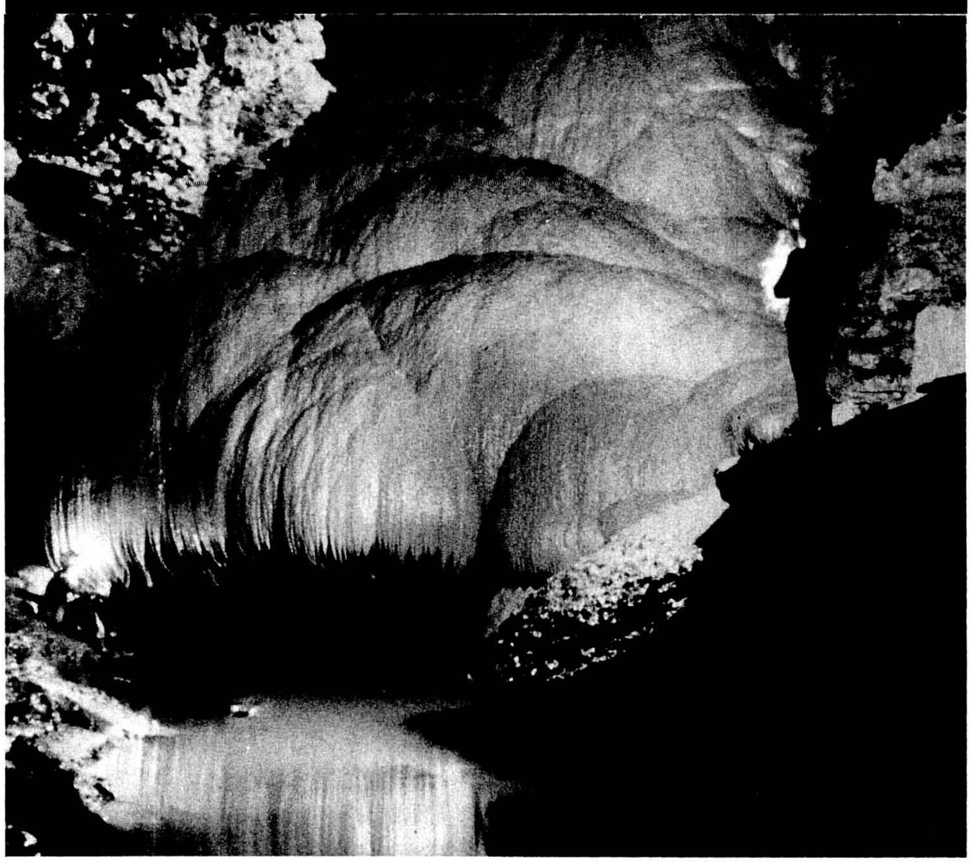
CAVE RESEARCH FOUNDATION

CAVE RESEARCH FOUNDATION 1979

Annual Report



Cave Research Foundation

1979 Annual Report

Cave Research Foundation
5507 Boca Raton
Dallas, Texas 75230

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.

Thomas L. Poulson
EDITOR
Bethany J. Wells
ASSISTANT EDITOR

COVER: The Hawkins River area under Doyel Valley of the Mammoth Cave System. This was one of the key areas in the connection of that part of the system under Joppa Ridge to that under Mammoth Cave Ridge. This connection brought the mileage total to 214 miles. Bob Buecher is to the left and Jim Goodbar to the right of this photo by Pete Lindsley.

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Contents

Acknowledgements

Many of the projects outlined in this report have been conducted within the boundaries of public lands. The support and encouragement of the superintendents and staffs at Mammoth Cave National Park, Carlsbad Caverns National Park, Guadalupe Mountains National Park, Sequoia-King's Canyon National Park, Jewel Cave National Monument, Lincoln National Forest, and Buffalo National River have contributed greatly to the success of these projects, and their assistance is greatly appreciated.

Kathleen H. Lavoie and Dr. Thomas L. Poulson's research was supported in part by The National Science Foundation.

Dr. Thomas C. Kane's research was supported in part by the American Philosophical Society.

Dr. Patty Jo Watson's Shellmound Archeological Project was supported in part by The National Science Foundation.

Kathleen H. Lavoie's bacterial studies were supported in part by The Ralph Stone Research Award from the National Speleological Society.

Barbara J. Martin's study was supported in part by a grant from the World Wildlife Fund of Canada.

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

Inventory of karst resources at Sequoia-King's Canyon National Park was supported by a National Park Service contract.

All of the projects in this report have been supported by the numerous CRF Joint Venturers that are the logistic backbone of our operation. Their enthusiasm and fellowship are especially appreciated.

Highlights of 1979

1979 was an exciting year in Kentucky as our knowledge of the cave increased and new discoveries and connections were made. The outstanding news concerned the simultaneous discovery of two sections of what probably is the largest underground river of the Mammoth Cave Area in Kentucky. Named Amos Hawkins River (after the Superintendent), the major low level stream passage passes under Doyel Valley and was the basis for the connection between Mammoth and Joppa Ridges. Mammoth Cave now connects to Proctor Cave and presently totals 214 miles of surveyed passage. Numerous side passages in the new area will probably add many more miles when surveyed.

Unfortunately the new river complex is polluted and dye traces indicate tributaries to the river are hydrologically connected to sinkholes near both Cave City and Park City. A large die-off of the crayfish population occurred just days before many of the river passages were explored, a grim reminder of the major importance of pure, unpolluted, underground water. Since even a small amount of pollution can have a major impact on the aquatic cave communities, the Foundation has become involved in numerous studies. The 201 regional sewage study is of particular importance to the headwaters of the Mammoth Cave region. The total destruction by pollution of Hidden River Cave is an example of what Foundation researchers hope to prevent in the Mammoth Cave region. The continued presence of the Great Onyx Job Corps Center on Flint Ridge, located over passages of outstanding mineralogical content, is a continued source of pollution which alters the cave's natural environment. Even the Green River, the base level of the Mammoth Cave Region underground streams, is of major importance in the study of the sensitive aquatic cave communities. An environmental assessment of the 1906 Lock and Dam No. 6 (which was deactivated in 1951) wasd published in January, 1980. The study emphasises that removal of the old structure would allow the water level in portions of the cave near the Green River to return to its natural base level and allow the restoration of previously altered cave communities.

In 1980 and 1981 we will see an increased emphasis on interpretation of the cave resource in the Mammoth Cave Region. Foundation scientists will be supporting Western Kentucky University and its Center for Cave and Karst Studies through a summer university program. Planning for support of the 1981 8th International Congress of Speleology, the first ever held in the United States, will be occupying the time of Foundation workers for over a year. Plans are being finalized for several pre-Congress and post-Congress field camps in both the Mammoth Cave Region and the Guadalupe Escarpment Area. Maintenance of Foundation field facilities will also see increased emphasis as the summer of 1981 approaches.

1979 was an important year for publishing data from the Guadalupe Escarpment area. The most complete map of Carlsbad Caverns was published following cartographic field work initiated in 1965 by Foundation workers. The Foundation also printed David Jagnow's thesis "Cavern Development in the Guadalupe Mountains", making available much new information on cavern development of caves in what is now an arid zone—a direct opposite of the underground stream-related cavern development of the Mammoth Cave area discussed above. Copies of the Carlsbad Caverns map, the thesis on Guadalupe Speleogenesis, and numerous other items of speleological interest are available from Cave Books, 1909 McGavock Pike, Nashville, TN, 37216.

Two other areas which have received major Foundation emphasis during 1979 are California and Arkansas, with field work continuing through 1980. Calilfornia workers are continuing studies of caves in the Sequoia-Kings Canyon National Parks Karst features. Arkansas workers have completed the field work for the second segment of the Buffalo National River karst inventory with over 100 caves in all being investigated. A second project, initiated in the fall of 1979 in the Sylamore District of the Ozark-St. Francis National Forests, will result in the detailed inventory and survey of 23 caves by summer 1980. Ins both California and Arkansas the information resulting from the intensive study and inventory of the caves will provide a key input to the managers of the caves and karst area. These projects have been supported by the National Park Service, the National Forest Service and the Cave Research Foundation. The Foundation, approaching 25 years of karst-related research, will continue to support all aspects of karst research through fellowships, grants, field support, and in-house studies.

Perhaps one of the most interesting challenges facing the Foundation at the start of the 1980's is improved data reduction, correlation and presentation. For instance, the cartography program has slowly lost ground as Foundation survey teams continue to generate field data at a faster rate than the passages can be drafted. Careful planning now with available computer technology is key to the future solution of the cartography dilemma.

In 1974 Foundation Directors established an Endowment Fund, interest from which would support the Foundation's research grants and fellowship program. The Endowment Fund is currently on schedule towards our goal of $25,000 by the summer of 1982. Your tax-deductible donations are welcome and will help support future karst-related research.

R. Pete Lindsley,
President-Elect

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Scientific Program

Limestone caves provide a unique natural laboratory in which to study important processes. Using a multidisciplinary approach, researchers from several fields often combine talents in the search for answers to general questions at the interface of two or more disciplines such as geology, hydrology, mineralogy, microbiology, archeology, anthropology, evolution, and ecology. In addition to these scientific fields, CRF personnel represent expertise in the social and applied sciences and in many professional fields from medicine to engineering and from art to advertising. The cross fertilization of ideas from such diverse approaches to problem solving often provides new insights which may lead to breakthroughs in the immediate area of research. At the very least this interdisciplinary sharing of ideas adds new dimensions to our view of the cave natural laboratory.

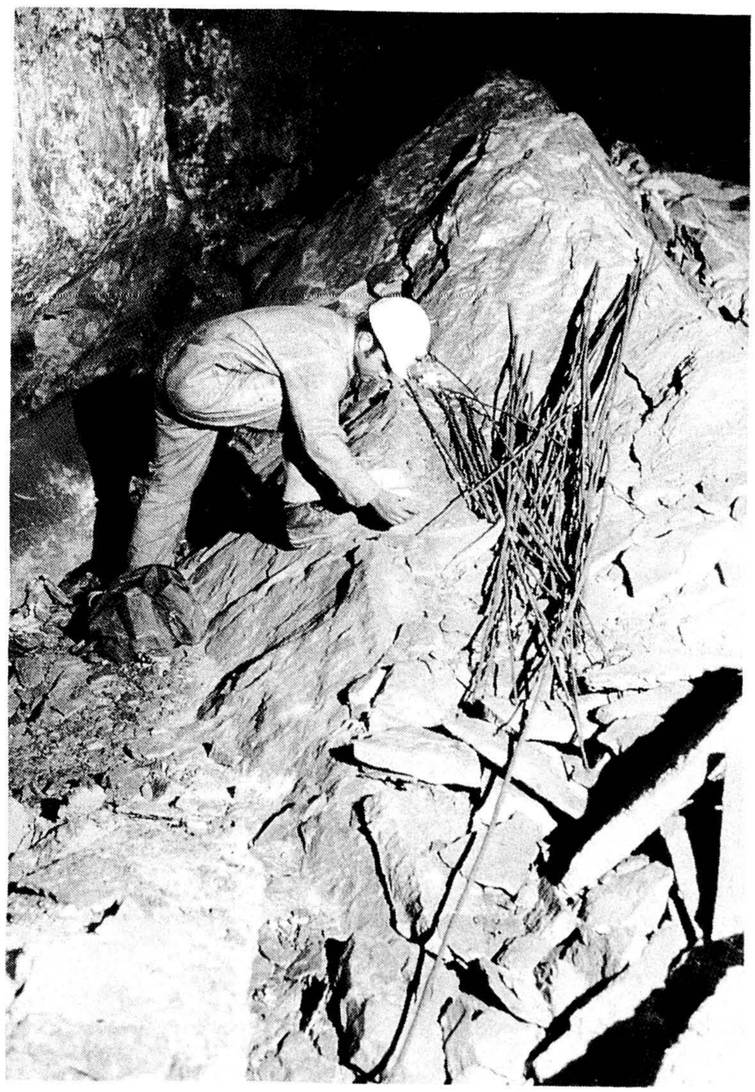

Figure 1. Indian torch-reeds in Lee Cave. Photo by P. Lindsley.

Cartography and Exploration

While exploring a cave, you often do not know where you are but only where you started from and (you hope) how to get back. A mountaineer can usually see where he *is*. Cavers usually have to wait until their surveys are turned into maps to know where they *have been.*

The cartographic program provides a framework—maps—on which all other underground studies are built. Cartography and exploration expand the natural laboratory physically and open new opportunities to scientists. Even though it may be more engineering and computer technology than other sciences, cartography is indeed research. The development of methodology and theory for the cartography of great cave systems—managing data, adjusting loops, producing maps—is itself a pursuit of magnitude and importance.

Figure 2. The Mammoth Cave Region "map factory." Richard Zopf and Roger Brucker check the course of a new survey in relation to surface karst features. Photo by Lynn Weller.

The Guadalupe Escarpment Region

Robert H. Buecher

In 1979 the majority of work in the Guadalupes was in Carlsbad National Park with additional work in caves managed by the Lincoln National Forest and the Bureau of Land Management.

A detailed map of Carlsbad Caverns at a scale of 1" = 200' was completed and published last year. The map is 18"x28¾" and printed on heavy yellow stock in three colors. It is presently being sold at the Carlsbad Caverns Visitor Center and by C.R.F. This map is the first half of a planned interpretive text and map. John McLean and Joe Repa spearheaded the effort to produce the map. The original map was drawn at 1" = 100' for field checking, before reducing it to 1" = 200'. Field checking and cleaning up survey problems were the primary objectives of several expeditions last year.

Joe Repa has completed a draft map of Lower Cave at 1" = 50'. The map is based on a theodolite survey that loops through Lower Cave with ties into Mystery Room and the Big Room. A connection between Lower Cave and the Boneyard was surveyed. An unsurveyed, possibly virgin passage was found to extend from the new survey approximately 400'. This new passage merits further work, but we must exercise care since this area of the cave is relatively fragile.

During the New Year's and February Expeditions the area between the Big Room and Scenic Rooms was surveyed. We should now be able to finish a draft map of all of the public areas from the Green Lake Room to the Big Room. Only the Green Lake—Iceberg Rock area requires survey for completing the 1" = 50' map between the Entrance and the Big Room. Pencil versions of the four 1" = 50' quadrangles covering the Big Room have already been completed.

Work also continued in the backcountry caves of the park. The survey of Scout Cave was completed on the Thanksgiving Expedition. A final version of the map was finished in February. Long-lost Rockslide Cave was discovered again and surveyed last winter. A draft version of the map has been completed.

Work also continued in Deep Cave with one trip at Thanksgiving adding detail to the draft map. The depths of the guano deposits in New Cave were studied by Darrell L. Connelly using seismic methods.

Ridgewalking and searching for new caves was the object of the Easter Expedition. Three days were spent ridgewalking in West Slaughter Canyon. Several entrances that had been spotted by helicopter were checked but no significant caves were found.

Surveying in Dry Pot Cave on Bureau of Land Management land was the object of the March Expedition. 1194' of passage were added to the survey.

Jim Hardy laid the groundwork for a future project in the Gypsum Karst by having aerial photos flown of the area. Prior work in the area was hampered by the large number of sinks and lack of landmarks. The photos provide an excellent framework for identifying and locating interesting features. Jim has already located over 400 entrances on the photos.

The Memorial Day Expedition was held in Lincoln National Forest where the survey work in Three Fingers Cave was continued. 620.7 feet were surveyed and a new virgin section of cave was found that ended in 70-100' pits. Carol Hill began a study to examine thoroughly the gypsum blocks in Cottonwood Cave. Gypsum blocks were measured to approximate height, width and volume. The end objective of this research is to determine the significance of the gypsum blocks to the speleogenesis of the Guadalupe Mountains.

Two major organizational goals were completed last year. First, all of our survey books were duplicated and catalogued by Diana Northup and John McLean. The file of survey books is brought on most expeditions. This gives us added flexibility in our map making efforts and for planning and assigning survey teams. Second, a rescue plan was developed by Don Morris and approved by the Park Service at Carlsbad Caverns. This plan details actions of C.R.F. members in the event of a cave rescue.

John McLean has stepped down as Personnel Manager for the Guadalupe Escarpment. Doug Rhodes will be taking over his duties.

Our goals for 1980 include: finishing a draft version of the 1" = 50' map of Carlsbad Caverns, working on an interpretive text for the back of the 1" = 200' map, and starting a folio of backcountry caves.

The Mammoth Cave Region

Richard Zopf, Lynn Weller, Tomislav Gracanin, Thomas Cottrel, and Roger Brucker

Although CRF personnel in the Mammoth Cave Region have occasionally worked outside MCNP boundaries, the discovery of a major river system extending east from Proctor Cave has extended the regular cartography program outside the park. Over six miles of survey, a new entrance, and the connection of this system with both Proctor Cave and Mammoth Cave have made this area the highlight of 1979.

These discoveries have increased participation in the cartography program, ended three years of declining survey totals, and increased threefold the miles surveyed over last year. (Fig. 3). Over fourteen miles were surveyed underground and the present length of the Mammoth Cave System is 214.52 miles. Renewed efforts in the New Discovery section of Mammoth Cave and more usual work throughout the system also contributed significantly to this total.

Reduction of survey data and production of maps continue slowly. Our field map of Proctor Cave was finished and the development of new procedures for map production is being investigated.

In Flint Ridge, a steady effort to "clean up" leads in Salts Cave has produced the bulk of Flint Ridge surveying this year. Passages are rarely virgin or extensive, but work continues to be productive. Rigdon Pit, a small cave in the northwestern section of the ridge has begun to be surveyed; joint ventures still have not descended the final drain. Trips throughout the ridge continue to add to our survey totals but have yielded no breakthroughs.

One quarter of the survey trips in Mammoth Cave this year went to New Discovery and produced over half of the Mammoth Cave mileage. An extensive, active drainage system in the southwestern area is still being delineated. A new segment of large passage was found heading northwest. Party after party continues to unravel the maze along the Roaring River route. Other surveying in Mammoth was without fanfare. A connection was found between Miller Avenue and Kentucky Avenue via Bishop's Domes. Survey is growing rapidly in the Cocklebur area which promises to be a significant area in 1980.

In Joppa Ridge and eastern areas, efforts to survey loose ends in Proctor Cave prior to completion of the field map took several parties down a series of pits and ultimately led to the discovery of a major river. At the same time, independent parties, which included CRF cavers, were exploring Morrison Cave, which is just outside the park boundary. They too found the river system which more recent surveys have integrated and expanded. Most explorers feel we have just begun to map the largest parts of the system, and vast amounts of passage remain to be explored.

In terms of map production, the Proctor field map is up to date; the New Discovery map is being augmented and a field map of the new river system is growing rapidly. The Cleveland Avenue field map has been increased to show Miller Avenue and Mystic River Tributary. Efforts have gone into updating some of our log books, and the realization that we are not converting data to maps quickly enough has hit hard enough that serious thought is being given to new data processing means which will not depend on individual whims.

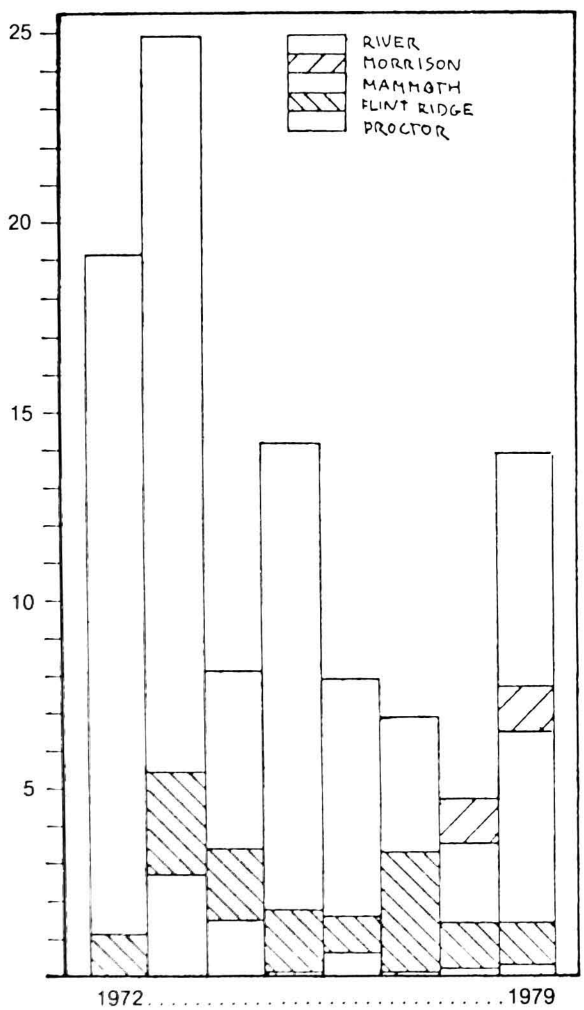

Figure 3. Miles surveyed in the Mammoth System each year since the Flint-Mammoth Connection.

The King's Canyon National Park Region: Lilburn Cave

Ellis Hedlund

More traverses were made on the surface in Redwood Canyon to locate the numerous karst features relative to the subsurface survey network in Lilburn Cave, Cedar Cave, and May's Cave. The 1979 traverse surveys came down to the northwest of the high karst area. This lower Redwood Creek karst portion comes to within 3.4 km north of Lilburn Cave where Redwood Creek ponds in dry years. This increased our traverse surveys by 1.3 km; the new total is 5.72 km.

Surveying in Lilburn Cave proper was in the northeastern part, i.e., the Meyer Entrance area. Most of this exploration and mapping was in a complex maze of passages.

