers could not reach his ankle because the passageway was too small.

During the next few days workers fed Collins intermittently, arranged covers and finally a light bulb to keep him warm. They tried several ways to free him by digging, by pulling, and by jacking up the trapping rock. None worked. Then the ceiling collapsed.

Although workers could see the light bulb burning through the collapse, none were able to reach the victim. A shaft was started from the surface. Diggers encountered one unexpected delay after another, such as large boulders they felt would be unsafe to blast, collapsing shaft walls, rainwater runoff, cold weather alternating with thawing, and limited access room. When the shaft broke through into Sand Cave, Collins's dead body was found where it had been trapped. The cave was sealed, reopened two months later for removal of the body, then resealed.

In 1977 Murray and Brucker began a collaborative effort to do research on the history of this event. Both had been working individually prior to that time. In October, 1978, G.P. Putnam's Sons agreed to publish the resulting manuscript. The book, tentatively called *Trapped!*, is expected to appear in the autumn of 1979. Field work during early 1978 included an examination of Sand Cave, which was sealed in 1925 and resealed upon the completion of the current field investigation. Accounts of activities and descriptions of Sand Cave during the January-February, 1925 rescue attempts contained many ambiguities and contradictions. Cavers and historians have remained puzzled by these reports over the years.

As a result of National Park Service cooperation, extraordinary permission was granted to CRF investigators to survey and photograph the interior of this dangerous cave.

Sand Cave is formed almost entirely of spaces between collapsed breakdown blocks of limestone. It is wet, muddy, and made inhospitable by strong winds that blow through the single passage. Rocks fall from the ceiling in places. The passageway is small, averaging 0.5 x 0.5 m to its end about 35 m from the entrance and terminating in a gravel fill.

The new investigation revealed that it was possible to penetrate the ceiling collapse, and it would have been possible to have continued to feed Collins and work to release him from inside the cave.

Additional work has included interviewing participants in the event, writing, and editing the true saga of Floyd Collins and America's first media event.