Notes on the caves and rock shelters of Ohio

H.H. Hobbs

The first mention of Ohio caves appeared in four separate articles in 1838 (Atwater), (Hildreth), and (Locke a and b). However, it was not until 1895 that any systematic approach was taken in the study of caves of Ohio (Moorehead, 1895). Twenty-one years elapsed before Hills (1916) made a detailed description of Reames Cave (Ohio Caverns), and in 1926 White published his master's thesis in which he described 29 "limestone caves and caverns." Various workers explored, unearthed archaeological remains, and occasionally mapped some of the caves and shelters within the state. In 1952 the Central Ohio Grotto of the National Speleological Society, in cooperation with the Ohio Geological Survey, established "The Ohio Cave Survey" (Smith, 1953). The survey was organized for the purpose of gathering data concerning the "general description of the caves,

Figure 4. Entrance to Snow Cave, Franklin County (a "typical" small Ohio cave).

their locations, and a discussion of the geological features of the caves" (Smith, 1953). The survey has experienced periods of quiescence and activity since its origin. In 1953 Verber and Stansbery published a description of the caves in the Lake Erie Islands and others, primarily from the N.S.S. Central Ohio Grotto, periodically continued exploration.

Ohio's caves and shelters are developed in Silurian, Devonian, Mississippian and Pennsylvanian rock in 56 counties.

"Generally all are rather small (maximum length of 550 meters); caves developed in limestones and dolomites are restricted to the Silurian and Devonian stratigraphic units in the western half of the State [Fig. 5], whereas shallow shelter 'caves' are formed in the Mississippian and Pennsylvanian sandstones, shales and conglomerates of southcentral and northeastern Ohio" (Hobbs, 1979).

Little is known concerning the fauna of Ohio's caves. Three

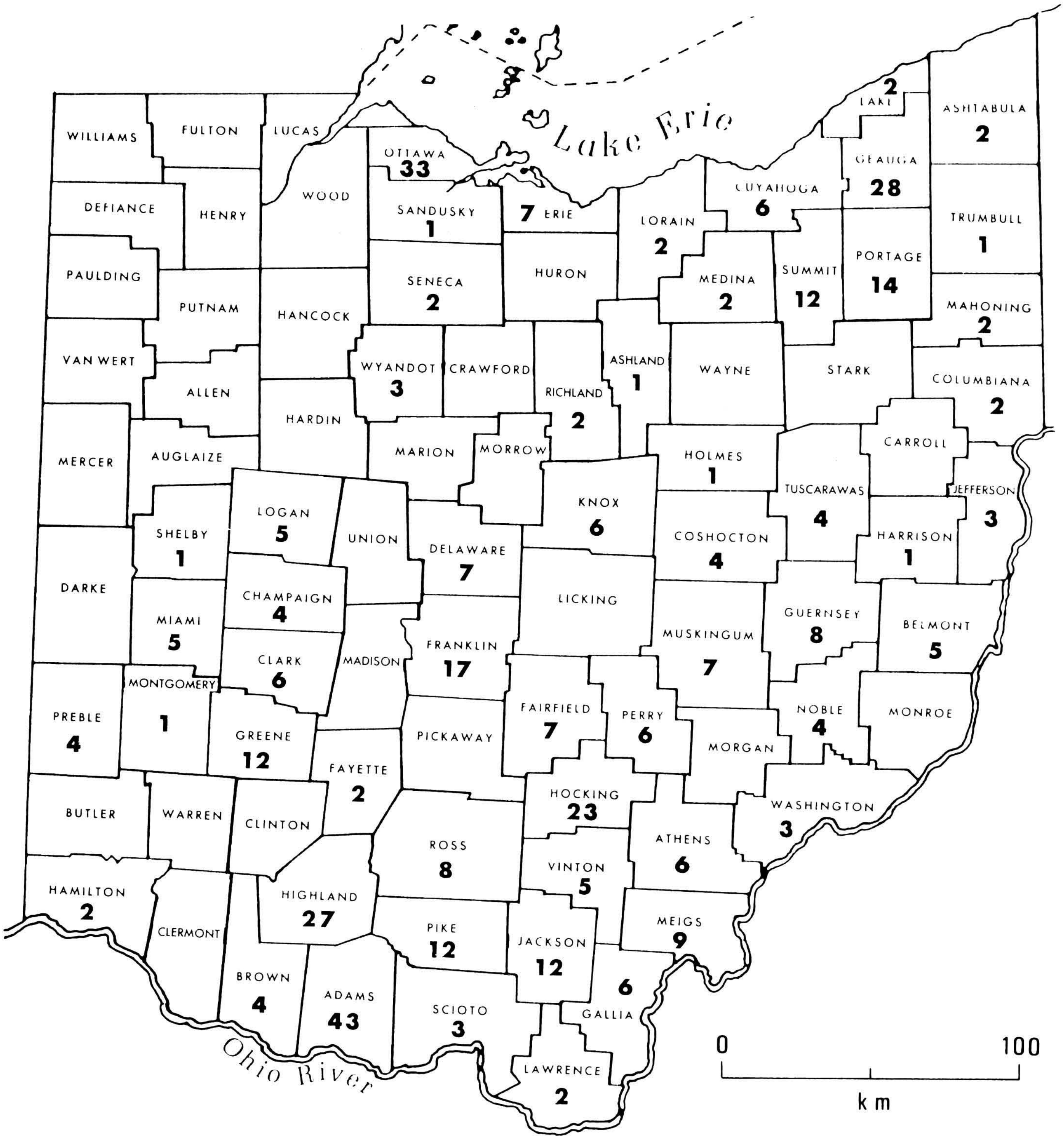

Figure 5. State of Ohio with frequency of caves shown by county.

caves from two counties serve as type localities for two taxa of cave carabid beetles. A summary of the occurrences of recent Ohio cavernicoles (with corresponding references) is available from the author. Numerous investigators have reported animal remains (including man) from the state's caves and shelters. Also, several studies have been made on "blue holes" in northern Ohio.

Currently the "Ohio Cave Survey" is again active and has resumed the systematic study of caves of Ohio. This entails determining entrance locations, mapping and drafting, compiling species lists and measuring various physical and chemical parameters, obtaining historical data, conducting photographic studies (black and white and color transparencies), making geological interpretations, examining paleontological and archaeological remains, and studying cave origin and development as related to glacial history. Presently 407 caves and shelters are known (Fig. 5), and undoubtedly that number will increase with continued field work. Only 56 (14%) of these features have been mapped.

Note: a detailed bibliography and annotated list of fauna are available from the author.

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Geosciences

The geosciences deal with processes that both create and destroy caves. Speleogenesis involves hydrology, lithology, and structure. Sediments and mineralization fill caves and provide evidence of paleoclimatic conditions.

Mineral deposition fills passages and obscures walls which hold many clues to past hydrology and lithologic or structural control of speleogenesis. But the type of mineral does give clues to more recent geological and climatological conditions and we are just starting to be able to read this record. Alternating wet and very dry conditions and a variety of mineral sources in the rocks around the limestone in the Southwest have resulted in a seemingly endless series of discoveries for the mineralogist. Until now, most studies have involved cataloguing the varieties of minerals and speleothems in different caves and conjecturing the mechanisms of deposition. In Mammoth Cave there are no exceptional minerals, but the great variety of sulphate and carbonate speleothems in one cave raises the hope that we will be able to interrelate past hydrology and climate with present microclimate and lithology in order to understand mechanisms of deposition.

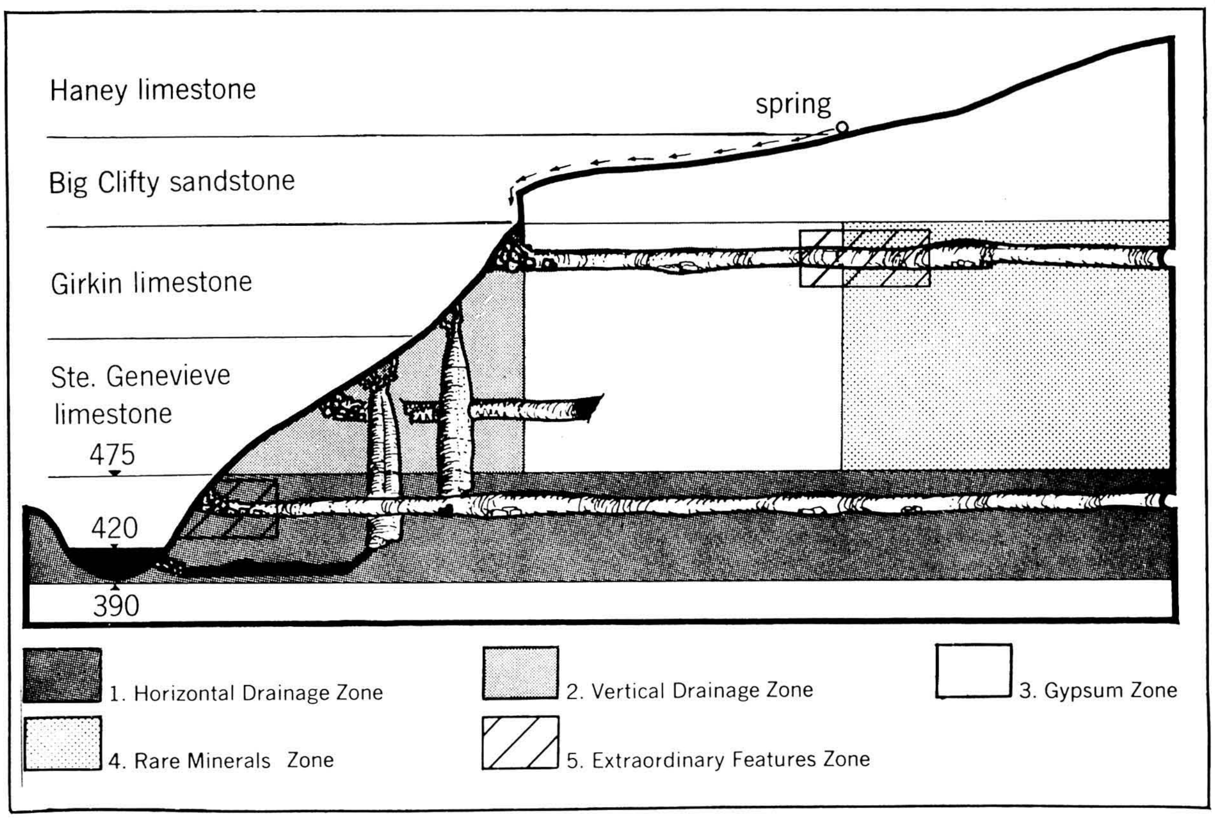

Figure 6. Schematic Diagram of cave passage classification from *Wilderness Resources in Mammoth Cave National Park — A Regional Approach* written by J.K. Davidson and W.P. Bishop, published by the Cave Research Foundation in 1971.

The Mammoth Cave Region

The Mammoth Cave Region has provided the clearest and most complete record of geomorphic and climatic changes, for the last 10-30 million years, of any readily accessible continental feature in the world. Techniques used range from mapping of old river terraces in relation to cave levels to isotopic dating of calcite speleothems from upper and lower levels of the cave. Insights have not been forthcoming from sediment analysis in the cave or pollen records in cores from surface ponds. Paleomagnetic analysis of sediments may be a useful approach and reflectance spectroscopy has helped match surface soil types with derived sediments in the cave.

In the Mammoth Cave Region, a combined use of water tracing (making use of flourescein, *Lycopodium* spores, optical brighteners, and thermal sensing) in order to locate spring outlets on Green River, and direct studies of flow patterns (making use of well records, flood hydrographs, and exploration) have culminated in the identification and partial characterization of eight major and minor drainage basins. These start at the sinking streams and on the sinkhole plain and end at big springs on the Barren and Green Rivers. The paleohydrology of presently disconnected segments of upper level cave passages has been determined by correlative studies. Passage location, character, and rock strata give information on the routes of flow, while on the other hand, passage cross section along with wall scallop size and orientation give information on direction and volume of flow. These deductions are consistent with volume flows of currently active spring resurgences of the major trunk passages which are still enlarging. There were clearly periods of fast downcutting and relative stasis of the master surface river, the Green, which affected passage shape along with sediment size and sorting. Such fluctuations were even more extreme in the California mountain site of Lilburn Cave where there have been alternative periods of fine sediment filling and coarse clastic scouring and enlargement of the passages.

Controls of speleogenesis, specifically of passage location and direction, are greatly different in Kentucky, California, and New Mexico. In the gently dipping, multiple, and relatively thin beds of the Mammoth Cave Region, details of stratigraphy and lithology interact with subtleties of structure to determine passage and cave characteristics. These insights come primarily from detailed stratigraphic study underground and are consistent with laboratory studies of rates of dissolution of limestone blocks of different lithologies. By way of contrast, joint sets control most passage orientation in the varied calcitic to dolomitic marbles of Lilburn Cave. This marble rests among steeply tilted and highly folded igneous rocks of the Sierra Nevada mountains. And, in New Mexico, unraveling the mechanisms of speleogenesis in the giant sponge-like caverns of the Guadalupe Mountains and the deep-lying network mazes beneath the plains poses a considerable challenge. Unlike the Mammoth and Lilburn Cave settings, the climate is very dry and geologic processes have come to a virtual standstill.

Lilburn Cave, King's Canyon National Park, California

Update on the analysis of structural control of speleogenesis

Gail McCoy

Continuing study of the structural control of speleogenesis in Lilburn Cave has resulted in further insights into the fracture-control of solution and collection of additional fracture-attitudes. Surface mapping is 85% complete. More than 10 days of mapping the surface geology has located all outcrops and aided in the determination of most lithologic contacts. Many hours of subsurface work included detailed study in the Dry Passage, Lake Room Passage, River Pit Avenue and the Blue Passage. The extensive structural control of cavern development becomes increasingly evident with continued research.

Lilburn Cave has formed in a lens of distinctively foliated marble. The foliation, defined by alternating white to light gray and dark gray to black bands, varies from irregular, isolated patches to spectacular, even bands that are meters long. The grain size of the marble ranges from aphanitic to 8 mm and often changes across a few centimeters of exposure. Locally common platey masses of aphanitic metachert also occur. Minor amounts of copper oxides and sulfides frequently occur in association with these lenses.

Schist and metachert also consitute part of the metasedimentary roof pendant that contains the cave. Black, biotite quartz schist weathering to brownish-red with a variable degree of foliation and an aphanitic metachert are the chief components of this roof pendant.

Rocks of the Sierra Nevada 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 on the west (Ross, 1958). Pods of green copper-bearing garnetiferous tactite locally occur at the granite/marble contact.

Few marble outcrops penetrate the regolith in Redwood Canyon. The regolith mantling the karst and surrounding rocks consists of abundant fine detritus and humus with numerous granitic boulders and less common schist or metachert cobbles. Most tributaries to Redwood Creek that flow on the nonkarstic rocks sink at the contact with the marble. These streams radically change morphology upon crossing the marble contact. On the nonkarstic rocks, streams have high gradient, narrow, "V"-shaped channels, while downstream on karst, the channel becomes a broad, flat, indefinite gully choked with cobbles. Sinkholes also help to define the minimum extent of the marble in this area.

This season's work within the cave mainly consisted of detailed study of Dry Passage, River Pit Avenue, Lake Room Passage and Blue Passage for a total of 520 m of passage examined. These major passages generally have clean, accessible walls and ceilings. The orientation, extent and frequency of all fractures and the shape and general features (size, type of passage, special features) of the passage were measured or analyzed.

Fractures control the trend and development of all bends in the tall, narrow, vadose-developed Dry Passage. Straight passage segments between the bends are dissolved along steeply dipping fractures. Acute passage angles occur at the intersection of steeply-dipping fractures. In contrast, Blue Passage, a subparallel passage about 33 m higher in the cave, exhibits much less obvious structural controls. Blue Passage has a variable shape but usually appears keyhole-like in cross-section. The passage development shows strong influence by the few fractures that do intersect the passage.

River Pit Avenue, a major, sometimes flooded passage, lies near the lowest known areas in the cave. Parts of the passage have a subrectangular cross-section, developed along parallel, gently dipping fracture-sets. Where steeply dipping fractures do occur the passage has enlarged along the intersection of the steeply and gently dipping fractures. Two elongated pits that intersect this passage have developed along steeply dipping fractures. Each pit offers access to passages in the cave at lower elevations.

All fractures measured on the surface and within the cave have been plotted on Rose diagrams. A plot of all subsurface fractures shows a preferred orientation of 330° (Fig. 7). This figure shows how many of the cave's passages trend subparallel to the dominant fracture-trend. Individual plots for each passage generally don't exhibit as clear a preferred orientation. The Rose diagram of fractures measured on the surface includes fractures in all lithologies. These fractures form a bimodal distribution with modes at around 70° and 315°. The bimodal distribution of surface fractures is of interest because one mode (315°) corresponds to the dominant mode measured in the subsurface, whereas the other surface mode corresponds to a frequency minimum in the subsurface. Thus, the 70° surface mode does not have a counterpart in the subsurface. The reasons for this phenomenon are not well understood. Possibly fractures trending 70° are a result of near-surface, tensional stress-relief while fractures trending approximately 315° resulted from regional stress-patterns.

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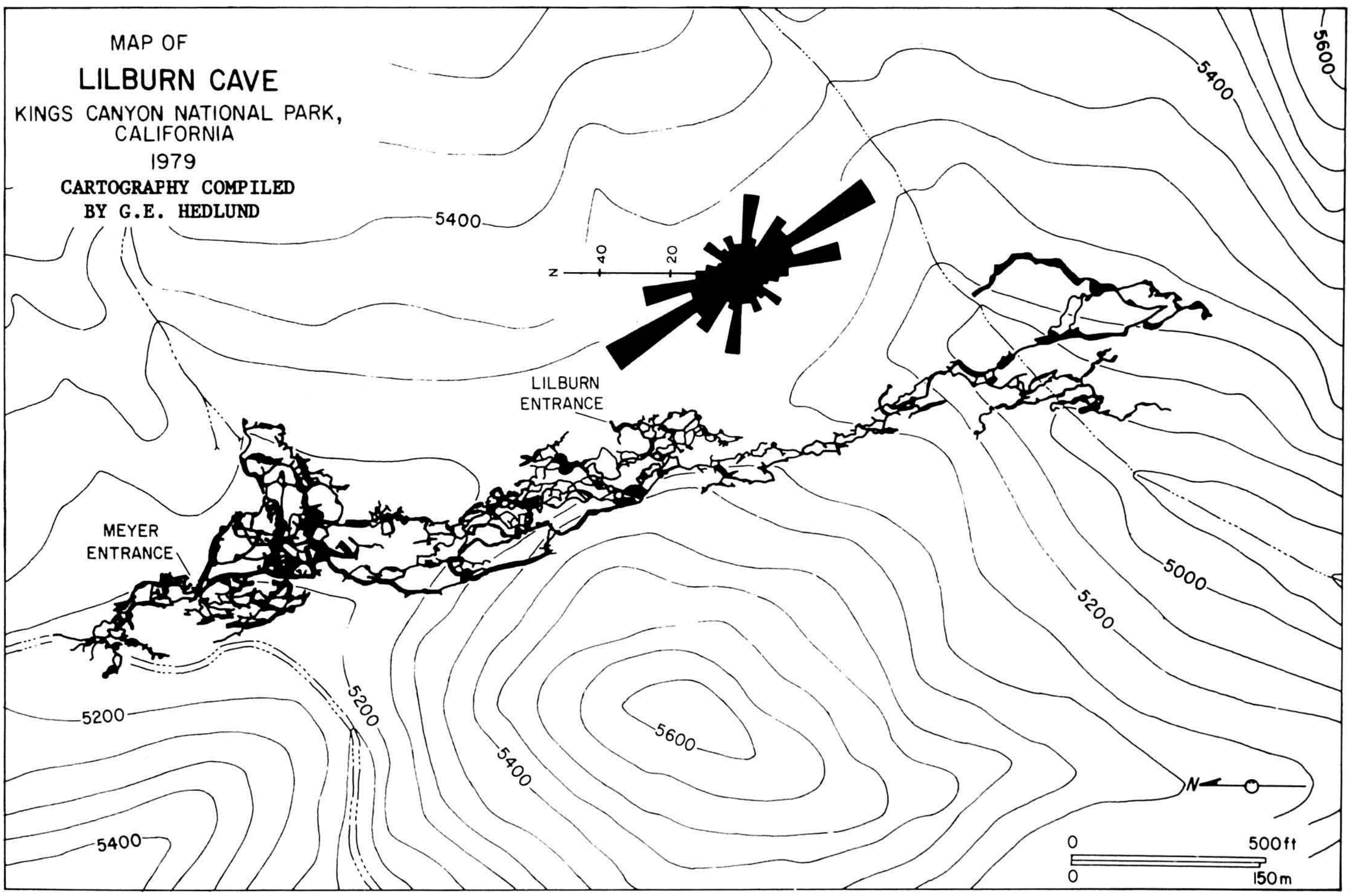

Figure 7. Rose diagram depicting orientations of all fractures measured in selected passages in Lilburn Cave in relation to the cave and the topography of Redwood Canyon. Contour interval is 50 feet. Plotted orientations are grouped in 10-degree increments of arc. The lengths of rays are proportional to the number of fractures per group.

Lilburn Cave and the bedrock of Redwood Canyon

Bruce W. Rogers

In the vicinity of Sequoia and Kings Canyon National Parks, metamorphic rocks occur as isolated roof pendants surrounded by the Sierra Nevadan granitic batholith. The Redwood Mountain roof pendant, which underlies Redwood Mountain and Redwood Canyon, is bounded on its eastern margin by the Big Baldy Granite. The pendant is flanked on its other sides by the Giant Forest pluton, which is composed of rocks with a quartz dioritic to quartz monzonitic composition (Ross, 1958). The roof pendant itself consists chiefly of a black biotite quartz schist having variable degrees of foliation. A very fine-grained metachert occurs locally as tabular lenses less than 10 meters in diameter within the marble and also occurs as larger masses within the schist.

As Figure 8 shows, Lilburn Cave has developed entirely within the soluble marble of the Redwood Mountain pendant. Cave passages intersect marble-schist or marble-granite contacts where they develop along these contacts; however, the cave never develops in the non-soluble rock. The resurgence of the cave stream, Big Spring, emerges adjacent to a marble-schist contact.

The marble enclosing the cave has a distinctively banded appearance, defined by alternating white to light gray bands and dark gray to black bands. This metamorphic foliation varies locally in appearance from irregular, isolated patches to spectacular, uniform bands tens of meters long. Pods of green garnetiferous tactite occur locally along the contact of the granite and the marble.

Even within a soluble rock mass, subtle variations in rock composition and texture can affect cavern development (Rauch and White, 1970). Accordingly, I measured the composition and texture of 56 marble samples collected from surface and subsurface outcrops in Redwood Canyon. As Table 1 and Figure 8

TABLE 1
Marble compositions and grain sizes in Lilburn Cave

Marble Type	*Samples*	*Calcite, %*	*Grain Size, mm Mean*	*Range*
Calcite	32	93-96	4.3	0.25-7
Magnesian Calcite	14	54-86	1.9[a]	0.25-5[a]
			1.4[b]	0.5 -3.5[b]
Limy Dolomite	7	36-39	-	-
Dolomite	3	6	2.5	0.25-9

a Calcite grains only

b Dolomite grains only.

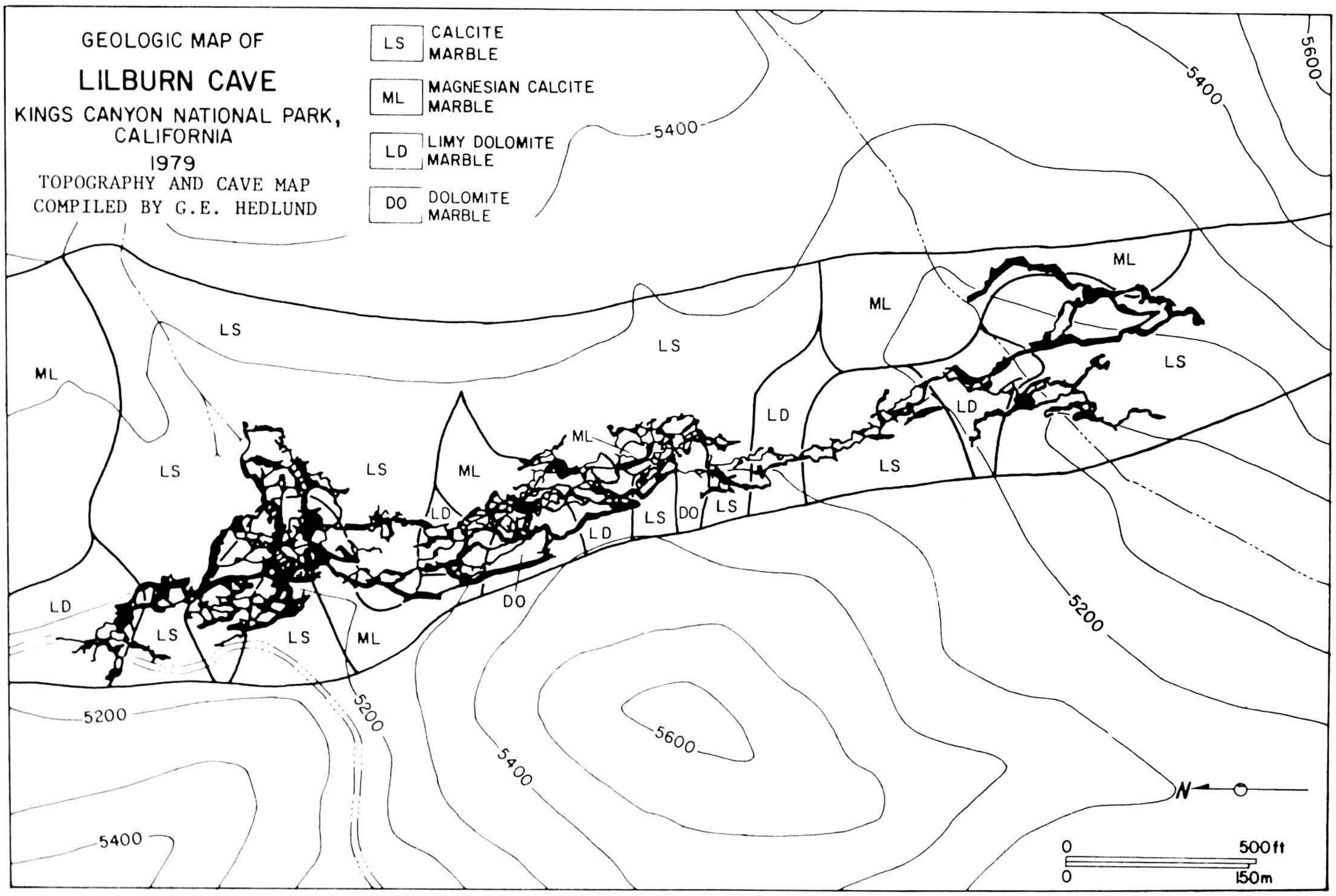

Figure 8. Map showing the relation between topography, Lilburn Cave and variations in the composition of the marble in Redwood Canyon. The contour interval is 100 feet.

indicate, the parts of the marble composed of almost pure calcite are the most abundant. The dolomitic parts of the marble tend to be finer-grained and are concentrated in the darker, more carbon-rich bands of rock. Although the four basic compositions of marble are irregularly distributed across the roof pendant (Figure 8), the finer-grained more dolomitic members are more abundant in the western part of the pendant. The cave passages are entirely contained within the marble, but they apparently indiscriminately traverse the boundaries which separate marbles of varying calcium and magnesium compositions. Consequently, marble composition apparently does not significantly control the development of this particular cave system.

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Clastic sediments: A summary

John C. Tinsley

The central part of Lilburn Cave contains sediments deposited during three episodes which occurred under contrasting hydrologic conditions. This reflects changing conditions during evolution of Redwood Canyon and its karst. I gave a detailed discussion of the field relations and the sedimentology of these deposits in the *CRF 1978 Annual Report* (pp. 26-27).

Investigations and Results

1. There are three distinctive episodes of sedimentation that characterize the central part of Lilburn Cave: a) deposition of the "banded clay," thinly laminated (= varved ?) silts and clays that record subaqueous (probably ponded) low-energy conditions during a period of about 10,000 years when coarse clastic detritus was not being delivered to this part of the cave system; b) deposition of the old coarse clastics that records a prodigious and presumably rapid influx of granitic cobbles, gravel and sand that filled major passages to the ceiling and triggered formation of ceiling anastomoses and channels in these areas; c) deposition of granitic sand and gravel that is the sediment in transport through the cave under the present hydrologic conditions. It can be interpreted that the old coarse clastics reflect changes in sediment supply and hydrology that occurred when Redwood Creek eroded into fissures and passages connecting directly with this part of the cave. The modern sediments indicate active conduits and reflect the continuing role of sediment during speleogenesis and vadose modification of caves.

2. A map (scale 1:360) depicts the texture and distribution of the deposits described above. The map includes 75% of the central part of the cave and represents about 35% of the entire cave.

3. Four additional cores have been procured from critical localities to test the hypothesis that deposition of the "banded clay" was synchronous in widely separated parts of the cave. A total of about 25 cores have been procured. Although the analyses are incomplete at this writing, the work done to date is promising and paleomagnetic techniques are expected to demonstrate the synchronous deposition of the "banded clay."

Future Work

We anticipate completing mapping in the central part of the cave and finishing the paleomagnetic analyses during 1980. Preparation of an interpretive report for submittal to Sequoia and Kings Canyon National Parks and a manuscript for publication is anticipated during late 1980 or early 1981.

The ebb and flow of Big Spring in Redwood Canyon

Stanley R. Ulfeldt

During the seasons when rainfall and snowmelt swell the volume of Redwood Creek, Big Spring exhibits intermittent, short pulses of very high discharge. A permanent water level recorder installed at Big Spring has recorded these pulses for more than ten years. Such ebb and flow behavior has been reported elsewhere, including the Ozarks region (Bridge, 1923). The unique feature of Big Spring is that Lilburn Cave provides access to the upstream end of the system of conduits and chambers which cause the flushing action. In the cave, some 700 meters north of the spring and about ten meters above it, water rises slowly in a chamber while the spring drains suddenly from the chamber and the spring flow increases abruptly, sometimes tenfold or more.

Often, just as the chamber has drained and begun to fill again, water level oscillations with the periods of about 100 seconds occur in the cave chamber. These oscillations are exactly out of phase with the oscillations observed simultaneously at the spring. In addition, the water level records reveal that the greater the flow of Redwood Creek, the more frequently these large, abrupt discharges occur in groups, rather than as isolated events. The first surge of a group is always the largest in the group, and the first surge at the onset of the wet season is often the largest of that season.

At least three theories have been advanced to explain the observations outlined above (Ulfeldt, 1970; Moore and Nicholas, 1978). I favor the explanation involving two conduits which link the observable cave chamber with a lower-level, water-filled chamber which is itself linked to the spring via a single conduit. One of the two conduits linked to the upper cave chamber is lower than the other and is permanently water-filled. This lower conduit carries all the water flow during seasons when no surges occur. The conduit also carries most of the base flow during seasons of higher discharge. However, this conduit is too small in diameter to transmit the entire discharge and the water backs up into both the upper cave chamber and the other, high conduit leading from the upper cave chamber to Big Spring. At a critical water level, a siphon is estabished in the upper conduit. A surge occurs as the larger upper conduit delivers the enormous volume of water observed in the flush. When the upper cave chamber has drained, air enters the siphon and interrupts the flush. The complex clustering of surges may be explained by an appropriately complex geometry in the larger upper conduit. For example, multiple siphons in this conduit could produce the stochastic

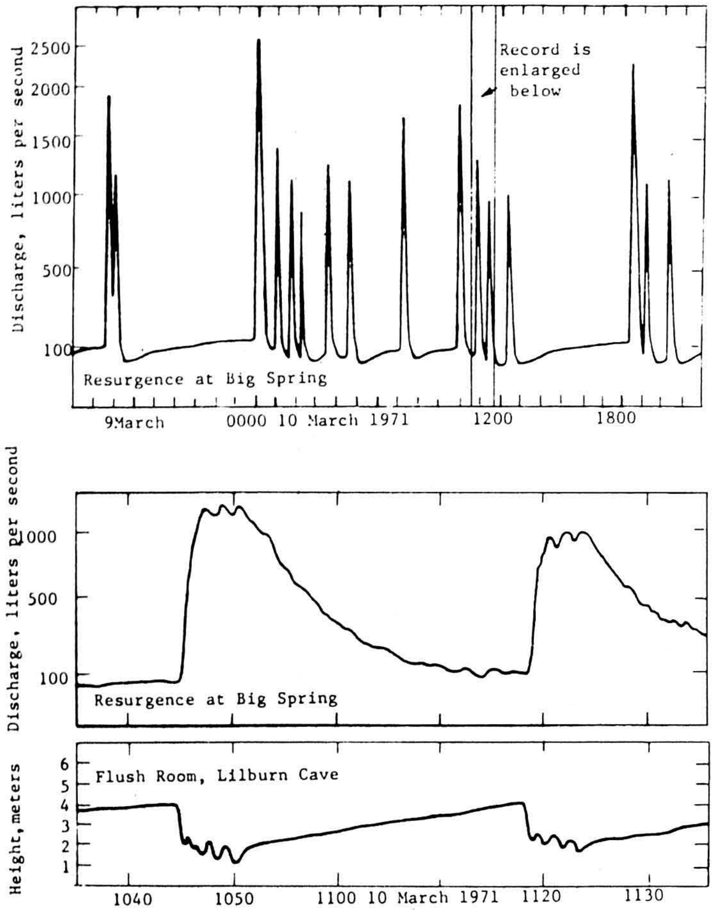

Figure 9. Ebb and flow behavior at Big Spring, Redwood Canyon, and the corresponding water level fluctuations within Lilburn Cave.

behavior observed in the frequency of flushes. Future observations and models of this hydrologic phenomenon promises to sharpen our understanding of the hydrodynamics of karst spring systems.

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Mineralogy

Spider Cave, Carlsbad Caverns National Park, New Mexico

Carol A. Hill

Spider Cave, located about 2 km from the entrance of Carlsbad Caverns, is unusual geologically in that it is developed in an interfingering of limestone sandwiched between two wedges of the Yates Sandstone. In the entrance room of the cave, orange sandstone of the Yates Formation forms the ceiling. The limestone itself is argillaceous; upon weathering the walls become coated with a very fine-grained, brownish clay. When squeezed between the fingers this clay feels wet (i.e. it may lose its interstitial water). The clay, as determined by x-ray diffraction, is probably a combination of kaolinite (principal lines 7.2 [90], 3.60 [100], 4.48 [80]) with a lesser amount of illite (principal lines 10 (20), 4.48 (80) and 3.34 (80).

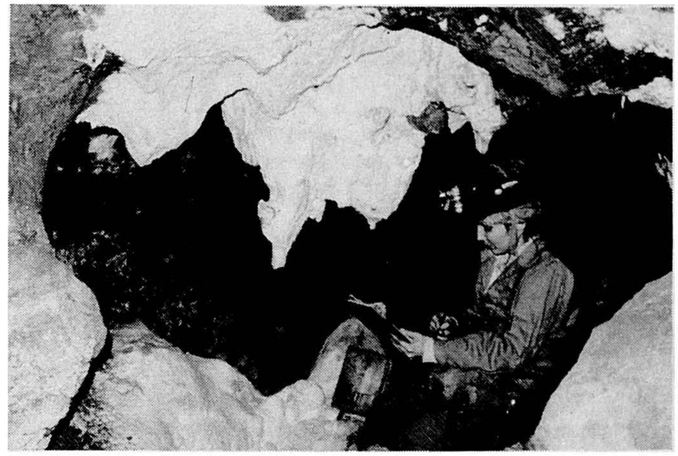

Figure 11. Moonmilk Stalactites, Spider Cave. Photo by Alan Hill.

Helictites and Anthodites

Spider Cave is admired by cavers for its magnificent display of helictites with areas such as the "Wall of Medusa" (a 12 m long wall covered with profuse helictites) and the "Plumbers Nightmare" (Fig. 10). Helictite curtains in the Mace Room are stained a brownish color below the 1 meter level demarcating a former water level in the cave. Some exquisite aragonite anthodites reaching at least 20 cm in length occur on a high ledge in the Lake Room.

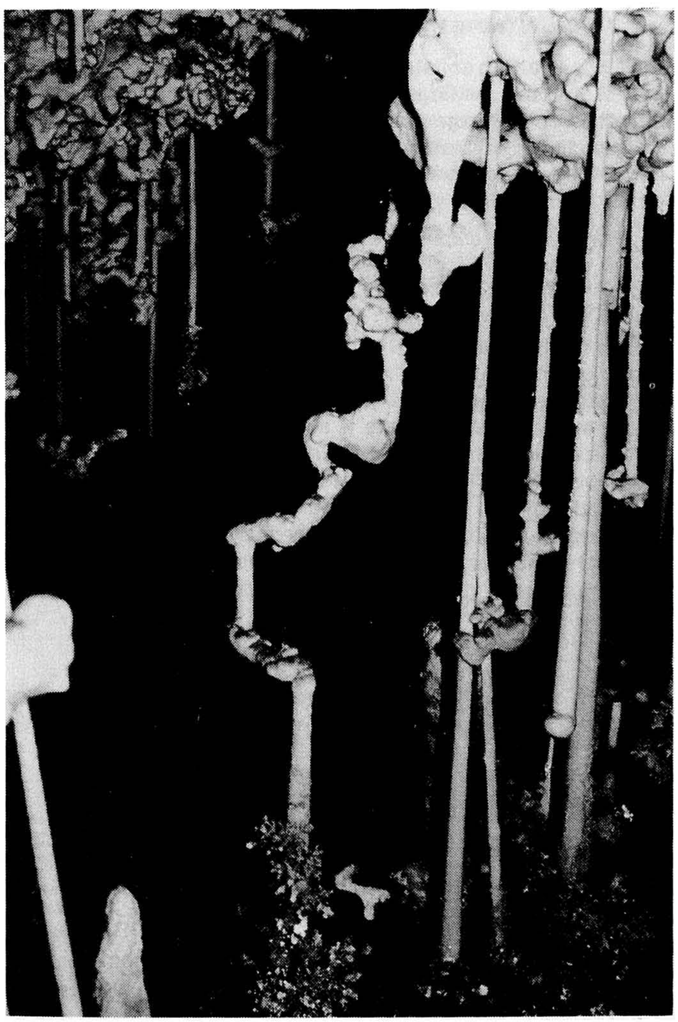

Figure 10. "Plumbers Nightmare," Spider Cave. Photo by Alan Hill.

Gypsum

Gypsum rinds are located in the entrance area of Spider Cave, near the Mace Room, and near the bottom of the chimney off the Moonmilk Room. The rinds drape over the wall rock and coat the upper surfaces and, to a lesser extent, the undersides of ledges. The gypsum is massive granular to fibrous. The gypsum of Spider Cave is contemporaneous with the large gypsum blocks and rinds of Carlsbad Caverns, the McKittrick caves, and the other caves of the Guadalupe Mountains. Small gypsum flowers are associated with some of the gypsum rinds, especially in the chimney area.

Moonmilk Stalactites

The most bizarre feature of Spider Cave's mineralogy is the presence of dull, chalk white, opaque stalactites in the Gnome Dome and Rabbit Ear Pass sections of the cave (Fig. 11). The stalactites have typical crystalline calcite cores, but atypical moonmilk exteriors covering the cores. The stalactites may have weathered from the crystalline to moonmilk state with desiccation and old age or, more likely, the outer portions of the stalactites formed directly from incoming solutions as moonmilk. Although the chalk-white moonmilk outer part of these stalactites x-rayed as calcite, they probably first formed as aragonite (i.e. calcite after aragonite) since the sample collected contains tiny acicular needle-like crystals. In this same area, piles of moonmilk cover the floor and are estimated to be 1-2 meters deep. This floor moonmilk x-rayed as dolomite, a rare cave mineral. On the ceilings and walls of this same area are globs of hydromagnesite moonmilk.

Most of the moonmilk stalactites of Spider Cave have, to some degree, begun eroding to their crystalline cores. The erosion of the outer moonmilk layers is less severe in some cases where the stalactites are so smoothly eroded and scoured that they look like they have been sandblasted. In the highly eroded stalactites, even

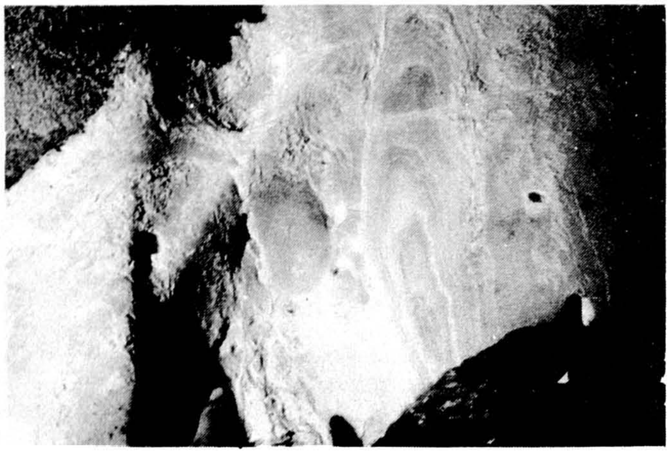

Figure 12. Truncated moonmilk stalactites, Spider Cave. Note the limestone is eroded flush with the eroded stalactite; also notice the "V" pattern on the side of the stalactite. Photo by Alan Hill.

the underlying crystalline layers are polished and truncated so that they exhibit contorted banding (Fig. 12). The surrounding limestone bedrock has been eroded flush with the truncated erosion surfaces of the stalactites. Where vugs exist in the limestone, they have been planed perfectly smooth to the wall; yet, the insides of these same vugs are filled with tiny globs of moonmilk or delicate aragonite needles.

The above field occurrence suggests the following mode of origin for the unique stalactites of Spider Cave:

(1) Typical crystalline calcite stalactites deposited first.

(2) Later solutions entering the cave became progressively magnesium-rich causing a shift in mineralogy from crystalline calcite to microcrystalline moonmilk (i.e. a trend toward aragonite, hydromagnesite and dolomite).

(3) Since moonmilk is always very finely crystalline, it weathers easily; drying caused peeling of the moonmilk layers.

(4) Wind erosion smoothed and polished the sides of the speleothems in non-protected areas along the direction of air flow in the cave. Even the cave's "breathing" (inward and outward flow of air) can cause moonmilk particles to fluff off and fall to the floor.

Jewel Cave, Jewel Cave National Monument, South Dakota

Carol A. Hill

Jewel Cave, developed in the Pahasapa Limestone of late Mississippian age, has one of the most complex geological and mineralogical histories of any cave in the world. This report contains some preliminary observations on the mineralogy of Jewel Cave.