CONSERVATION PROGRAM, INTERPRETIVE PROGRAM AND SPECIAL PROJECTS

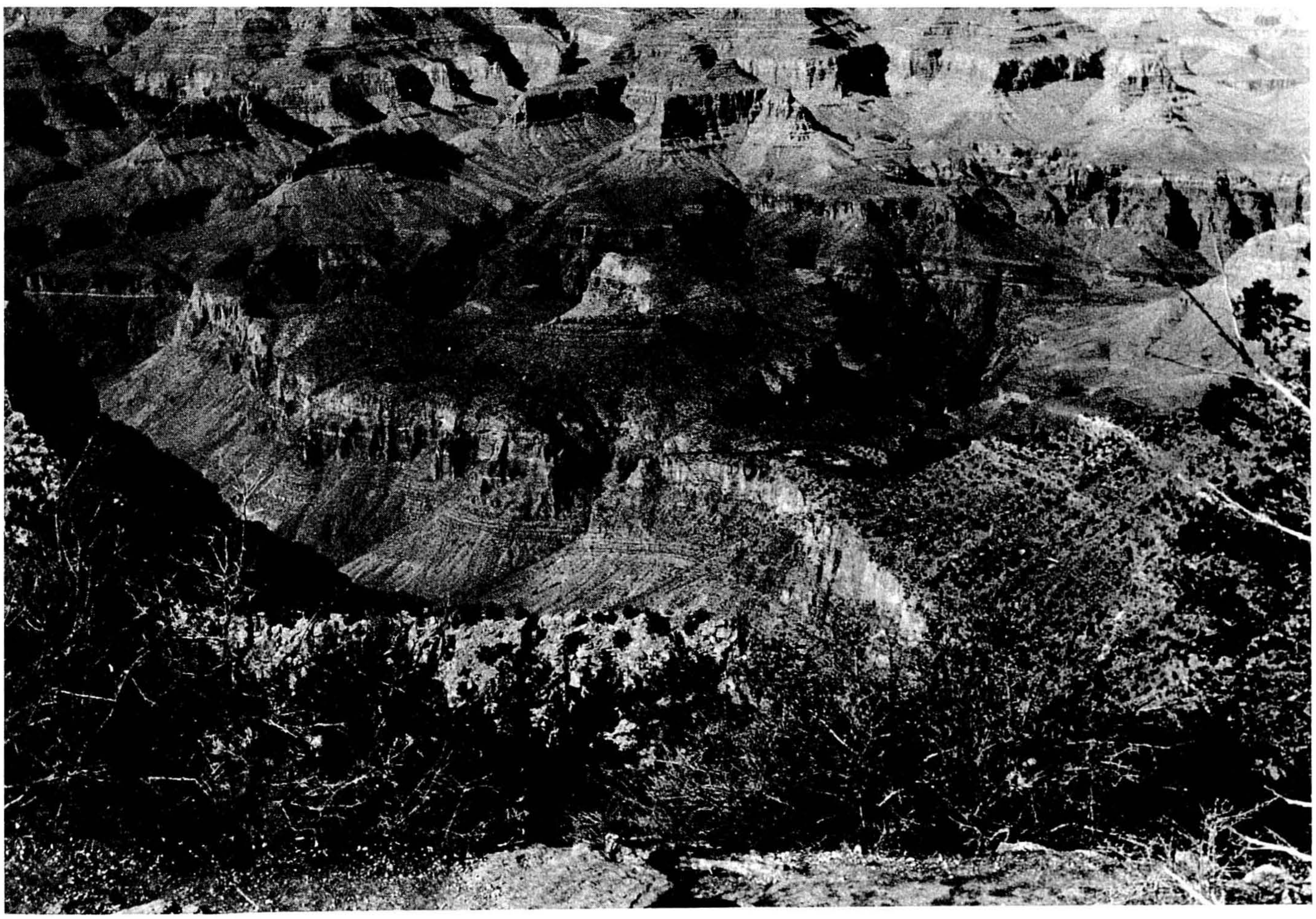

Figure 37. Caves developed in Redwall limestone (high vertical cliff) along edge of mesa. Horseshoe Mesa area in the Grand Canyon National Park, Arizona.

Conservation

Roger W. Brucker

Conservation activities were focused in three areas during 1978: 1) continuing efforts to help the National Park Service implement the Master Plan for Mammoth Cave National Park, 2) cleanup of trash from Floyd Collins' Crystal Cave, and 3) the establishment of a CRF cave location disclosure policy in contract studies.

Master Plan

As a result of disturbing reports that the Master Plan implementation schedule had been postponed for five years, Kip K. Duchon and Roger W. Brucker met with NPS South-East Region Director Joe Brown and his staff. At that meeting we reviewed steps to date and learned that the Master Plan had been stretched out. CRF presented evidence that the Master Plan was closer to gaining local acceptance than its opponents wished. We made suggestions for an alternative approach to the road-closing provisions of the Master Plan. CRF was promised nothing by the NPS but was told to watch for action.

Action followed quickly: the Park connected into a domestic water line from Cave City. It will enable the release of natural spring flows on Flint Ridge. The Park funded the archeology assessment of the proposed staging area at Union City on Joppa Ridge and also funded the Transportation Study. The transportation consultant later reported at a public meeting that he would recommend no road closings, because vehicular traffic would drop substantially when a new staging area is established. The recommendation was hailed by responsible local leaders who had feared that some roads would be closed in the Park.

In September, work was begun to tear down the old Mammoth Cave Hotel that had been built in 1925. Opponents of the Master Plan orchestrated a public outcry against this, and a local attorney obtained a temporary restraining order that stopped demolition.

One outcome of this controversy was a move by the NPS to transfer the Superintendent. At the same time, the main Master Plan opponent, the president of National Park Concessions, Inc., was claiming success in causing the Superintendent to be removed. CRF, the National Parks and Conservation Association, and friends intervened, and NPS Director William Whelan promised to stop the transfer.

Amid this clash, CRF discovered new Job Corps vandalism of speleothems, disclosed this to the newspapers, and, as a result, one Job Corps official claimed the camp would be relocated in two months. As this is written, a sewage line break from the Job Corps outfall has spilled effluent into the Three Sisters Hollow, and the Job Corps camp population is being halved.