Jewel Cave contains a variety of carbonate, sulfate and silicate minerals. The most profuse area of carbonate deposition is in the Formation Room directly under Lithographic Canyon, where surface drainage has truncated and eroded the Minnelusa Sandstone cap. The carbonate speleothems in this area are late-stage in that they postdate (cover) spar crystal wall linings. Typical speleothems such as stalactites, stalagmites, flowstone, soda straws, columns, helictites, "velvet" and draperies adorn the cave. Other notable carbonate speleothems in Jewel Cave are aragonite anthodites, hollow stalagmites, hydromagnesite balloons, and boxwork. Gypsum flowers, starburst gypsum, gypsum needles, and gypsum "transistorites" (a composite flower-crust speleothem) (Fig. 13) are some varieties of sulfate speleothems in the cave and scintillites are a variety of silicate speleothems (see Conn and Conn, 1977; Deal, 1966; and Hill, 1976 for a description of all these speleothems).

Among the most interesting speleothems in Jewel Cave, in terms of unraveling the geologic history of the cave, are the spar, manganese, and rim types.

Spar

Calcite spar (predominantly the dogtooth scalendohedral form but also sometimes rhombohedral) occurs as crystal linings over limestone bedrock throughout the entire cave (in contrast to nearby Wind Cave, Wind Cave National Park, which has spar only in its lower levels). The spar linings vary in thickness within the cave and in number (usually 3 or 4) of bands or layers comprising them. The spar crystal linings are often cracked (perhaps due to later earthquake movement) and have, in many places, broken off from rounded limestone pendant knobs on ceilings and walls, or in places where less competent red clay fillings occur in the underlying limestone. The Jewel Cave spar is redissolved in many places, especially in constricted passages which connect to more cave, or at the ceilings of domes. Etched and polished rhombohedral cleavage lines can be seen in some of the redissolved spar crystals.

Manganese

In Jewel Cave pure manganese deposits fill floor irregularities, in some places up to 3 meters. The manganese is light weight when dry, very slippery when wet, and always makes a caver grimy! Most of the manganese is soft enough to crumble or smear between the fingers. Also, it sticks to the tongue when licked, drinking up drops of water like a blotter. The color of the Jewel Cave manganese deposits is a dull "dead" black, except near the very top of the cave fill where it sometimes lightens to a dark brown. The deposits are fine-grained and porous, having the consistency of dry clay. Some of the manganese fill has cracked into reticular blocks resembling desiccated, cracked, mud flats. White speckled mold has grown over the manganese deposits where cavers have trod. The manganese in Jewel Cave is

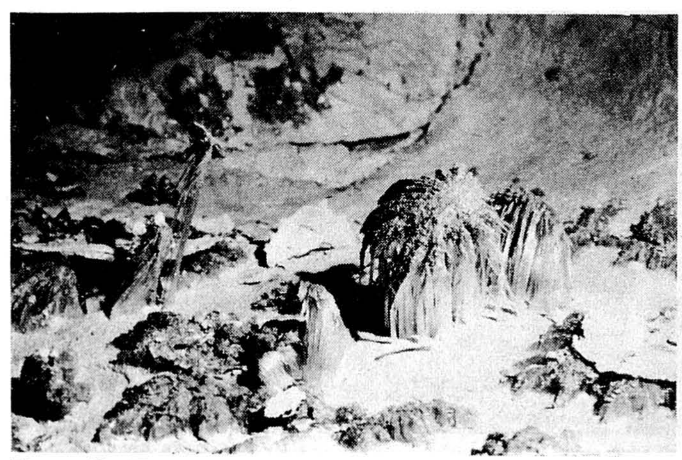

Figure 13. "Transistorites" in Jewel Cave. Photo by Alan Hill.

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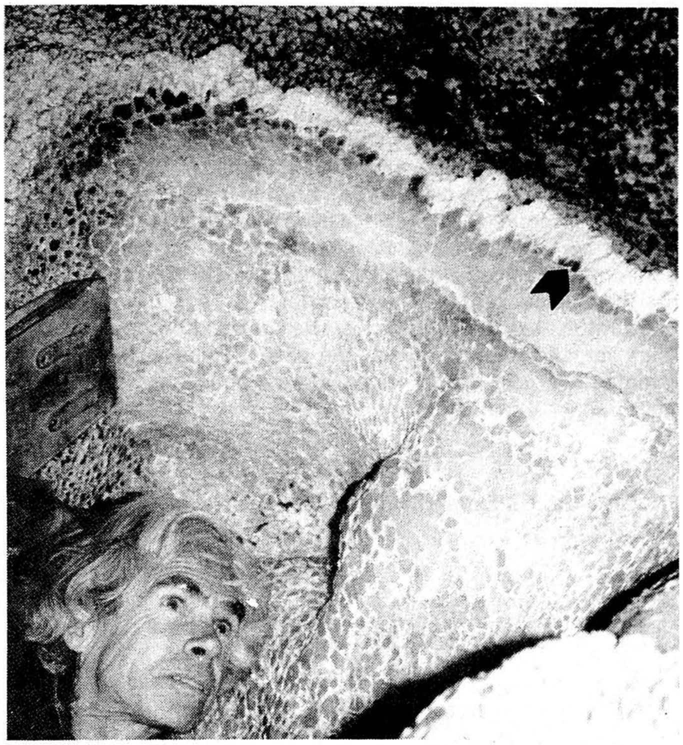

Figure 14. Title: Herb Conn inspecting rims (arrow) in Jewel Cave.

scattered throughout most parts of the cave and at all cave levels, but is especially prominent in the lowest levels and the southern parts of the cave (Herb and Jan Conn, personal communication). The Jewel Cave manganese fill probably derives from minor amounts of dendritic manganese oxide minerals in the limestone bedrock—these dendrites look like moss growing within the rock. When the Jewel Cave bedrock was dissolved and its cave passages formed, the manganese released from its bedrock precipitated directly out of solution as residual cave floor fill. Dendritic limestone was found in the near (a few meters) vicinity of the manganese fills examined; however, since only a small part of the cave was visited, it is not known if this association holds for all of the Jewel Cave manganese deposits.

Rims

The rims of Jewel Cave form (1) around apertures in the cave walls and floors (Hill, 1976, Fig. 41 and 42), and (2) at the junctions of smaller, constricted passages with larger rooms. In the latter case, the rims often occur with redissolved spar (Fig. 14), an association which may provide a clue as to how rims originate.

Calcite spar precipitates from warm water or from a decrease in the partial pressure of carbon dioxide. It dissolves in high CO_2 and cold water. The spar in Jewel Cave could have deposited in a warm hydrothermal episode and redissolved in a later, cold water episode. When saturated water flows through a constricted passage or small aperture into a larger room there is an increase in turbulence which results in a decrease of CO_2 partial pressure and a precipitation of calcite. In Jewel Cave, this precipitation occurred as rims around the openings of the smaller passages. Later, after the water drained from the cave, wind flow through the constrictions may have scoured, polished and smoothed the inside surfaces of the rims.

I would like to thank Herb and Jan Conn and Jewel Cave National Monument personnel for their assistance.

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Higgins Mine Crystal Cave, Bisbee, Arizona

Carol A. Hill

Copper mine tunnels at Bisbee, Arizona, have intersected many natural cavities in the Escabrosa and Naco Limestones of Carboniferous age. These caves are highly decorated with carbonate speleothems, often stained green with copper minerals such as malachite.

Higgins Mine Crystal Cave is one such cave that has been intersected by a tunnel. This cave is a large room about 45 m long and 15 m wide, well decorated with stalactites, stalagmites, soda straws, helictites (Fig. 15), draperies, flowstone, aragonite anthodites, popcorn, and rimstone. The surface texture of some of the speleothems is macrocrystalline and sparkles like sugar candy.

The most unusual and notable mineralogical feature of Higgins Mine Crystal Cave is its "rims." Rims are a rare type of carbonate speleothem previously known only in Jewel Cave, South Dakota (Hill, 1976), and in Virgin Cave, Guadalupe Mountains, New Mexico (Donald Davis, personal communication). Rims are so named because they rim apertures in cave walls or rim passages where a small constricted passage meets a large room. The inside surfaces of rims are smooth and appeared scoured.

About 10 different rims occur along the right wall in Higgins

Figure 15. Helictites in Higgins Mine Cave. Photo by Luther Perry.

Figure 16. A rim in Higgins Mine Cave. Photo by Luther Perry.

Mine Crystal Cave; some are stained a light green color. The largest rim is about 60 cm high and 20 cm in diameter with rim sides about 1-3 cm thick (Fig. 16). The rims are probably aragonite (needle-shaped crystals), but since collection was not allowed, a positive identification of their mineralogy could not be made. The rims are dry and powdery and the insides appear highly smooth and scoured as if they had been wind eroded. Small holes in the floor directly below each rim could be seen with a flashlight. It is possible that wind currents could have entered the cave from below via the holes and rims.

I would like to thank Bob Davis, Manager of the Copper Queen Mines for allowing access to the cave, Michael Bednorz for arranging the visit, Luther Perry, photographer, and Larry Hill, photographer's assistant.

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Reconstruction of past climates by isotopic studies of speleothems

R.S. Harmon and H.P. Schwarcz

It has been an active year on several fronts. Although the major focus of our speleothem paleoclimatological work has been shifting from North America to Europe, analytical work on deposits from the Mammoth Cave Region has continued at a steady level. A brief description of current projects is given below.

Paleoclimatological Studies in the Mammoth Cave Region

Work in 1979 centered on a Davis Hall stalagmite which was collected for analysis after being vandalised by the Job Corps in 1977. During the year, $^{18}O/^{16}O$ and $^{13}C/^{12}C$ isotope ratios were determined for several growth layers. This showed that the speleothem is suitable for paleoclimate study since its calcite was deposited under conditions of isotopic equilibrium. An axial

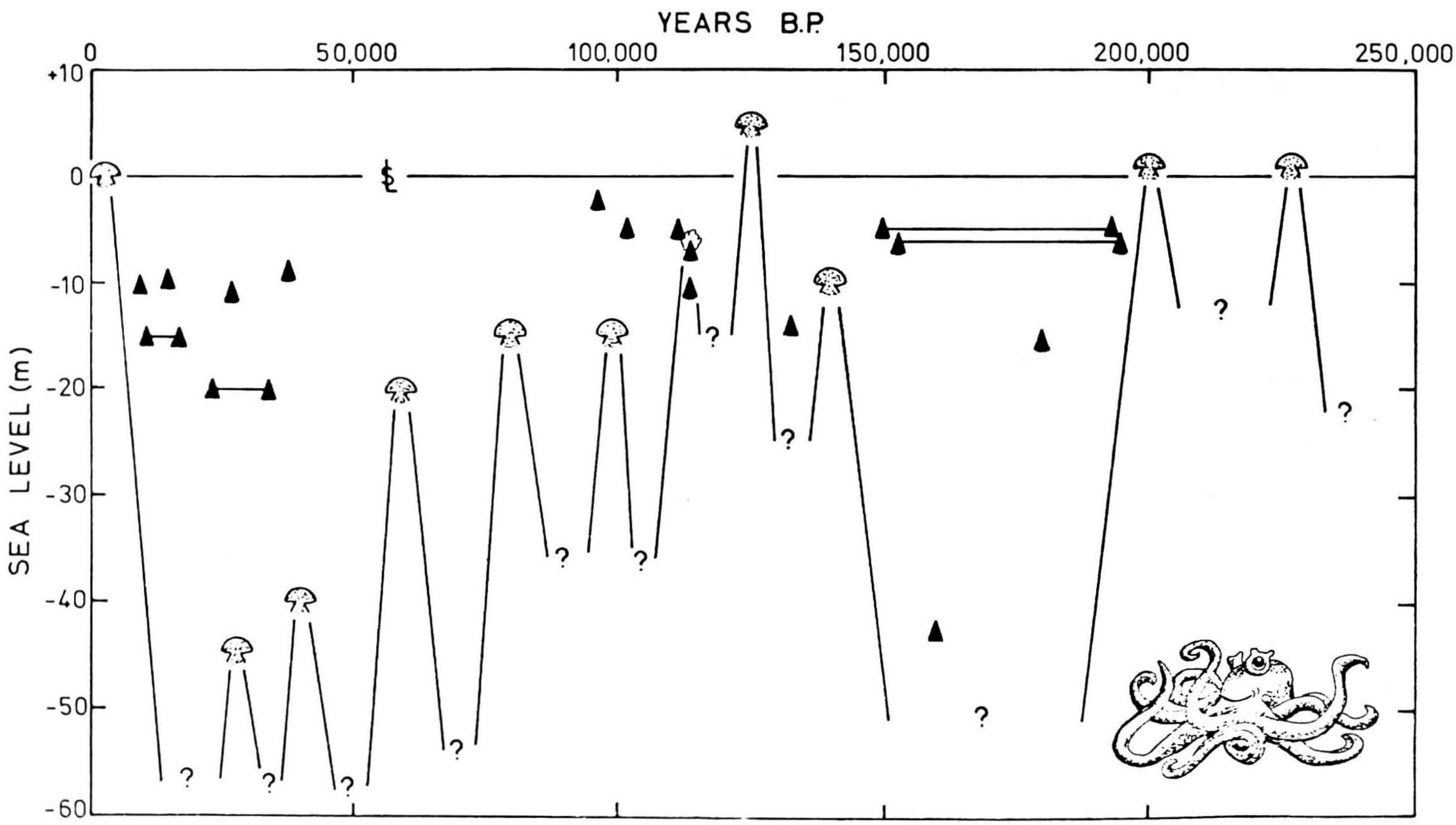

Figure 17. Nine age determinations for six stalagmites submerged in various depths of sea water in Crystal Cave.

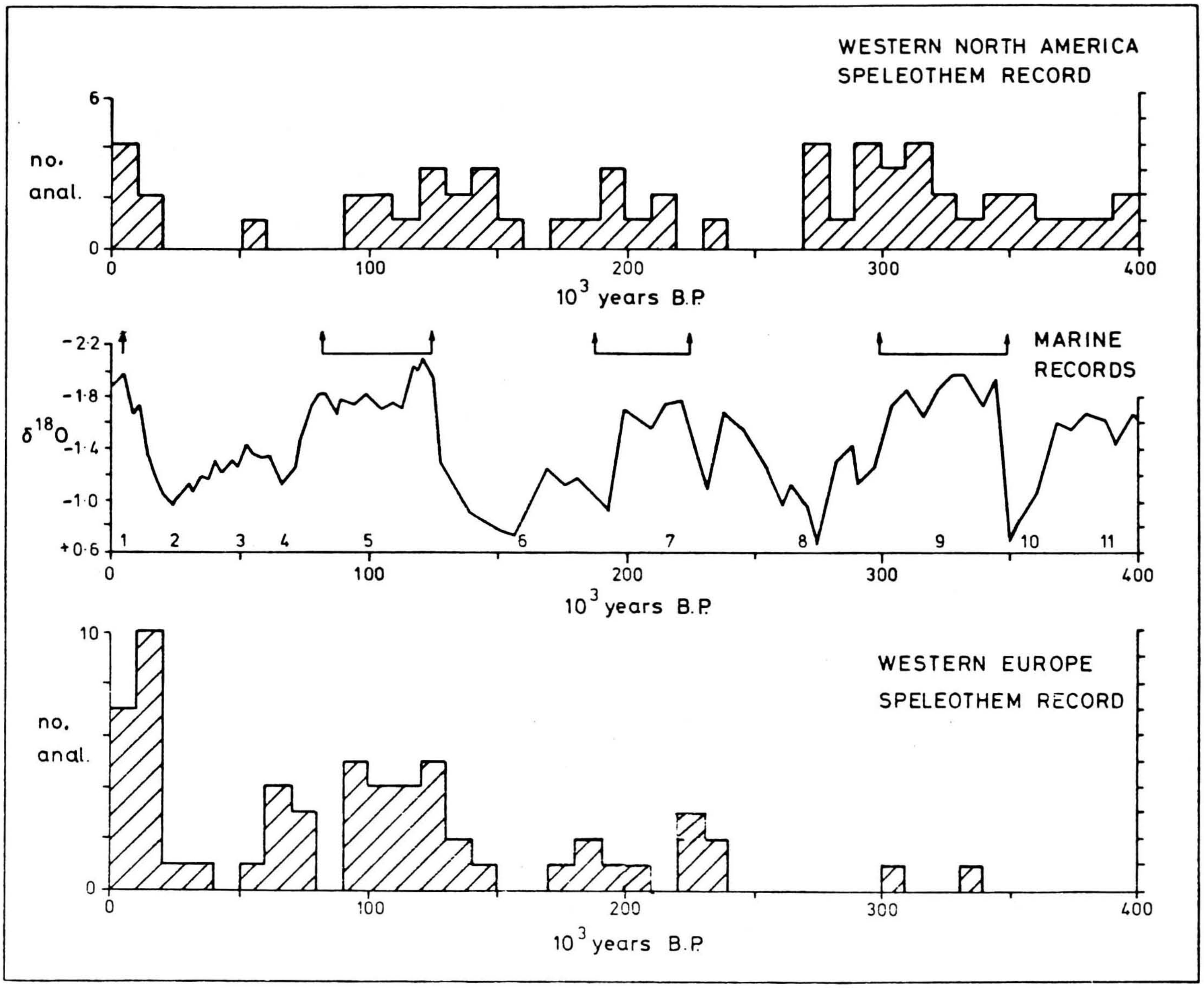

Figure 18. The ^{230}/Th/^{234}U age distribution for speleothems in central and western Europe is compared with that for western North America and two marine paleoclimate records.

profile of $^{18}O/^{16}O$ ratios was subsequently measured and observed to have recorded substantial oxygen-isotopic variations. The $^{230}Th/^{234}U$ dating of the stalagmite has been difficult because of its low uranium content but should be completed within the next few months. Hydrogen isotopic study of the fluid inclusions entrapped within the speleothem calcite will begin once the dating is completed.

Reconstruction of Bermuda Sea-Level History

The aim of this project is to determine the fluctuation of Late Pleistocene sea level within the vicinity of the tectonically stable Bermuda platform during the past 250,000 years. During 1979 nine $^{230}Th/^{234}U$ age determinations were made on six stalagmites that had been submerged in various depths of sea water in Crystal Cave. These data, (shown as black triangles in Fig. 17) together with earlier Bermudian and Bahamian speleothem data (Harmon et al., 1978; Gascoyne et al., 1979), show a picture of Late Pleistocene sea level history which is consistent with coral data from carbonate islands such as New Guinea and Barbados.

Determination of the Timing of Late Pleistocene Glacial Events

Speleothem age distributions in areas of climate stress, such as the arctic and alpine areas of North America, can provide information on the timing of periods of cold (glacial) climate because speleothem deposition in such areas is a climate-dependent phenomenon. This past year age-dating work has centered in the Mendip Hills of England and the karst areas of Poland. The results of this geochronology program are shown in Figure 18 where the $^{230}Th/^{234}U$ age distribution for speleothems in central and western Europe is compared with that for western North America (Harmon et al., 1977) two marine paleoclimate records (the ^{18}O variations in Pacific V28-238 of Shackleton and Opdyke, 1973 and the Barbados coral reef geochronologic records of Mesolella et al., 1969; Bender et al., 1972; and Bender et al., 1979). As can be seen from Figure 18, there is a general correspondence between the timing of glacial events on the two continents and the two marine ice-volume records, although distinct regional climate effects are apparent between the two speleothem records.

$^{230}Th/^{234}U$ Dating of the European Archaeological Sites

The Bilzingsleben, D.D.R. archaeological site is extremely important because of the diversity of Middle Pleistocene plant and animal fossils directly associated with hominid remains. $^{230}Th/^{234}U$ age dating of a travertine deposit associated with the hominid remains places an age of 228,000 + 17,000 years B.P. on this site and so permits direct intercorrelation of this hominid site with the local glacial stratigraphic sequence.

Other sites dated during the past year are the Petralona Cave in Greece (600,000 years B.P.) and the Chaise-de-Vouthon rock shelters in France (146,000 + 16,000 years B.P.)

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Ecology

Mammoth Cave has a diverse set of terrestrial cave communities because it has diverse microhabitats, microclimates, and food sources. Each of the six major kinds of organic input has its distinct community. These include communities based on raccoon, pack rat, cricket, and beetle feces so it seems surprising that there is no community of decomposers associated with bat feces. There are two reasons. First, all the common bat species, such as the Little Brown Bat pictured here, (Fig. 19), only use the cave for hibernation and produce scant feces at that time. Second, even the scant feces produced are in areas with cold, dry winter microclimates. The cold is selected by the bats for energy conservation in hibernation. But the associated desiccation is bad for cave invertebrates.

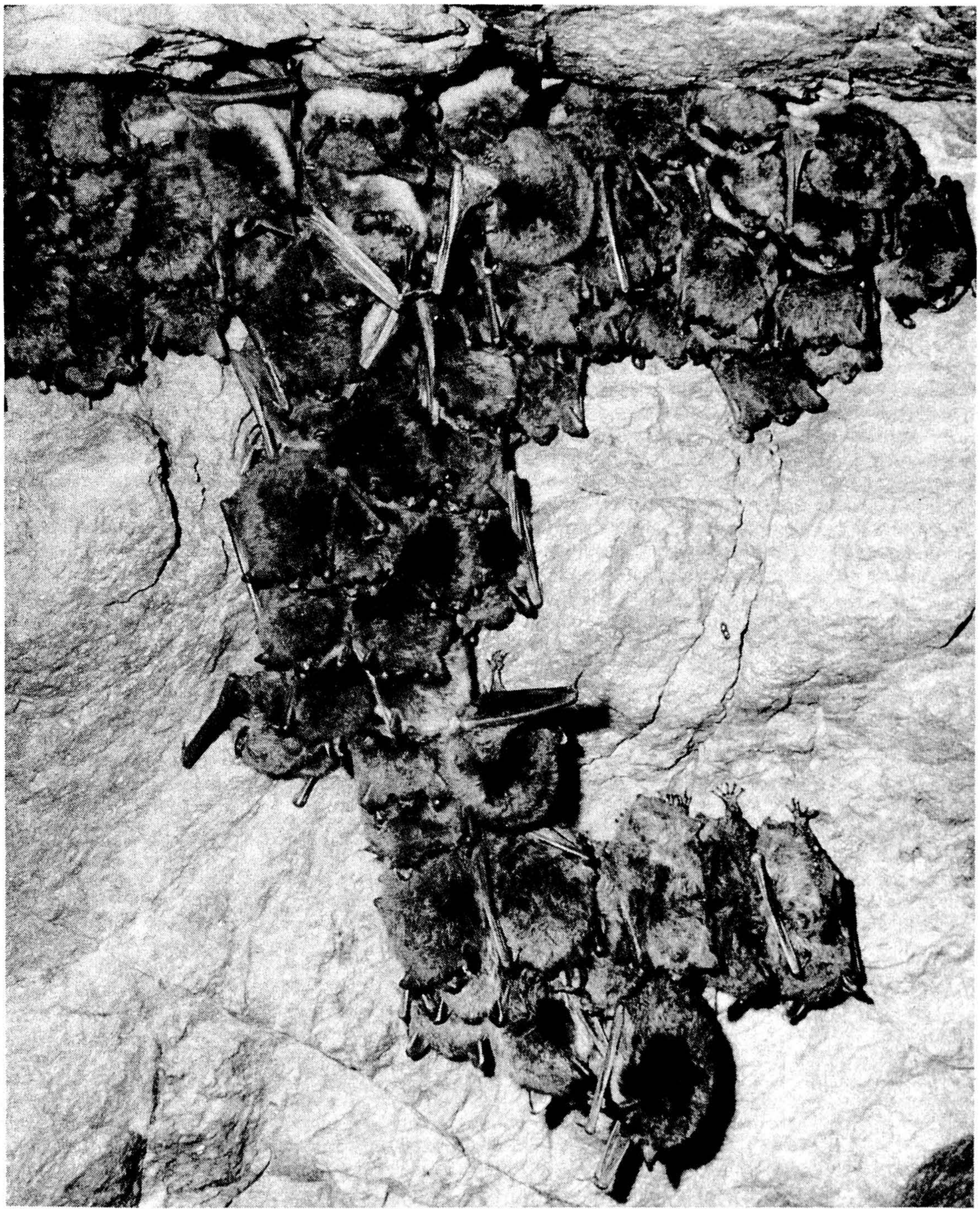

Figure 19. Hibernating Little Brown Bats, *Myotis lucifigus*. Photo by Charles Mohr.

Aside from general faunal surveys and studies oт bat guano in Missouri and New Mexico, competitive structuring of gravel stream communities in West Virginia, and effects of biological clocks on cricket migration in New Mexico, most biological work has been in or near the Mammoth Cave region. The region has a high diversity of cave fauna because of a diversity of cave types, habitats, food types, and geographic sources for the fauna. In this "ecological theater" the "evolutionary play" has involved both local species and those that have migrated in from three adjacent cave regions. The rate and frequency of migration, over geologic time, depend on cave size, density, and interconnectivity and are reflected in patterns of speciation and geographic variation. Data enzyme variation, in the wide-ranging beetle *Neaphaenops,* are now complementing traditional morphological criteria by giving a clear genetic basis to geographic patterns of evolutionary differentiation.

A guiding hypothesis has been that constraints on underground dispersal, local competition, predation and energy availability determine the species present and thus the organization of communities. Six terrestrial communities in Mammoth Cave have been characterized by the rank order importance of each species' biomass + density + frequency of occurrence. From high to low energy availability per area per time these component communities are based on isolated raccoon turds, piles of rat pellets, concentrations of fresh twig-leaf litter, veneers of guano below cricket roosts, pepperings of beetle feces on sand-silt substrates, and dissolved organics and/or highly leached detritus and highly scattered cricket feces on sand-silt-clay substrates. High energy foods are dominated by short-lived, time-efficient, habitat generalists; whereas, low energy foods have long-lived, energy-efficient, habitat specialists and there is no dominance. Seasonal rigor of flooding or cold-dry microclimate reduces the number of species and increases the dominance of some, but no new species are added. More species occur and specialist importance values decrease when component foods are mixed in a compound community setting. Part of the explanation is that the short-lived species show extreme developmental and physiological flexibility and so can persist when their preferred food is reduced in density by admixture with other food. On the other hand the long-lived specialists have little flexibility and seem to avoid their usual food if mixed with some of higher energy availability. The long-lived species cannot persist since the increased overall density of consumers favors generalized populations by living a long time and breeding infrequently. These patterns have been delimited by field-laboratory studies of pairs of related beetle, spider, and millipede species from communities of contrasting energy availabilities.

In contrast to the terrestrial, there are few aquatic communities and each has few species and few specialists in Mammoth Cave. The community associated with upper-level springs and pools around formation areas grades into that in vertical shafts; the community of vertical shaft drains grades into that of major baselevel rivers; and that, in turn, grades into the community in backflooded areas near spring outlets into Green River. The aquatic communities are based more on hydrology—with associated differences in amount of food, kinds of substrate, and rigor of flooding—than on type of food. Organic matter entering the aquatic environment of caves is not diverse in type and is continually leached, mixed, and dispersed. Thus, there are no discrete patches of single food types or great differences in energy availability which would favor specialization. The wide size range within each species, from baby to adult fish and crayfish as the extreme, also tends to preclude species specialization to food type or size. This and the low energy availability overall restrict the number of species that can be supported by the food base. The type of organism that lives in the terrestrial vs aquatic environmentment is also an important reason for differences in community organization. The crustaceans and fish which predominate in aquatic habitats have large body sizes, indeterminate growth, and long lives; whereas, the arachnids and insects which predominate in terrestrial habitats have small body sizes, determinate growth, and short lives. This contrast has theoretical implications which should be explored and conservation consequences which must be faced.

The aquatic communities are not only simpler than the terrestrial but are also more vulnerable to disturbance. For example, pollution has a great effect because the area and number of aquatic habitats are restricted, local and remote upstream or downstream perturbations affect the entire community, and the long-lived, slow-reproducing species cannot recover quickly if there is a local dieoff. The detailed consequencesd of this scenario are explored in the article by Lisowski and Poulson in the Conservation Program section of this Annual Report.

The role of bacteria and fungi in the aquatic environment of caves has not been studied, and the study of their role in terrestrial systems is in its infancy. Some preliminary projects are reported in this Annual Report. The most detailed report concern pack rat feces, which is one of the distinct terrestrial communities discussed above. This community appears to have specialist fungi as well as invertebrates, and the mechanisms of species replacement during successional decomposition are the main focus of the work. With more scattered and less energy-rich foods, such as highly leached leaf or twig detritus, there is a precedent, from the deep sea, of bacteria as gut symbionts within invertebrates. The bacteria is transported to the scattered organic matter and provides enzymes for its digestion in return. The possibility of such a coevolved mutualism has yet to be explored in caves. The ostracod-crayfish symbiosis has been studied and seems to be an example of the weak mutualism which is now receiving a lot of theoretic attention in evolutionary ecology.

The coevolved cricket prey with beetle predator system has received detailed attention in the cave areas of Kentucky. Researchers infer a sequence of escalating point and counterpoint responses to mutual selection pressures. These involve such things as synchronized egg laying, false egg holes, deeper egg holes, and shortening the in-sediment part of developmental time on the part of the cricket to decrease egg predation by the beetle. The beetle predator responses involve such things as sand-silt substrate selection, digging in areas of disturbed sediment, and use of chemical cues.

Since scientists first discovered the obligate cavernicoles, troglobites, these organisms have been regarded as curiosities rather than products of usual evolutionary processes and parts of usual ecological communities. We are finally changing the image of cave ecology and evolution to a positive one where studies in caves are accepted as important contributions to theory and to understanding general processes. But we have just touched the surface...much remains to be discovered.

Studies of Invertebrates

Cave beetle biogeography and genetics

Thomas C. Kane and Edwin J. Turanchik

Genetic variability and similarity were examined in eight populations of the Kentucky cave beetle *Neaphaenops tellkampfi* using the technique of polyacrylamide gel electrophoresis. The results of this study substantiate the preliminary findings of Guiseffi, Kane and Duggleby (1978) with regard to high genetic variability in populations of *N. tellkampfi*. Further, the similarity data suggest that the eight populations examined are nearly identical genetically.

It appears from the results of this study that the assumption that the limestone in the Mammoth Cave Region provides an underground highway for dispersal for cave limited species is valid. The genetical population structure of species in this region, however, is greatly influenced by their ecological characteristics. In particular, species with restricted habitat requirements and limited dispersal abilities may produce sets of local populations within which genetic variability is low and between which genetic distance is great. To the extent that stochastic events affect these species, the above qualities may be further enhanced. Species with less restrictive habitat requirements, such as *Neaphaenops tellkampfi*, tend to be more continuously distributed and less influenced by chance events. In these species genetic similarity among populations is great. It might also be suggested that high genetic variability in these species is adaptive for dealing with a heterogeneous environment.

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Distribution of aquatic isopods in Mammoth Cave

Julian J. Lewis

The first record of a subterranean isopod from Mammoth Cave was the 1871 description of *Caecidotea stygia* by Alpheus Packard. Since that time many other reports on the occurrence of *C. stygia* in Mammoth Cave have appeared in the literature. During the preparation of a paper on the subterranean *Caecidotea* of Illinois, I found that a new species from a southwestern Illinois cave also occurred in western and central Kentucky, including a localilty on Joppa Ridge in Mammoth Cave National Park. The purpose of my research has been to find if both species occur in the Flint-Mammoth Cave system. If 2 species actually occur in the cave, all of the records of *C. stygia* will have to be re-evaluated to ascertain which species was actually being discussed.

The investigation to date has consisted of searching, mostly in the Historic section of Mammoth Cave, for aquatic habitats which are inhabited by isopods. Ten places have been located where *Caecidotea* occur, and a total of 132 specimens have been taken for identification. Numerous other areas containing appreciable amounts of water have been found, but these either have been inhabited by no macroscopic invertebrates or others besides *Caecidotea* (usually flatworms—*Sphalloplana* spp.). Of all of the isopods collected, all but one were either *C. stygia* or undetermined females. A single speciment of *Caecidotea* n. sp. was found in the Shrimp Pools near Roaring River, where *C. stygia* was also found.

The confirmation of the presence of 2 cavernicolous isopods in Mammoth Cave presents a unique situation, since no other cave in North America is known with certainty to be inhabited by two species of *Caecidotea*. The goal of future study will be to ascertain the distribution of both species of *Caecidotea* within Mammoth Cave National Park.

Changes in ecosystems at baselevel in Mammoth Cave National Park

Edward A. Lisowski

The purpose of this project (MACA-N-59) is to collect baseline data so that the restoration of the natural ecosystems in the baselevel stream passages of the Mammoth Cave system can be followed if the U.S. Army Corps of Engineers removes Lock and Dam No. 6 at Brownsville. This research has three foci: 1) an invertebrate faunal survey, 2) a detailed census of the crayfish and fish and, 3) a life history study of the Mammoth Cave blind shrimp, *Palaemonias ganteri* Hay.

The invertebrate survey included collecting and identifying the smaller arthropods encountered in the Roaring-Echo-Styx river passages. Four species of Collembola (*Anurida granaria, Arrhopalites pygmaeus, Pseudosinella sp. z,* and *Folsomia stella*) were found either on the water's surface or on mud banks. *Anurida* and *Arrhopalites* were the most common springtails. Adult chironomids (midges) were frequently collected as they flew around lights, and larval and pupal culicids of the genus *Anopheles* were found in pools in Cascade Hall. Two species of troglobitic isopods (*Caecidotea stygia* and undescribed species of *Caecidotea*) along with white amphipods (*Stygobromus*) were collected in the Shrimp Pools, where a dead Mammoth Cave blind shrimp was also found. Several mites which represent new species were also collected.

A detailed census of the crayfish and cave fish populations in Roaring, Echo, and Styx rivers was not made this summer because the pools and streams were severely roiled by the heavy rains which preceded my visits.

The life history study of the Mammoth Cave blind shrimp was included at the request of Superintendent Hawkins to assist the Park Service in making future management decisions. No living shrimp were seen but a single dead specimen, which proved that the shrimp was still extant, was found in the Shrimp Pools. It probably came from a population, upstream of the Shrimp Pools, in a section of Roaring River that was inaccessible because of high water levels last summer. Since the shrimp was rediscovered, the Office of Endangered Species has begun the process of listing *P. ganteri* as an endangered species, and they will give it 120-day emergency endangered status during the listing process.

For their assistance in identifying specimens I thank Dr. Kenneth Christiansen (Collembola), Mr. Jerry Lewis (Isopoda), Dr. John Holsinger (Amphipoda) and Mr. W. Cal Welbourn (Acari).

The relation of bacteria and fungi to invertebrate communities

Invertebrate response to inorganic enrichment of cave substrates

Kathleen Hoey Lavoie

Introduction

Cave organisms are dependent for food on detrital material washed or carried into the cave. This debris and other animal waste products are converted into usable food by the action of heterotrophic bacteria and fungi. This detrital food base is often renewed unpredictably and of poor quality and can usually support only one or two trophic levels of higher organisms.

The actual importance of microorganisms, both heterotrophic and autotrophic, as sources of food in caves has not been determined exactly, but they are widely assumed to be the source of organic material and vitamins in deposits of clay and silt. Some invertebrates are known to feed directly on the cave sediment, and some species cannot be raised in the laboratory without having direct access to sediment from their native cave.

Despite this apparent relationship, very few studies have been done to determine associations between cave invertebrates and heterotrophic microorganisms in the cave substrate. One study which was aimed at showing such a relationship was done by Dickson (1976) in three Virginia caves. He obtained mud samples aseptically in areas where he observed high and low concentrations of cave invertebrates. He counted the bacteria and fungi in the soil samples and compared them to the invertebrate numbers in each area. He found that the invertebrates and the fungi were positively correlated while the invertebrates and the bacteria showed no correlation. He concluded that the presence of fungi was related to the secretion of substrates by cave invertebrates, but bacteria were not important in substrate selection.

Dickson's study, as done, had several drawbacks. Only direct plating techniques were used to count the microorganisms. These methods are commonly regarded as giving an unreliable estimate of active microbes since the nutrients in the media may favor the growth of forms normally dormant, as Dickson noted. Areas of organisms and invertebrates, and the populations could be associated with the presence of this foreign material. The decomposing detrital material could have been serving directly as a source of food for the invertebrates as well as for the bacteria and fungi. Some areas could also have been receiving nutrient enrichment by pollution input from streams.

A study by Baåth, et al., in 1978, indicates that the productivity of fungi and bacteria in the soil does influence the populations of microbial consumers. A microcosm experiment was performed using coniferous forest humus to study the interactions of energy source, nitrogen availability, activity of soil organisms, and plant growth. They enriched soil containing seedlings, with carbon and nitrogen sources, and found that both carbon and nitrogen were needed by bacteria to reach a high biomass, while fungi and yeast needed only a readily available energy (carbon) source.

I decided to perform a similar study in caves, without the complications of photoautrophic plant interactions, to determine if an enrichment of the sediment would stimulate the growth of heterotrophic bacteria and fungi, and if such a stimulation would influence the invertebrates of the next trophic level.

Methods

In June of 1979 I selected the Natural Bridge area near River Hall in Mammoth Cave as the site for this experiment. It had an apparently uniform expanse of mud with no obvious organic debris, and had been recently flooded. Six 30 x 30 cm plots were laid out in a line 60 cm from the wall with 20 cm between each plot. Care was taken not to disturb the surrounding mud. Pitfall traps 9 cm in diameter were placed in the center of each plot. The cups were ⅓ filled with Galt's solution as a preservative.

I decided to use glucose for a carbon and energy source since it is readily utilizable by most heterotrophic microorganisms. Ammonium Nitrate (NH_4NO_3) was used as a nitrogen source since both forms of the nitrogen in this compound can be used by a wide range of microorganisms. 4.5 g carbon and/or 9 g nitrogen were dissolved in 20 ml of distilled water. These enrichment solutions were evenly spread over the mud plots as outlined below:

Plot	*Treatment*	*Purpose*
1	Glucose	Carbon enrichment
2	Glucose & NH_4NO_3	Carbon and nitrogen enrichment
3	None	Control for normal population levels
4	Water	Control for effects of moisture addition
5	NH_4NO_3	Nitrogen enrichment
6	Glucose & NH_4HO_3 *in* trap.	Control for scent attraction

The pitfall trap contents were collected in July (1 month after enrichment) and fresh Galts added. They were collected again in September (3 months after the enrichment) when this preliminary study was ended. The enrichments were not renewed after the first treatment.

The trap contents were returned to the laboratory and the animals identified and counted.

Results and Discussion

The responses of all invertebrate species that totaled at least five individuals are compared in Figure 20. The results from the August-September trap data are averaged over two months to be comparable with the July data and represented as a double-width column in Figure 20. Pitfall trapping techniques sometimes cause an increase in the number of animal trapped shortly after the traps are placed, and these results must be interpreted with this caveat in mind. The drop seen in most treatments during the second sampling period may be the result of this complication or may indicate that the enrichment treatments are no longer effective in stimulating a microbial response; this would result in less food for invertebrate consumers during the second sampling period.

Neaphaenops is a predatory beetle specializing on cricket eggs and is attracted to sandy areas which have been physically disturbed by cricket egg laying or biospeleologists. It is not attracted to any particular treatment, although it does seem to be repelled by the nitrogen source used. The repelling effect of the nitrogen persists for at least three months and may indicate that it is difficult for this compound (NH_4NO_3) to be degraded in the cave. I have not been able to satisfactorily interpret the large drop seen in the August-September samples; it occurs for all treatments and so could represent a trap effect or a normal seasonal decrease in *Neaphaenops* population density.

Omnivorous *Hadenoecus* crickets forage for food by homing in on scent (Ellen Levy, unpublished M.S. Thesis, Department of

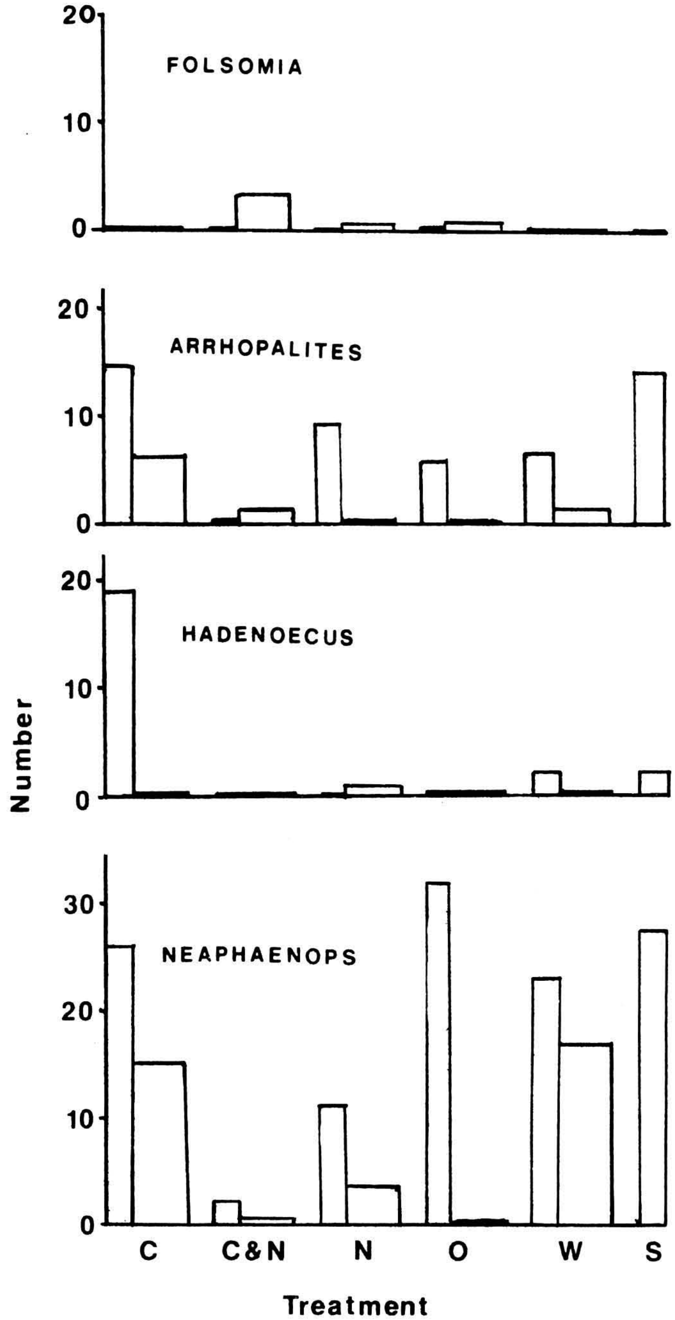

Figure 20. Number of individuals of each invertebrate species trapped per month with different enrichment and control treatments. The shaded bar represents the July sample and the open bar represents an average for the August-September sample. Treatment: C = carbon; C&N = carbon and nitrogen; N = nitrogen. Controls: 0 = nothing added to mud; W = water on mud; S = scent control (nothing on mud; C&N added to Galts in trap).