We do not know the outcome of these struggles. Cal Welbourn described them at the National Cave Management Symposium in Carlsbad, N.M., on October 16; he cited them as examples of cave conservation political battles with an economic motive. CRF continues to urge that the Job Corps camp be removed.

Cave Cleanup

In 1954 the National Speleological Society conducted a week-long expedition to Floyd Collins' Crystal Cave. They left behind miles of telephone wire, food cans, equipment, clothing, sleeping bags, and trash. In 1977 Joint Venturer Curtis Weedman became concerned enough about the unsightly trash to organize several trips of volunteers to remove it. The idea grew, like Tom Sawyer painting the fence. On September 28, people—many of them from the Michigan Interlakes Grotto of the NSS—carried out about 250 pounds of trash. The cave resembles a wild cave again because of the cleanup. Weedman has promised to continue this project until all the trash is removed.

The project is having a favorable impact on the cave similar to the 1976 Sierra Club cleanup trip to Mammoth Cave organized by Joe Davidson and P. Gary Eller. That week-long trip resulted in 11 dump-truck loads of old trash hauled out of Mammoth Cave.

Cave Location Policy

A dilemma faced CRF: how could we report to National Park Service cave managers on the cave resources within their parks without revealing the locations of the caves to cave vandals? After considerable discussion, CRF implemented an experimental policy in its report, *Survey and Assessment of Cave Resources at Buffalo National River, Arkansas*. CRF held that since the study was financed jointly by the NPS and CRF, CRF would assert ownership of the cave location data. The NPS was advised to detach the cave location data and return it to CRF in the event the report was requested under the Freedom of Information Act, because it is CRF property. This policy has not been tested, but it seems to be a promising approach to the fact that cave location information is an invitation to vandalism.

Final Report of the Horseshoe Mesa Project, Arizona

Robert H. Buecher

The cave resources of Horseshoe Mesa, Grand Canyon National Park, Arizona, were investigated from April, 1977, through April, 1978, by members of the Cave Research Foundation. The final report of the project was submitted to the National Park Service in September, 1978. A limited number of copies of the final report have been produced. Persons wishing copies should be referred to the Cave Research Foundation by the National Park Service.

Management of the study was provided by the Cave Research Foundation in cooperation with the National Park Service. Funding of the study was provided by the Cave Research Foundation. Fourteen members and joint venturers of the Cave Research Foundation participated in the five expeditions during the project. 200 man-days were expended in field work and preparation of the final report.

The primary objective of the study was to provide the National Park Service with a comprehensive, descriptive survey of the cave resources on Horseshoe Mesa. The study provides a data base to aid in the management and preservation of the caves. Horseshoe Mesa contains the greatest concentration of caves in the Grand Canyon (a total of over one mile of cave passage). Results of the study are briefly summarized below.

Cave Descriptions

During the project a total of ten caves was investigated. Detailed descriptions were made for each cave. Plan and profile maps of each cave have been made and the caves are tied together by surface surveys. Previous maps by others were updated to modern standards. Total cave passage surveyed during this project is 2583 ft (787 m), and surface surveys comprise 5916 ft (1803 m). One new cave was discovered during the project and twenty additional karst features were located.

History

The history and early exploration of the caves, since their discovery in 1896, are traced. The factors which led to their exploration as a tourist attraction, and their sudden decline are examined. Patterns of early and recent visitation are reconstructed from historic signatures and from registers placed within the caves.

Archeology

Each cave on Horseshoe Mesa was entered and examined for archeological material. No new material was noted within the caves or around their entrance areas. One area of worked lithic scatter was recorded on the Mesa surface. Common features of caves in which split-twig figurines are found is discussed, such as location, entrance size and degree of difficulty.

Biology

Eight caves on Horseshoe Mesa were examined for cave fauna. The fauna associated with the caves are represented by 14 arthropods and one mammal. The species found have been listed according to their taxonomic status and their apparent relationship with the cave and its environment. Fauna is very sparse, especially when compared with data from other caves in Arizona and New Mexico. The single most important limiting factor for the cave fauna is the lack of moisture.