Biological Sciences, University of Illinois at Chicago Circle). They were initially attracted by the carbon enrichment and repelled by the nitrogen alone or in combination with carbon. The drop in *Hadenoecus* after the first month is probably due to depletion of the glucose and/or associated microorganisms in the soil. All crickets collected were sub-adult.

The response of the Collembola are especially interesting since Folsomia, at least, can survive on mud-clay substrates with no added food, and are known to feed on bacteria and fungi. The response of the *Arrhopalites* is not clear-cut principally because there are fewer in the C & N than on the N or O control treatments. The C and Scent control treatments may not have significantly greater numbers of *Arrhopalites* than the N, O, or W treatments. Further experimentation should help clarify these findings. *Folsomia* showed a late response to the carbon and nitrogen enriched plot, but not to the individual nutrients. The *Folsomia* collected were all adult-sized, so this doesn't appear to be a "founder effect" where one animal finds a "hot" food site and reproduces parthenogenically to take advantage of it. It could be just that *Folsomia* are rare, and slow-moving compared to *Arrhopalites*.

In the study by Baath, carbon with nitrogen stimulated bacterial growth while carbon addition alone caused an increase in fungal biomass. The differential response of the two Collembola species could be due to differential feeding on these microbial groups. An alternative possibility would be the direct use of the enriched sediment without a microbial "middleman."

Thus there does appear to be some response of higher organisms (invertebrates) to nutrient enrichment of the cave substrate, but the cause of the response is not known and requires further study.

I am repeating this experiment in Columbian Avenue of Flint Ridge and have modified the experimental procedure by substituting calcium nitrate and/or ammonium carbonate for the ammonium nitrate to try to eliminate the possible repelling effect of the nitrogen source.

I will continue to collect ana analyze the invertebrates from the pitfall traps. In addition, samples of mud will be removed aseptically from each plot and examined for the population levels of fungi and bacteria by estimating the biomass of each group. All data I collect will be statistically tested to determine the significance of any population level changes in response to the enrichments. The enrichments will also be renewed periodically as necessary.

The preliminary results reported here indicate that there is an invertebrate response to the inorganic enrichments, and I hope this continuing experiment will help show the importance of heterotrophic microorganisms in the sediment to the higher organisms in the cave. Based on current knowledge, I expect to see an invertebrate response to the enrichments due to an increase in microorganisms. Any change from this would be extremely interesting.

Acknowledgement

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Autogenic and allogenic factors in successional decomposition

Kathleen Hoey Lavoie and Thomas L. Poulson

Introduction

The decomposition of detrital material such as dung, litter, and carcasses is an essential process in all ecosystems. Without the recycling and mineralization of nutrients by decomposers we would literally be buried in dead material, and elements necessary for growth and development would become exhausted. Decomposer microorganisms and detrital material form the food base for many systems including soil, streams, dung, the rumen, artificial sewage systems, and, of course, caves. Despite the extreme importance of the decompositional process it is still not well understood, due in part to the complexitites of interactions involved.

The decomposition of detrital material is successional; there is an increase in the number of species which occur during the succession over time until some equilibrium is reached. The level of biotic activity drops as readily utilizable energy sources become depleted, toxic metabolites accumulate, and the organisms begin to senesce. A succession can occur in any size system and in any time scale. It will involve many different groups of organisms, but in all cases the successional changes in species are regular and predictable. In the absence of food production by the plants, the localized successions end when the energy source is exhausted.

The mechanism for the successional changes in species seen during decomposition has been the subject of considerable observation and debate, but little field experimentation has been done. Using caves as a model system, Lavoie plans on studying the causes of the regular changes seen in microbial and invertebrate species during the decomposition of dung.

Successional Hypotheses

We have divided the theories of successional decomposition using a combination of classical views and the divisions advanced by Alexander (1971) and Connell and Slatyer (1977) Table 2 shows our classification into Indeterminate (Stochastic) and Deterministic Models.

The Stochastic Model is a neutral model in ecology—the order of species establishment is strictly due to chance, but this does not preclude operation of deterministic factors.

The Deterministic Models are more varied but all regard some outside factor(s) as being important in determining the succession. The factors(s) are abiotic (allogenic) and/or biotic (autogenic) in nature, according to Alexander.

Connell and Slatyer were dealing primarily with 3 autogenic models in their review of succession. In the Facilitation Model later speices grow only after early ones have made conditions more favorable for the next species. The Inhibition Model includes density independent interference competition and density dependent exploitation competition; thus early arriving species inhibit later ones. Many models overlap or fit into the Tolerance Model grouping. Each one involves a change in species due to either a shift in conditions which favors a more tolerant species or the appearance of an energy efficient colonist which can grow in the presence of an earlier, less efficient, species.

The classification of successional theories outlined here is by no means complete or iron-clad. There is overlap in many areas and some of our classifications could easily fit in another category, but this grouping may make some of the relationships easier to grasp. Which hypothesis is correct? In principle it seems unlikely that any one model would apply to all successions or even explain all aspects of one succession, but we can narrow the possibilities. This research will differentiate among the influences of both autogenic/biotic interaction and allogenic/abiotic factors on the successional decomposition of dung.

Proposed Research

The cave ecosystem is optimally suited to this research due to the simplified communities, moderate physicochemical conditions, and reduced effects of seasons and weather. In the Mammoth Cave area the communities are based on detrital input from washed-in litter and silt and from inputs from facultative cave species which feed outside the cave. All three of the naturally occurring dung types used in this research (raccoon, rat, and cricket) are found near entrance areas where they are seasonally renewed and subject to the abiotic rigor of winter drying. These conditions result in a seasonal cycle of availability. The fecal types differ in the size and shape of individual fecal units, energy availability, structure and shape of individual fecal units, and the predictability in time and space. For a thorough comparison of these resources, see T.L. Poulson, "Community Organization," in the *C.R.F. 1978 Annual Report.*

This research will be based on field observations and experimentation in both the field and the laboratory. Tests of each of the pertinent successional mechanisms are briefly outlined in Table 2. Some of these tests are very preliminary while others are more specialized and will be done only if that mechanism is shown to be important in the succession.

In order to study decomposition over a range of abiotic conditions and different availabilities of colonizing organisms, this work is being duplicated in the entrance area of Little Beauty Cave in Joppa Ridge and in the deep cave of Columbian Avenue in Flint Ridge. Winter and summer replicates will also be compared.

To avoid interference by curious cave rats, 6x6x3 foot exclosure pens of wood and chicken wire (mesh size 2.5 cm) have been built at both study sites. Cave rats have seriously interfered with research in the past and it was decided to eliminate this possible complication from the start. Rats would not normally be a problem in Columbian Avenue, but the exclosure pen was built there to control for the effect of the pen.

Dung collected from laboratory speciments of *Neotoma* (cave rat) will be broken up and mixed with sterile water and formed to mimic the size, shape, consistency, and moisture content of naturally occurring rat, raccoon, and cricket dung. All of the manipulated dungs will have the same nutritional value and will be starting with the same type and amount of fungal spores due to prior inoculation of the animals' food and of the collected feces, with a fungal suspension derived from natural in-cave fecal dumps at all stages of succession and microclimate. The manipulated dung types and unmanipulated fecal pellets will be placed in the exclosure pens and the process of successional decomposition will be followed by identification of microbial and invertebrate species. These successional changes will be correlated with allogenic conditions and biochemistry changes.

The interactions of microbes and invertebrates will also be studied by comparing exposed feces to replicates under invertebrate exclusion cones.

TABLE 2.

Comparison of Models of successional decomposition with possible mechanisms and tests.

Models	Mechanism or Hypothesis	Test of Mechanism
I. Indeterminate = Stochastic or Neutral Model	Island Biogeography	
	-distance to source of colonists	-comparison of entrance to deep cave
	-size of target (island)	-size of fecal unit, dispersion of pile
	-kinds and densities of colonists	-r *vs* K selected species; which gets there first
II. Deterministic		
A. Allogenic	-Seasonal (temperature, RH, etc.)	-replicate experiment: winter *vs* summer
Abiotic Factors	-Microclimate (temperature, pH pile *vs* pellet, large *vs* small)	-manipulated dung of same nutritional value. Turd *vs* pellets *vs* veneer.
	-Leaching; simple molecules	-sterile control in the lab on rocks *vs* mud *vs* sand. Analyze biochemical concentrations. Bioassay leached feces.
B. Autogenic		
Biotic factors	-invertebrate grazing stimulates microbial growth.	-invertebrate exclusion (field). -manipulate invertebrate densities (lab).
1. Facilitation	-Key Predator; selective grazing by microbial consumer opens resource for other consumer species.	-As above.
	-Extracellular enzymes for complex molecules release excess simple compounds; allows early species to stay in the succession.	-Species/biochemical comparisons. (See Tolerance Model below) -possible comparison of % of species which produce extracellular enzymes.
2. Inhibition	Interference Competition -Antibiotic/toxin production -Hyphal interference	Density Independent -Do a few low density species influence the succession? -lab studies of antibiotic/toxin production and of resistance.
	Exploitation Competition -"1st come—1st served" -hierarchy of resource utilization and/or of colonization. -gradation into Tolerance Models	Density dependent e.g. if K species arrives 1st and depletes resource, then r species may not establish; or, whichever species builds up numbers fastest precludes species with similar requirements.
3. Tolerance	Resistant species accumulate	
	-antibiotic resistance	See Inhibition Model above.
	-changing allogenic conditions	Correlate species change with allogenic changes. Lab manipulations. See Allogenic Models above.
	Species hierarchy:	
	-same resource. Use at different concentrations. See Exploitation Competition.	-Nutrient enrichment in lab to show effect on succession.
	-different resources. Use in a hierarchy of com-- plexity and degradability. i.e. Nutritional Hypothesis. See also ~~Expoitation~~ Competition.	Leached *vs* fresh dung. -Dung dilution plate counts. -Analysis of change in the % of the population producing extracellular enzymes.

We hope that these experiments will result in a better understanding of the mechanism of successional decomposition and the importance of microbial-invertebrate interactions. These results will also tie in with the overall understanding of cave community ecology being developed by T.L. Poulson and provide basic information on the comparative ecology of coprophilous microorganisms and invertebrates.

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Psychrophilic (cold-adapted) bacteria from caves

Kathleen Hoey Lavoie

Temperature is one of the most important physical factors in determining the distribution and activity of any species, and microorganisms are no exception. Microbes have a range of temperatures where they are capable of growing, with some optimum where they show the best growth. Bacteria can be grouped based on their maximum growth temperature into psychrophiles (cold-loving; 15-18 C) mesophiles (mid-loving; 30-40 C), and thermophiles (heat-loving; 55-75 C). Organisms which can grow at a particular temperature can be either obligate or facultative. Obligate species can grow at the temperature but has its optimum in another range.

Psychrophiles have been readily isolated from many constantly cold environments including deep ocean water, regions in the Arctic and the Antarctic, and from cave soil. Gounot (1973) studied microorganisms grown from the soil of cold European caves averaging 2-5 C year-round. Many of the microbes she isolated were capable of growth in this range, but most had optima at 20 to 28 C, outside the range for obligate psychophiles.

In 1972, Brock, Passman, and Yoder searched for psychrophilic aquatic bacteria in constantly cool springs associated with caves in southern Indiana. These springs all had average temperatures of 10-12 C. All bacteria isolated had growth optima in the mesophilic range of 25-30 C, although many were able to grow from 2-20 C. The researcher suggested that psychrophiles might be found in the terrestrial cave environment.

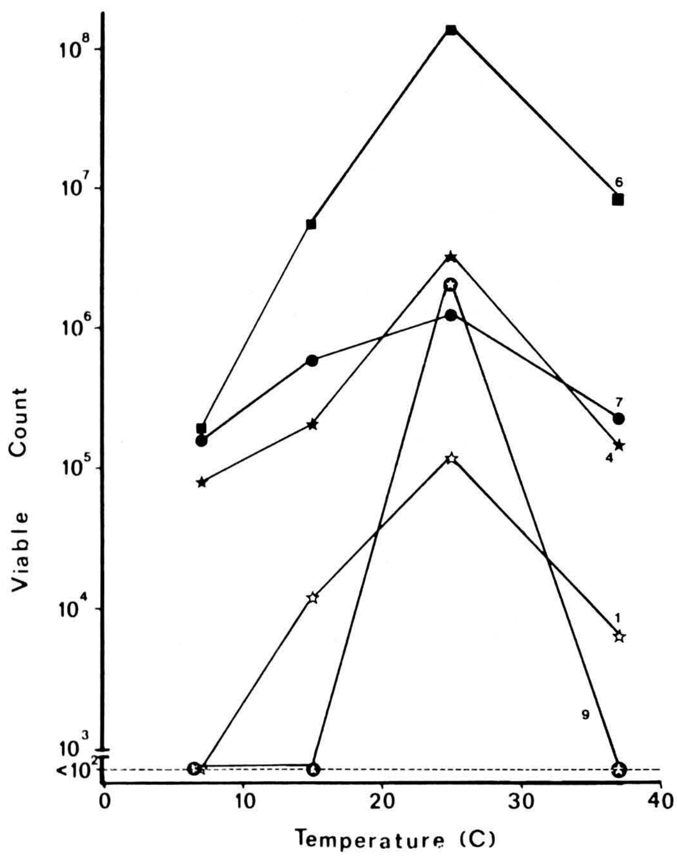

Figure 21. Viable population counts of heterotrophic bacteria per gram of sediment. The incubations were done at 7,15,25, and 37 C. Results from sites 1 (Rotunda), 4 (Richardson Springs area), 6 (River Hall), 7 (River Styx), and 9 (Historic Entrance).

Are obligate psychrophiles commonly found in the constantly cool cave environment? Barr and Kuehne (1971) have shown that the average temperature deep in Mammoth Cave is 13.5 $\pm$ 0.2 C, which is within the psychrophilic range, so I decided to look for terrestrial psychrophilic bacteria in Mammoth Cave.

Methods

I decided to do a sediment transect of nine sites from the Historic Entrance down to water level at the River Styx. This transect covered cave passages of variable age with different sediment types and water availability. The sites and a description of the soil and the percent of moisture in each are given in Table 3. The temperature at these sites is nearly constant year round except for the entrance areas (sites 1 and 9) which fluctuate seasonally.

I took 10 g of sediment from each site and made appropriate 1:10 dilutions in 0.5% sterile peptone water. Spread plates of the dilutions (1:10^2 to 1:10^6) were made on half-strength nutrient agar, to reduce spreading by bacterial colonies. Replicates were incubated at 7, 15, 25, and 37 C. Plates were incubated until there were no observed increases in the numbers of bacterial colonies at each temperature.

It was then necessary to determine if those organisms capable of growth at psychrophilic temperatures (7 and 15 C) were obligate or facultative psychrophiles by showing the range of temperatures over which they could grow. Every distinct colonial type was replicate-plated and incubated at 7, 15, 20 and 25 C. A random sampling of colonies from the 25 and 37 C incubations was also plated in the same manner.

The plates were examined after 2, 4, and 8 days of incubation and the growth of an individual colony type at each temperature was subjectively ranked from 0 (no growth) to + + + + (maximum growth).

Results

At all sites the highest population densities were obtained at the moderate temperature of 25 C. The counts from sites 1,4,6,7, and 9 are given in Figure 21. These sites show typical responses for the different sediment types and moisture contents surveyed (see Table 3). Counts from the psychrophilic temperatures were higher at 15 than the more extreme 7 C. No growth (less than 100 cells per gram) at 7 C was obtained at sites 1,2,3, and 9 after 1 month of incubation. The growth curves are fairly consistent in showing microbes which can grow over a broad range of temperatures, with the exception of the entrance site (#9).

The temperature growth range for all isolated colonies able to grow at 7 C is shown in Figure 22. Curve A represents the pattern seen with 27 out of 29 isolates and is typical of facultatively psychrophilic microorganisms. Only two islates of an obligately psychrophilic *Bacillus*, from sites 5 and 8, were made (Figure 22, curve B). The other 27 isolates were able to grow at the psychrophilic temperature of 15 C, but all had optima at 25 C or higher, making them facultative with respect to psychrophily. Three other isolates were unable to grow in the psychrophilic temperature range under the conditions I used.

Discussion

Why aren't obligate psychrophiles commonly found in the constantly cool Mammoth Cave environment? Many obligate forms of higher organisms from invertebrates through amphibians and fishes have evolved in caves during the Pleistocene. The evolutionary loss or extreme reduction of useless features such as eyes and pigmentation is common in these animals. Given the

TABLE 3.

Sediment transect for psychrophiles in Mammoth Cave. The soil type and percent moisture are given for each location.

Site	*Location*	*Sediment Type*	*% moisture*
1	Rotunda; saltpetre works	Extremely dry and dusty. Sand	3.2
2	Giants Coffin	Extremely dry. Sand and gypsum.	3.1
3	Wooden Bowl Room	Dry sand; some cohesiveness. Not dusty.	3.4
4	Richardson Springs area	Damp sand.	17.2
5	Bottomless Pit area	Damp sand	15.3
6	River Hall	Very damp. Mostly mud with some sand.	25.6
7	River Styx; past the Natural Bridge	Very damp. Mostly mud with a little sand.	23.7
8	Base of Mammoth Dome	Very damp. Sand, mud, and black material.	23.7
9	Historic Entrance; inside the gate	Dry sand with clay.	4.9

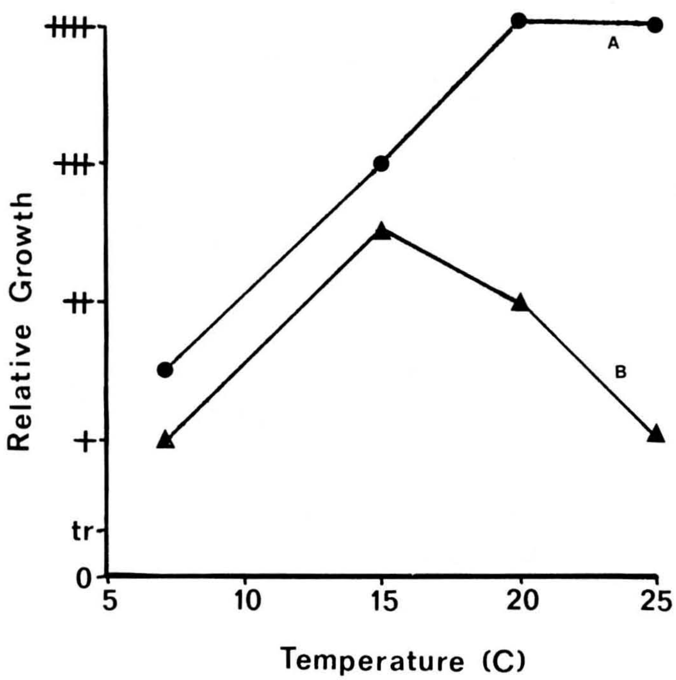

Figure 22. Optimum growth curves for isolated colonies of psychrophilic bacteria. Curve A shows the facultatively psychrophilic growth of 27 isolates. Obligate psychrophily (curve B) was seen with only two isolates of *Bacillus*.

short generation time of most microbes (on the order of days) it would be surprising if there were not enough evolutionary time to result in the loss of the ability to grow over a wide range of temperature and/or to develop obligate psychrophily.

Microorganisms in caves must cope with more than just constantly cool temperatures. The total lack of light, generally low nutrients, and different sediment types which influence nutrient binding and water availability for growth may be more important selective pressures. This may explain the unusually narrow temperature growth range at site 9. This entrance area would be subjected to all cave-related selective pressures as well as seasonal surface changes, although these are moderated by the cave environment.

Gounot has suggested that microbes isolated from caves which grow best at mesophilic temperatures are really forms washed in from the surface. Studies of microbes in caves have shown a wide range of normal surface organisms, both heterotrophs and autotrophs. Many species of bacteria, fungi, actinomycetes, and even algae have been identified (Barr and Kuehne, 1971). Only one autotrophic form unique to caves has been reported from Europe. This *Porabacterium spelei* was not found in Mammoth Cave by Barr and Kuehne.

Barr and Kuehne have shown seasonal variations in the number of bacteria able to grow at 20 C in some areas of Mammoth Cave, particularly where there is obvious surface incut. I expect that many of the sites I looked at will show seasonal changes and I plan on repeating this study in the summer.

I will also be making a transect from the Historic Entrance out to the surface soil to see if these microbes show the same temperature growth ranges as those I found for the cave sites. Finding a similar range in both groups would support Gounot's suggestion of a continual influx of surface forms into the cave. However, it might be wrong to consider this influx "contamination"; it could mean that there has been no need for uniquely adapted cave microorganisms to evolve since the available niches would already be filled by "surface" species able to grow in the cave environment. Those ready-made "cavers" would have to make few or no adaptations to survive in caves. They would not lose the ability to grow over a wide range of temperatures if the populations in caves are dependent on continual immigration from the surface. If this is the case, I predict that unique cave microbes will only be found among the chemoautotrophs or in caves with more extreme selective conditions than those found in central Kentucky.

Acknowledgements

This study is supported by the Ralph Stone Research Award for 1979 from the National Speleological Society.

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Surface studies in karst

The relationship of Barrens to karst landforms in Harrison Co., Indiana

James H. Keith

The relationship of plant communities to various types of landforms attracted the interest of the earliest ecologists and has occupied a prominent place in the ecological literature. Most studies of this type deal with extant communities which are often in various successional stages due to past logging and farming practices, and increasing urbanization and industrialization of the landscape. Thus, clear relationships do not always exist.