Geology

All of the caves studied are found in the upper 150 ft of the Mooney Falls member of the Redwall limestone. The largest group of caves, seven in number, extend 1100 ft along the west side of Horseshoe Mesa. The trends of these caves are controlled by a normal fault. The distribution of caves on Horseshoe Mesa is restricted and appears to be associated with minor faults of small displacement.

Management

Strategies developed for the management of caves on Horseshoe Mesa will be applicable to caves in other parts of the Grand Canyon. Management of the caves has two objectives: first, to preserve and protect the caves; and second, to interpret the caves to visitors and protect these visitors from hazards. The various options available for the management of the individual caves are discussed. These range from allowing uncontrolled access, permit systems, gates and highly restricted access for a few caves. An incremental program for the overall management of the caves on Horseshoe Mesa is presented.

Survey and Assessment of Cave Resources at Buffalo National River

W. Calvin Welbourn

The Buffalo National River was established in 1972 to preserve the free-flowing Buffalo River, along with 95,730 acres of spectacular Ozark Mountain scenery. As the new Park became established and a master plan was finalized, the National Park Service recognized the potential value of the cave resources. In 1977 the National Park Service and Cave Research Foundation jointly funded a 9-month survey and assessment of the cave resources. In that period 43 caves, 10 other karst features, and a preliminary list of cave fauna were inventoried.

In 1978, along with the completion of the final report of the earlier study, a proposal was submitted to the National Park Service to continue work through 1979. The proposal was accepted and jointly funded by the National Park Service and Cave Research Foundation for the period of September, 1978, to September, 1979. The goals in the 1978-79 project are to continue the description and assessment of the cave resources within the Park boundaries. The list of biological species will be expanded, with a special emphasis on gathering additional information on bats. In addition, the Cave Research Foundation will be looking at 6 major and 6 minor proposed development sites for cave resources. We will be assisting in the establishment of photomonitoring points in selected caves to aid in the Park Service cave management program.

Limited field work in 1978 resulted in the inventory of 19 additional caves and several karst features. Biological data were gathered in 5 additional caves, and new observations were made in several caves which had previously been examined at different seasons. With more than 60 caves inventoried, many additional leads to check, and known caves to be acquired by the National Park Service, the potential for all kinds of karst related research is becoming apparent. Future work will be to continue inventory of the cave resources and to initiate additional karst research.

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Figure 38. Simulated cave rescue operations in Great Onyx Cave, Mammoth Cave National Park. Photo by J. Grover.

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SPECIAL PUBLICATIONS

Lindsley R. Pete, Survey and assessment of cave resources at Buffalo National River, Arkansas, Cave Research Foundation, 106 pp, December 1, 1977.

Watson, Patty Jo, Early horticulturists of west central Kentucky, Report to the National Endowment for the Humanities on Grant RO-26228-77-371, September, 1978.

Fellowships, Grants and Research Projects

The 1978 CRF Karst Fellowship was not awarded; rather, three individual grants were selected, each a stipend of $300. These research grants were awarded to:

- Ms. Sara A. Heller, Ph.D. candidate, Department of Geology, West Virginia University, for her research entitled "A Hydrogeologic Study of the Greenbrier Limestone Karst of Central Greenbrier County, West Virginia".
- Ms. Ardith K. Hansel, Ph.D. candidate, Department of Geography, University of Illinois-Urbana, for her research entitled "Form as an Indicator of Process in Karst Landscapes".
- Ms. Barbara L. Dutrow, M.S. candidate, Department of Geological Sciences, Southern Methodist University, for her research entitled "A Study of Mammoth from a Karst Faunal Trap, Hot Springs, South Dakota".

A total of seven research proposals were submitted to the Foundation, and all were meritorious. Proposals were submitted from the following educational institutes: Indiana University, San Jose State University, University of Northern Colorado, and Northern Arizona University.

The following new research projects were initiated during the 1977-78 year:

- "Atmospheric Studies in Mammoth Cave National Park", Principal Investigator is Dr. Thomas J. Murphy
- "Biological Study of Caves North of Green River, Mammoth Cave National Park", Principal Investigator is Dr. James H. Keith.
- "Sedimentology and Stratigraphy of Clastic Deposits in Lilburn Cave, King's Canyon National Park, California", Principal Investigator is Dr. John Tinsley.
- "Biosurvey of Lilburn Cave, King's Canyon National Park, California", Principal Investigators are Mr. Tom G. Campbell and Mr. Stephen M. Juarez.

Visiting researchers included Dr. Paul Williams from the University of Auckland in New Zealand. Dr. Williams conducted a scientific tour of the major karst areas of the United States. Dr. Williams conducted research in the sinkhole plain near Mammoth Cave National Park in conjunction with Dr. James Quinlan. At Carlsbad Caverns National Park, Dr. Williams gathered information on infiltration measurements in the Guadalupe Escarpment region.

Field Operations

AREA	Number of Expeditions	Number of Field Days	Frequency of JV Attendance
Mammoth Cave National Park	35	111	395
Guadalupe Escarpment Carlsbad Caverns National Park Bureau of Land Management Lincoln National Forest	11	18	265
Kings Canyon National Park	5	13	132
Buffalo National River	3	10	46
Grand Canyon National Park Horseshoe Mesa	2	4	15

Management Structure

DIRECTORS

W. Calvin Welbourn, President
Roger E. McClure, Treasurer
Steve G. Wells, Chief Scientist
Charles F. Hildebolt, Operations Manager for the Central Kentucky Area
Roger W. Brucker
Rondal R. Bridgemon, Secretary
R. Pete Lindsley, New Projects Operations Manager
Robert H. Buecher, Operations Manager of the Guadalupe Escarpment Area
Elbert F. Bassham
Patty Jo Watson
David DesMarais

OFFICERS AND MANAGEMENT PERSONNEL

Guadalupe Escarpment Area Management Personnel:

Manager	Robert H. Buecher
Personnel	John S. McLean
Cartography	Joe Repa
Field Station	Ron Kerbo
Finance and Supply Coordinator	Linda Starr
Log Keeper and Survey Book Coordinator	Diana Northup
Safety	Don P. Morris

Central Kentucky Area Management Personnel:

Manager	Charles F. Hildebolt
Cartography	Richard B. Zopf
Field Station	Robert O. Eggers, Roger L. McMillan
Log Keeper	Jennifer A. Anderson
Personnel	Walter A. Lipton
Safety	Lewis Dickinson, M.D.
Vertical Supplies	Donald E. Coons
Supplies	Tomislav M. Gracanin

Lilburn Cave Project Management Personnel:

Manager	Stan Ulfeldt
Cartography	Ellis Hedlund
Personnel	Luther Perry
Safety	Howard Hurtt

Operating Committees

Administration Committee: Sets goals, identifies problems, and evaluates progress in the operation of the Foundation. Present membership is:

R. Pete Lindsley, Chairman
Rondal R. Bridgemon
Roger W. Brucker
David DesMarais
Patty Jo Watson
W. Calvin Welbourn
Steve G. Wells

Finance: Drafts Foundation budgets, provides advice to Treasurer, and seeks sources of funds to support Foundation programs. Present membership is:

Roger E. McClure, Chairman
Roger W. Brucker
David DesMarais
Charles E. Hildebolt
Stanley D. Sides
W. Calvin Welbourn
Linda Starr

Interpretation and Information: Deals with the dispersal of information in a form suitable for the public. The output of the committee has mainly taken the form of training sessions for guides and naturalists and the preparation of interpretive materials and trail guides for Park use. Present membership is:

Thomas L. Poulson, Chairman
Elbert Bassham
John W. Hess, Jr.
Carol H. Hill
Arthur Palmer
William B. White
W. Calvin Welbourn
Steve G. Wells

Conservation: Is the Foundation's liaison with all aspects of the conservation movement, including Wilderness Hearings, and maintaining contact with conservation organizations. Present membership is:

Roger W. Brucker, Chairman
William P. Bishop
Rondal R. Bridgemon
Robert H. Buecher
Joseph K. Davidson
John P. Freeman
Stanley D. Sides
Philip M. Smith
Richard A. Watson

Initiatives: Is a special committee charged with stimulating thought about "provacative and risk" future directions. Present membership is:

Ron Bridgemon, Chairman
Stanley D. Sides
Elbert Bassham
Patty Jo Watson
Steve G. Wells
Robert H. Buecher

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