In southcentral Indiana and central Kentucky, the early settlers reported that vast tracts of land were treeless, and supported a flora consisting of shrubs, stunted trees, prairie grasses and herbaceous plants. Such areas were usually termed "barrens," due, in part, to the belief that a land incapable of supporting trees was infertile. Collett (1879) reported that barrens in Harrison County, Indiana had once burned each autumn, from either natural or man-caused fires. By the time of his writing, however, he stated that most of the former barrens areas were gone, either farmed or covered by a growth of timber 12-18 inches in diameter. This was about 50 years after the land had been generally settled. Today, no barrens remain in Harrison County. It is possible to locate small (less than one acre) areas of prairie grasses and forbs (herbaceous plants) but these are in upland glades and not near any of the areas known to have been occupied by barrens.

The field notes of the General Land Survey of the State of Indiana are kept at the State Archives in Indianapolis, Indiana. These notes were studied to determine the locations of the original barrens areas. The survey of southcentral Indiana was completed between 1804 and 1806. Surveyors were instructed to survey section lines and at each section and quarter section corner to set a post and measure the azimuth and distance to the two closest trees. The species and dbh (diameter at breast height) for each tree was also recorded. In addition, a general description of topography, soils, vegetation and other features of interest was made along each section line. I identified former barrens from these descriptions, and their locations were mapped on 6x6 grids corresponding to Congressional Townships. Information on tree species, dbh and distance from the center post was also recorded.

Practically all of the barrens of southcentral Indiana occur in Washington and Harrison Counties (Fig. 23), but only Harrison County will be discussed here. Barrens once covered about 53,000 acres (17%) of Harrison County and were confined to the Mitchell Plain (dashed lines). In Figure 24, the barrens are shown to be specifically confined to soils of the Baxter-Crider Association, which developed upon sinkhole topography (Soil Conservation Service 1975).

Perhaps just as striking is the relationship of the surrounding timber types to Indian Creek and Buck Creek. Oak-hickory forest ends at the western banks of these two streams, and a forest of white oak, beech and sugar maple begins (Table 4). An island of white oak, beech and maple occurs in the southwest corner of the county in an isolated segment of the Crawford Upland, while an island of oak and hickory occupies an area of heavy sinkhole concentration in the southeast corner of the county. Oaks and hickories are tolerant of fire, while beeches and maples are not.

The origins of prairies have been discussed by many authors (e.g., Gleason 1923, and Braun 1950). Most believe that the warm, dry conditions of the Xerothermic Period permitted the spread of the prairie into the Midwest. At the close of this period the prairies were gradually replaced by forests except where they were maintained by fires or by unusual soil or topographic features.

The sinkhole topography of Indiana and Kentucky probably permitted prairie vegetation to persist for three reasons:

1) The rapid percolation of water through the soil and rock left little soil moisture available for plant use. During times of drought, water stress and the increased chance of fire favored fire-adapted grasses and forbs over trees.

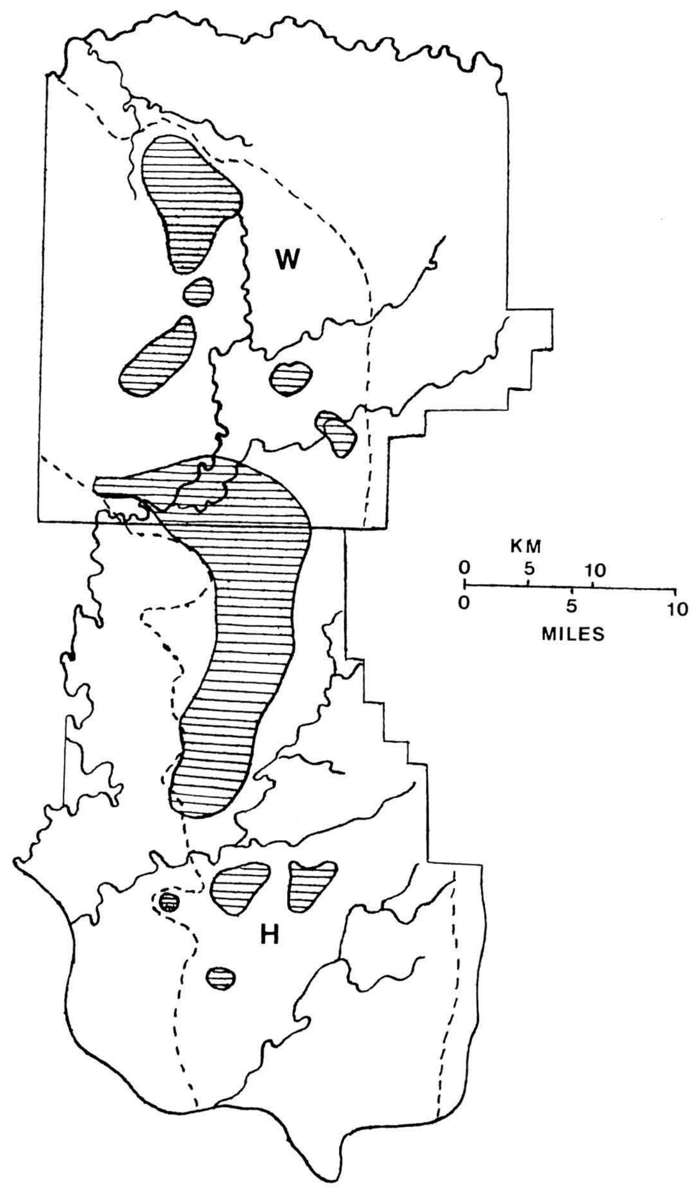

Figure 23. The barrens of southcentral Indiana were located mainly in Harrison (H) and Washington (W) counties. The dashed line represents the approximate eastern and western boundaries of the Mitchell Plain.

TABLE 4

A comparison of tree species frequency in the three major vegetation types of Harrison County. Fire-intolerant trees are virtually absent in the oak-hickory and barrens areas. Major species are those with a frequency of 0.05 or greater.

	OAK-HICKORY (N = 480)	BARRENS (N = 392)	WHITE OAK-BEECH-MAPLE (N = 425)
WHITE OAK	0.29	0.32	0.22
BLACK OAK	0.25	0.29	---
HICKORY	0.20	0.25	0.08
SUGAR MAPLE	0.05	---	0.10
TULIP POPLAR	---	---	0.08
BLACK GUM	---	---	0.05
DOGWOOD	---	---	0.05
	0.81	0.86	0.83

2) The lack of surface streams permitted fires to spread once started.

3) The great extent of sinkhole topography in Indiana and Kentucky permitted factors 1) and 2) to operate over a large area, increasing the chances for widespread fires and statistically decreasing the chances that prairie vegetation would vanish.

The fact that forest type in Harrison County changed from fire tolerant trees to fire intolerant trees across the major streams strongly suggests that fires were a major factor in maintaining the barrens. The fact that barrens were confined to areas of sinkhole topography further suggests that additional factors, such as severe soil moisture depletion, acted to maintain the barrens within strict geographical limits.

Settlement meant the suppression of wildfires and the erection of barriers such as roads, plowed fields, and towns which halted the spread of fires that did occur. The rapid change from barrens to forest following settlement indicates that the barrens were maintained in a delicate equilibrium, an equilibrium that was destroyed with the coming of white settlers.

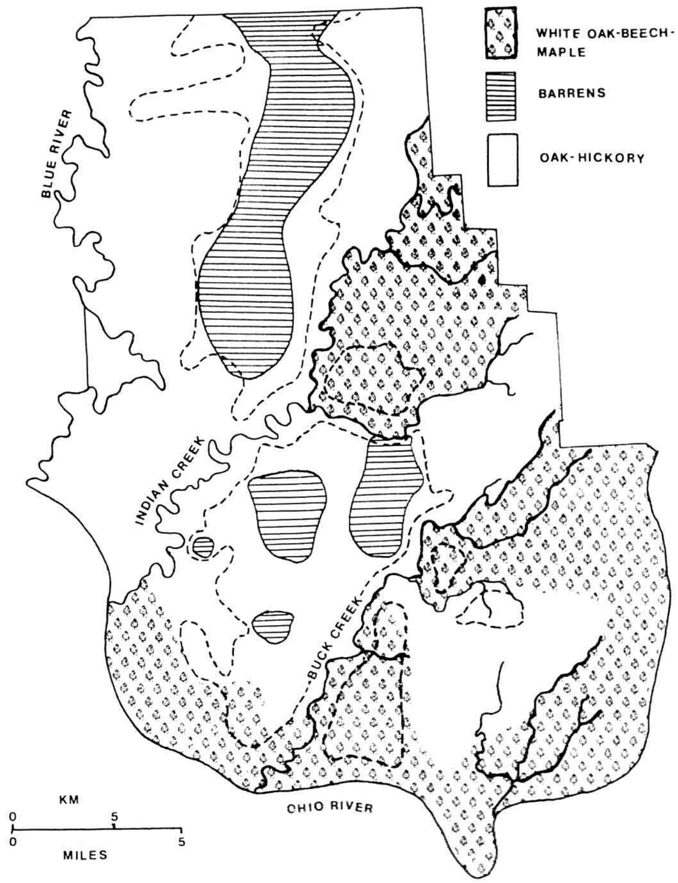

Figure 24. The barrens of Harrison County were maintained by a combination of factors. Baxter-Crider soils, enclosed by dashed lines, are found in those areas of greatest sinkhole density. Frequent fires, halted by the major streams, or by topography, probably favored oak-hickory forest and barrens west of those streams.

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Carbon Isotope Biogeochemistry of the Individual Hydrocarbons in Bat Guano and the Ecology of Insectivorous Bats in the Region of Carlsbad, New Mexico

David J. DesMarais

The structures and ^{13}C contents of individual alkanes extracted from bat guano found in the Carlsbad region of New Mexico can be related to both the photosynthetic pathways of the local plants and the feeding habits of the insects that support the bats.

Carbon isotopic analyses of the 62 most important plant species in the Pecos River Valley, the most significant feeding area for the Carlsbad bats, reveal the presence of 29 species with C3 photosynthesis and 33 species, mostly grasses, with C4 photosynthesis. Although the abundances of nonagricultural C3 and C4 plants are similar, alfalfa and cotton, both C3 plants, constitute over 95 per cent of the crop biomass.

The molecular composition of the bat guano hydrocarbons is fully consistent with an insect origin. Two isotopically distinct groups of insect branched alkanes were discerned (Fig. 25). These two groups of alkanes derived from two chemotaxonomically distinct populations of insects possessing distinctly

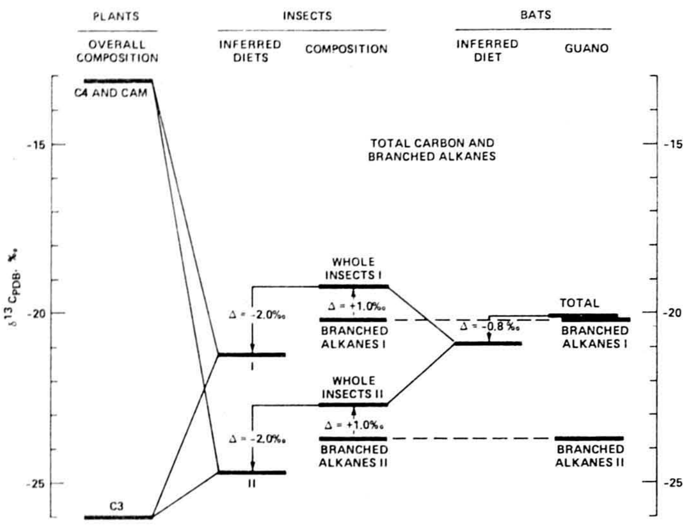

Fig. 25. Diagram representing the flows and isotopic compositions of bulk carbon and of branched alkanes in the plant-insect-bat ecosystem studied in this work. The existence of two isotopically distinct families of branched alkanes is used to infer the existence of two isotopically distinct insect populations that must have isotopically distinct diets derived from differing proportions of C3 and C4 plants.

different feeding habits. It is likely that one population grazes predominantly on crops whereas the other population prefers native vegetation. This and other isotopic evidence supports the notion that crop pests constitute a major percentage of the bats' diet.

Because the guano sample was less than 40 years old, this material reflects the present-day plant community in the Pecos River Valley. Future studies of more ancient guano deposits should reveal a measurable influence of both natural and man-induced vegetative changes with time upon the ^{13}C content of the bat guano hydrocarbons.

Archeology, Anthropology, and Paleontology

The Mammoth Cave system contains the greatest known assemblage of subsistence data of the Early Woodland time period (1200-200 B.C.), unequaled in quantity or quality anywhere in the world. It provided the first evidence of organized agriculture in the eastern part of the United States. The plant remains, preserved in paleofeces by dry sediments, document one episode of the most important revolution in man's life on earth, the domestication of plants and the shift from hunting and gathering to a farming way of life. These same Indians were the first explorers in Mammoth Cave, with footprints and torch remains nearly two miles into the cave.

Modern day action archeology experiments have tested the feasibility of Hypothesis derived from the prehistoric remains. CRF personnel clad only in swimming trunks found that dried cane and weed torches provided warmth and adequate light for several hours. But what were the Indians after in the cave? Concentration of artifacts in dry passages with sulphate minerals suggests that exploration was not their only purpose in venturing deep into the cave. Most of the activity seems to have involved pounding brown crusts of gypsum off walls rather than collecting the more spectacular gypsum speleothems shown in the accompanying photograph (Fig. 26). Experiments are needed to test the hypothesis that prehistoric Indians pounded off crusts of gypsum to encourage seasonal growth of epsomite and mirabilite which action archeology experiments have shown to be effective as a salt substitute or laxative, depending on dosage.

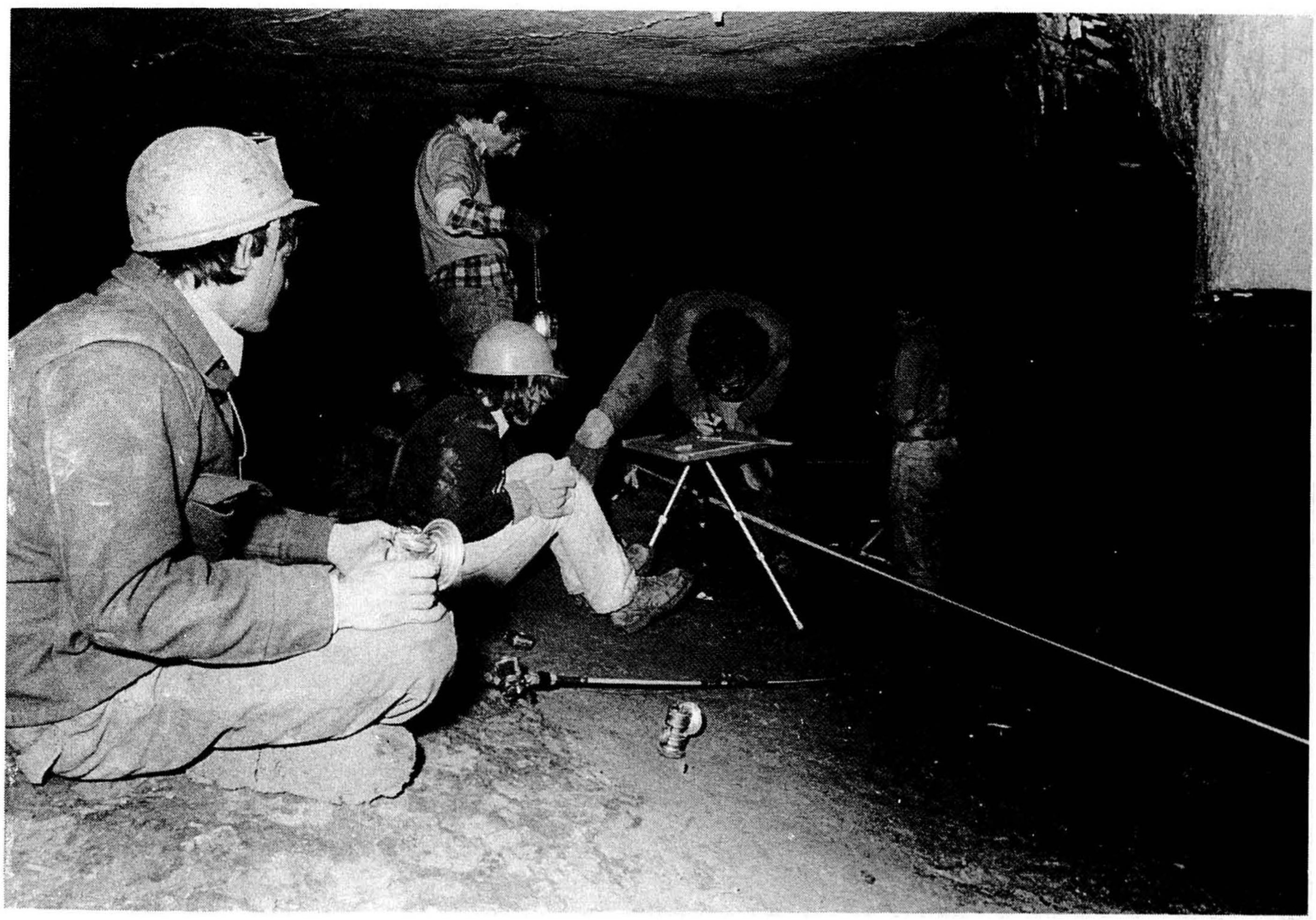

Figure 26. Jaguar Cave, Aborigine Avenue. Footprint mapping set-up. Photo by Jim Goodbar and Ken Russell.

In spite of successes with in-cave evidence of winter activity of prehistoric Indians, data from surface sites on other aspects of their life, and data on still older life in the region, fossils, remain elusive. There is a paucity of suitable surface sites for archeology and cave sites that have good preservation and stratigraphic control for paleontologists. Current surface archeological studies in Green River shellmound sites cover other time periods and the paleontological evidence is for individual species—including recent finds of long-nosed and flat-headed peccaries, mastodon, and short-faced bear—instead of faunal assemblages that would allow inference about past climates and communities. The recent ongoing studies in Jaguar Cave, discussed in this and last year's Annual Reports, may fill in some of both the archeological and paleontological missing pieces. The large number of human footprints in Jaguar Cave will allow anthropologists to reconstruct something of the Indians' stature and size. The hope is that we may someday reconstruct as detailed a past history of the Kentucky-Tennessee cave area as that provided by plant remains from fossil cave rat middens in caves of the Southwest.

CRF Archeological Project and Shellmound Archeological Project, 1979

Patty Jo Watson

As in previous years (see CRF Annual Reports for 1976, 1977, 1978), our archeological work took place in Mammoth Cave National Park, in the Big Bend of Green River near Logansport, Kentucky, and also in Jaguar Cave, Tennessee. Research done underground in Mammoth Cave National Park and vicinity, and in Jaguar Cave is referred to under the heading of the CRF Archeological Project. Related investigations focusing upon prehistoric shellmiddens in the Big Bend of the Green River (some 40 miles west of the Park) are referred to as activities of the Shellmound Archeological Project.

Cave Research Foundation Archeological Project, 1979

On July 22 Ken Carstens and Pat Watson presented the evening interpretive lecture at Mammoth Cave National Park: "Archeology of the Mammoth Cave Area." Carstens described the surface archeological sites (primarily rock shelters), while Watson related present understandings about the aboriginal spelunkers of Mammoth Cave, Salts Cave, and Lee Cave.

Carstens remained in the Park for two more days with a small crew to complete backfilling one of the sites previously tested.

On September 22 and again on November 22 archeological crews journeyed to Jaguar Cave in northern Tennessee to continue detailed mapping of the 4500 year-old human footprints

Figure 27. Jaguar Cave, Aborigine Avenue, near junction with Tremendous Trunk. Photo by Jim Goodbar and Ken Russell.

in Aborigine Avenue (CRF 1977 Annual Report, pp. 39-45). We still use the technique devised and equipment lent by Pat and John Wilcox on the first mapping trip in February, 1977 (Fig. 27). On both of the 1979 trips, Mike Fuller (Washington University graduate student and CRF JV-Arch.) was in charge of the mapping. So far we have cataloged 227 individual prints and have mapped about 200 of them. Two more trips should enable us to complete the mapping of all the prints clear enough to be accurately recorded. Louise Robbins is analyzing the footprint data, which seem to pertain to 8 or 9 individuals, some barefoot, some wearing soft footgear probably like the vegetable fiber slippers found in Salts Cave and Mammoth Cave.

During the September trip, Ron Wilson showed us where he and small crews of NSS and CRF cavers have been recovering fragments of fossil animal bone from a talus cone elsewhere in Jaguar Cave. The list of species found so far is long, and many—such as tapir, mastodon, and camel—are extinct forms.

Three cave photographers joined the November 22 Jaguar Cave trip: Diana Daunt, Jim Goodbar, and Ken Russell. Ron needed documentation of the paleontological findspots, and we also needed some cave room and passage photos (Figs. 28-29) to add to the fine pictures Roger Brucker and Mark Elliott took of the footprints two years ago.

The November 22 trip was outstandingly successful from both the cartographic and the photographic points of view. The footprint mapping crew, by superhuman concentration, completed the mapping and recording of 57 prints, while the photo teams obtained excellent black-and-white and color documentation of the cave passages.

Shellmound Archeological Project, 1979

A three-week field season (July 15 to August 7) was completed at the Carlston Annis shellmound (15Bt5) near Logansport in the Big Bend of Green River, Kentucky. We finished the phase of excavations begun in June, 1978 (for a summary see *CRF 1978 Annual Report*, p. 49). Our most exciting discovery was of a series of burned features (probably portions of ancient occupation horizons or walking surfaces) that might represent places where mussels were steamed or other foods were prepared.

Besides completing the sample of detailed debris maps begun last summer, we excavated a 1 x 1 m pit (D14-2) to sterile soil at some 2 m below the surface. The deposit from pit D14-2 is being analyzed by David Baerreis (gastropods), Gail Wagner (charred plant remains), Lathel Duffield, and Ron Wilson (animal bone). These analyses plus some new radiocarbon dates (now under negotiation with the University of Georgia radiocarbon laboratory) should help clarify the context of the early cultigen—squash—found at the site 3 years ago (see *CRF 1977 Annual Report*, and Chomko and Crawford 1978). This squash is apparently the same gourd-like species grown by the Indians who

Figure 28. Jaguar Cave, interior, between the cave entrance and The Towering Inferno. Photo by Jim Goodbar and Ken Russell.

mined and explored the Flint-Mammoth Cave system. Both prehistoric groups probably valued it more as a container (but one with edible seeds) than as a dietary item.

Members of the Shellmound Project also spent several days in the Big Bend during October (October 12-16) accumulating data on the characteristics of the weedy plants whose seeds were gathered by the Salts Cave-Mammoth Cave and other Late Archaic/Woodland groups in the eastern U.S. Under the supervision of archeobotanist-archeologist Wes Cowan we collected seeds of sumpweed (*Iva annua*), giant ragweed (*Ambrosia trifida*), and knotweed or smartweed (*Polygonum* sp.).

Sumpweed (as well as squash, gourd, sunflower, and possibly goosefoot weed) was cultivated by the aboriginal explorers of Salts and Mammoth Caves but seemingly not grown nor much used by the prehistoric inhabitants of the Carlston Annis site.

Shellmound personnel presented two symposia describing work at the Carlston Annis site: one on April 23 at the Society for American Archaeology meetings in Vancouver, and one on November 9 at the Southeastern Archaeological Conference meetings in Atlanta.

Acknowledgements

Our research in Mammoth Cave National Park was aided by Superintendent Amos Hawkins and his staff; we are very grateful for their help and encouragement. The Shellmound Archeological Project was partially supported in 1979 by NSF grant BNS78-08916. Our work in the Big Bend is made possible and highly enjoyable by the interest, support, and hospitality of the Logansport people, especially Mr. and Mrs. Waldemar Annis and Mr. John L. Thomas. We can never repay their kindness to us over the years since we began work in the Big Bend. In the Jaguar Cave area, we are thankful to Mr. James Williams, Mr. and Mrs. J.C. Copley, and the Misses Lera and Loma Pile for their continuing interest and help.

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Reanalysis of the Nelson faunal collections from Mammoth and Salts Caves

Ronald C. Wilson

In 1916 N.C. Nelson of the American Museum of Natural History conducted archeological investigations in the Mammoth Cave area. Examination of the animal bones recovered during these excavations revealed information not presented in the original report (Nelson 1917) as well as several mis-identifications by the original faunal analysts.

The following species reported from Mammoth Cave by Nelson were found to be *not* present in the collection: big brown bat (*Eptesicus fuscus*), bobcat (*Lynx rufus*), porcupine (*Erethizon dorsatum*), and mud turtle (*Kinosternon subrubrum*). Species present in the collection but not reported earlier include eastern pipistrelle (*Pipistrellus subflavus*), brown bat (*Myotis* sp.), raccoon (*Procyon lotor*), fox squirrel (*Sciurus niger*), and sheep or goat (*Ovis* or *Capra*). Two identifications that were tentatively presented in the original report were confirmed in the present study: wild turkey (*Meleagris gallapavo*), and whooping crane (*Grus americana*). In addition, the collection contains 28 large bird bone fragments of which perhaps 12 are potentially identifiable. Many of these are probably turkey bones, but an owl may also be represented. The carapace originally identified as mud turtle is actually a box turtle carapace modified into a vessel by grinding away the vertebrae and smoothing the marginal plates. The presence of sheep or goat bones in the collection indicates mixing of historic and prehistoric strata.

The Salts Cave bone collection had not previously been analyzed. Subsequent work by Watson (1974) and Duffield (1974) has added much to the knowledge of that site. Results of the present analysis of the bones from both Mammoth Cave and Salts Cave are presented in Table 5. Possible interpretations are limited by the lack of detailed provenience data and by the biased nature of the sample.

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Vertebrate paleontology in Kentucky and Tennessee, 1979

Ronald C. Wilson

Activities during 1979 centered on development of a vertebrate paleontological research program in Kentucky. This work was possible through the cooperation and support of National Park Service personnel, Cave Research Foundation and National Speleological Society volunteers, Carnegie Museum of Natural History, NSS Research Advisory Committee, University of Louisville Archaeological Survey and Department of Biology, and numerous land owners. Activities have been diverse but can be summarized as follows:

I. Study of Existing Collections

A catalogue of vertebrate fossils previously reported from Kentucky has been compiled via library research and examination of museum collections. Collections of Kentucky vertebrate fossils have been examined in the following institutions: American Museum of Natural History, Carnegie Museum of Natural History, U.S. National Museum of Natural History, University of Kentucky, and University of Louisville.

TABLE 5
Summary of bones recovered during the 1916 excavations by N.C. Nelson in the Mammoth Cave and Salts Cave vestibules and preserved in the collections of the American Museum of Natural History

SCIENTIFIC NAME	COMMON NAME	MAMMOTH CAVE		SALTS CAVE	
Mammalia	Mammals	Frags	MNI*	Frags	MNI
Pipistrellus subflavus	Eastern pipistrelle	9	5	-	-
Myotis sp.	Little brown bat	1	1	-	-
	Small bats	12	-	-	-
Didelphis virginianus	Opossum	3	1	1	1
Procyon lotor	Raccoon	2	1	-	-
Canis familiaris	Dog	15	2	-	-
Ursus americanus	Black bear	1	1	-	-
Sciurus carolinensis	Gray squirrel	-	-	1	1
Sciurus niger	Fox squirrel	1	1	-	-
Cervus elaphus	Elk	13	2	-	-
Odocoileus virginianus	White-tailed deer	83	3	2	1
Ovis or *Capra*	Sheep or goat	6	1	-	-
Homo sapiens	Human	4	2	14	2
	Large mammal	65	-	18	-
Aves	Birds				
Meleagris gallopavo	Wild turkey	1	1	8	2
Grus americana	Whooping crane	1	1	8	2
	Large bird	26	-	5	-
Reptilia	Reptiles				
Terrapene carolina	Box turtle	3	2	1	1
	TOTALS	246	23	50	8

*MNI = minimum number of individuals

II. Mammoth Cave National Park

Cave passages in Great Onyx Cave, Mammoth Cave ridge, and Proctor Cave have been examined in search of fossil bones. Edwards Avenue in Great Onyx Cave produced the bones of gray squirrel and domestic chicken, probably the remains of an early explorer's lunch. Passages in Mammoth Cave ridge have produced isolated remains of extant mammals such as woodrat, raccoon, deer, black bear, etc., but no extensive bone deposit has yet been found. The most productive passages have been those in Proctor Cave. Extinct mammals collected in Proctor Cave during 1979 include great short-faced bear, *Arctodus simus*; flat-headed peccary, *Platygonus compressus;* long-nose peccary, *Mylohyus nasutus;* tapir, *Tapirus*; and mastodon or mammoth, *Mammut* or *Mammuthus*. This is the first time extinct mammals have been reported from Mammoth Cave National Park. Analysis of the material is not complete at this writing.

III. Northern Tennessee

In this and earlier (1976, 1977) Cave Research Foundation Annual Reports, Patty Jo Watson has reported briefly on paleontological work in Jaguar Cave, Tennessee. In addition to the two jaguar skeletons previously reported, recent explorations in the cave have produced much of paleontological interest. More than 1.5 miles of passages containing fossil jaguar footprints and claw marks have been found. A large talus cone deposit was found to contain the remains of more than 50 vertebrate taxa. Extinct forms include horse, *Equus*; tapir, *Tapirus*; long-nosed peccary, *Mylohyus nasutus*] dire wolf, *Canis dirus*; and mastodon, *Mammut americanum*. Two nearby crawlways produced a tooth of an extinct camel, *Camelops,* and a fragment of a human skull. Neither the camel nor the human remains is directly associated with the talus deposit. The camel tooth represents the first confirmed record of this genus from east of the Mississippi River. Study of Jaguar Cave is continuing.

IV. Other Kentucky caves

Numerous cavers have reported caves throughout Kentucky that contain potential vertebrate paleontological sites. Test pits were excavated in two of these caves during 1979. Icebox Cave, on Pine Mountain in southeast Kentucky, produced a diverse fauna including long-nosed peccary, *Mylohyus nasutus,* and several small mammal species that no longer occur in Kentucky. Cutoff Cave, in Trigg County, southwestern Kentucky, contains a prehistoric carnivore den with abundant vertebrate remains. No extinct forms have yet been found in the cave. Analysis of bones from both of these sites is continuing. Additional sites are being sought.

Within species variation in a local population of Mammoths

Barbara Dutrow

Six field seasons of excavation at the Hot Springs Mammoth Site, South Dakota were climaxed by the designation of the site as a National Landmark and the recognition of its uniqueness among fossil elephant localities. The prominence of the site is due to: 1. The quantity of Mammoths preserved; 2. the exclusiveness of the trap, i.e., Mammoth specific; and 3. the unusual geologic mode of entrapment.

Sedimentological studies this summer further substantiated the theory of entrapment. That is, a subjacent karst depression, oval in shape with vertical to overhanging walls, contained a standing body of water less than 5 m in depth and was recharged by one main feeder spring. Of note also is the latest finding that the Mammoth site pond was fed by geothermally heated water. Temperatures of at least 35°C (95°F) were maintained year-round and may have been a megafauna attractant, especially in the winter months.

Excavation during July and August uncovered an additional 308 skeletal elements of *Mammuthus columbi* including 6 complete crania, five with ivory intact, and perhaps the most spectacular find, that of a nearly complete articulated adult mammoth skeleton. With the recovery of these elements, the total number of individual mammoths rose to 29. To my knowledge, this is the largest accumulation of Columbian mammoths in a single locality in North America and probably in the world. The site remains essentially a "mammoth exclusive" trap. Previously unearthed were a single element each of camel, peccary, coyote, bear, and a raptorial bird. No new species were added. Screenwashing of the spring conduit sands has yielded terrestrial microvertebrates and a few invertebrates.

My study is one of the first attempts to quantify the intraspecific variation observed within one local population of *Mammuthus columbi*. Its importance lies in that fact that the mammoths are from a geographically restricted area and represent a relatively short time span. Therefore, variation due to environmental/ecological factors is at a minimum. Traditional identification of mammoth species has been based on molar characters, usually of isolated finds. It is therefore important to ascertain the variation observed from a single locality, noting the overlap of certain characters in our local population with those of other previously described species. This may necessitate a redefinition of criteria used for determination of North American mammoth species.

Fellowship and Grant Support

Each year the Foundation sponsors a karst-related Research Fellowship ($750) and/or Grant ($300) for qualified students in graduate programs of the natural or social sciences. Applications are screened and evaluated by a committee of scientists. The judges seek promising or innovative topics, supported by evidence that the student has a command of the literature and methodology. A detailed announcement is mailed on 1 January; the deadline for the receipt of the detailed proposal, supporting documents, and letters of reference is 15 February. Announcement of the award is 15 March. Send proposals in triplicate to Dr. David J. DesMarais, Mail Stop 239-12, NASA-Ames Research Center, Moffett Field, California, 94035.

A list of past Fellowships (F) and Grants (G) awarded follows:

1967 (F) David C. Culver, Yale University, "The ecology of cave crustacea from West Virginia"

(G) Paul Goldberg, University of Michigan, "Cave sediments of the Near East"

1968 (F) Alan P. Covich, Yale University, "Paleoecology of lacustrine bored shells and ultrastructural diagenesis"

(G) David C. Culver, Yale University, "The ecology of crustacea from West Virginia"

1969 (F) Thomas E. Wolfe, McMaster University, "Clastic sediments of the Greenbrier Series in West Virginia"

1970 (F) John W. Hess, Pennsylvania State University, "Hydrology of the Central Kentucky Karst"

1971 (F) Horton H. Hobbs III, Indiana University, "A study of the crayfish and their epizootic ostracods in Pless Cave"

1972 (F) Russell S. Harmon, McMaster University, "Ages and paleoclimates of karst areas based on isotope distributions in speleothems"

1973 (F) Thomas C. Kane, Notre Dame University, "A comparison of foraging strategies: *Neaphaenops tellkampfii* vs *Pseudanophthalmus menetriesii*"

(F) Russell M. Norton, Yale University, "Convergent Predator-Prey systems in two Kentucky Plateau karsts"

(G) David Jagnow, University of New Mexico, "Factors controlling speleogenesis in the Capitan Reef Complex, New Mexico and Texas"

1974 (F) Stephen O. Sears, Pennsylvania State University, "The inorganic and stable isotope geochemistry of groundwater recharge through unsaturated soils in a carbonate terrain"

(G) Kenneth C. Carstens, Washington University, "Surface archeology of the Mammoth Cave National Park area"

(G) Glenn D. Campbell, Texas Tech University, "Activity rhythms of the genus *Ceuthophilus* (Orthoptera)"

1975 (F) Mickey W. Fletcher, Southwest Missouri State University, "Microbial ecology of bat guano"

(G) Barbara J. Martin, University of Illinois at Chicago Circle, "Cave communities around bat guano"

(G) Jim I. Mead, University of Arizona, Pleistocene plant and animal remains in Vulture Cave, Arizona"

1976 (G) David L. Bechler, Saint Louis University, "A genetic analysis of epigean and hypogean populations of *Gammarus* and *Crangonyx* (Amphipoda: Gammaridae)"

(G) Stephen A. Chomko, University of Missouri at Columbia, Small mammalian fauna as environmental indicators: A case study in northwestern Wyoming"

1977 (F) Ernst H. Kastning Jr., University of Texas, "Geomorphology and hydrology of the Edwards Plateau Karst, central Texas"

1978 (G) Ardith K. Hansel, University of Illinois at Urbana, "Form as an indicator of process in karst landscapes"

(G) Barbara Lee Dutro, Southern Methodist University, A study of Mammoths from a karst faunal trap, Hot Springs, South Dakota"

1979

(G) Sara A. Heller, West Virginia University, "A hydrologic study of the Greenbrier limestone karst of central Greenbrier County, West Virginia"

(G) David W. Bolton, Indiana University, "The hydrogeology and geochemistry of the Mitchell Rain Karst"

(G) William J. Resetarits, St. Louis University, "Ecological studies of cave-associated populations of pickered frogs"

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Kane, Thomas C. 1979. Genetic variability and similarity in the carabid cave beetle *Neaphaenops tellkampfi.* Annual meeting of the Society for the study of Evolution, Boulder, Colorado; June.

Kane, Thomas C. 1979. Ecological genetics of *Neaphaenops tellkampfi.* Annual Meeting of the National Speleological Society, Pittsfield, Massachusetts; August.

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-Annual Meeting of the Society for American Archeology, Vancouver, British Columbia, Canada; April.

-Southeastern Archeological Conference, Atlanta, Georgia; November.

Seminars, Talks, and Services.

Talks

Hobbs, Horton H. III. 1979. The Ohio Cave Survey. Meeting of the Central Ohio Grotto of the National Speleological Society, Fairborn, Ohio; April.

McCoy, Gail. 1979. Analysis of the structural control of speleogenesis of Lilburn Cave, California. Meeting of the Friends of the Karst, Ely, Nevada; September.

Poulson, Thomas L. 1979. Ecological and evolutionary studies in caves. Smithsonian Tropical Research Institution, Barro Colorado Island, Panama; April.

Seminars

Hobbs, Horton H. III. 1979. Cavernicolous crayfishes of North America. Graduate colloquium, Colorado State University, Fort collins; October.

Wilson, Ronald C. 1979. Prehistoric vertebrates from Kentucky caves. Biology Department, University of Louisville, Louisville, Kentucky; November.

Service

Research Advisory Committee of the National Speleological Society
- -Hess, John W., Chairperson
- -Poulson, Thomas L.
- -White, William B.

Editorial Board, *Bulletin* of the National Speleological Society
- -Watson, Patty Jo: anthropology
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Speleologia

A series of books of general and scientific interest on caving and karst research.

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Conservation Program

Caves are especially fragile. Their features and their organisms take hundreds of thousands of years to form and evolve, respectively. Unlike the surface, there are no green plants which, through succession, restore the natural landscape after disturbance. And many species are so specialized and have such small populations that they may not be able to adapt to great changes in their environment. Such is the case with the Endangered Mammoth Cave Shrimp pictured here in a photo by Thomas C. Barr Jr. (Fig. 29).

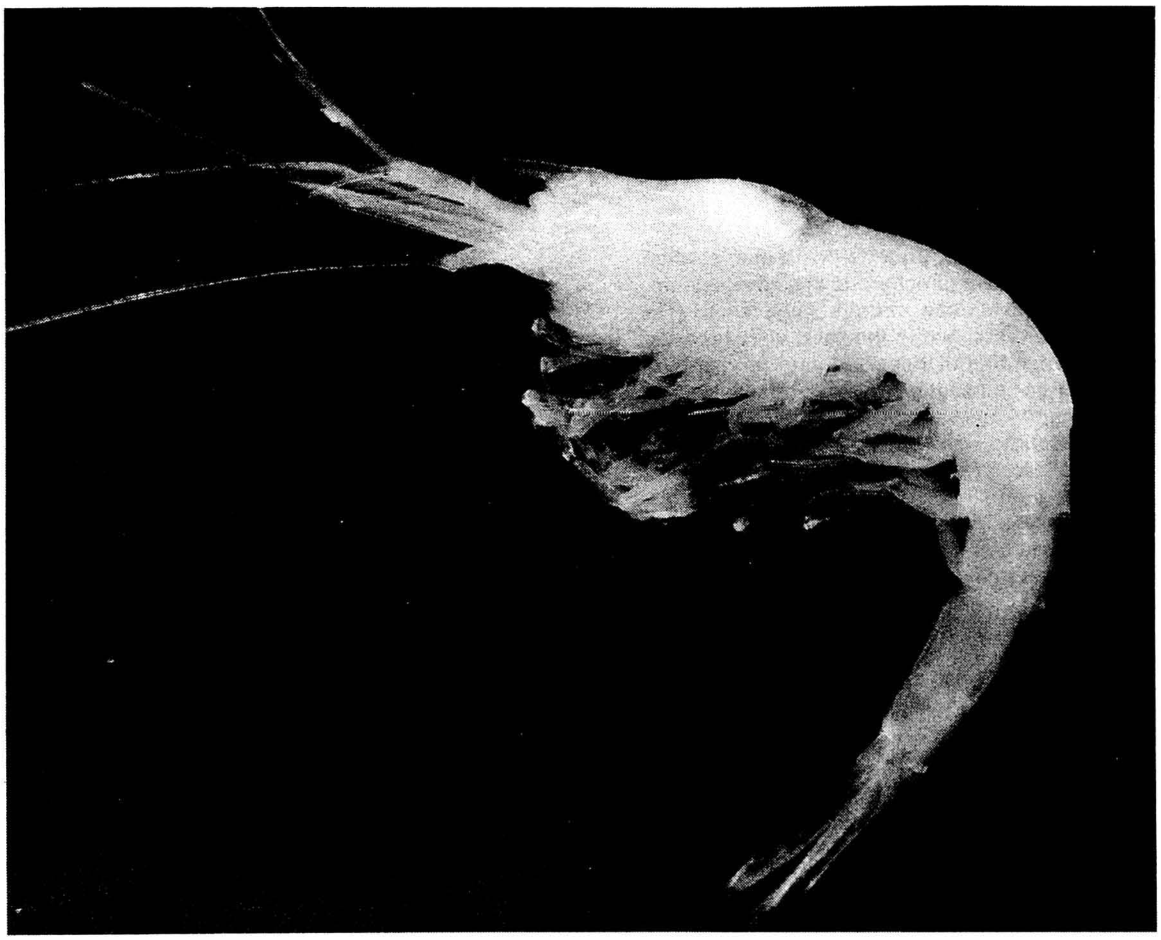

Figure 29. Shrimp feed in quiet water on bacteria and protozoans on fine organic matter. They feed on the bottom and even while hovering upside down at the water surface or under ledges. They appear to sift through the substrate with their front brushy claws and pick the material off the claws with their mouthparts which sort and strain the material further.

The shrimp are usually not seen while feeding since they are nearly transparent. They are generally observed when swimming in open water and are often first detected by their shadow moving across the bottom. They swim slowly, between bouts of feeding, by continuous sculling of the many paddle-like pleopods on the underside of their abdomen. The body is held fairly rigid and they appear to hover as they move slowly forward. If disturbed they rise quickly to the surface, swim forward for a few moments, and then settle slowly to the bottom again. This makes them easy prey for cavefish. This is in contrast to crayfish which perform staccato, backward, escape-swimming by repeatedly flexing their abdomen.

Conservation at Mammoth Cave

Roger W. Brucker

In 1979 CRF dealt with a variety of conservation challenges that threatened Mammoth Cave National Park. These threats led CRF to new ground, some of which include building relationships with other groups interested in the park, joining a lawsuit, negotiating with the U.S. Corps of Engineers to remove Lock and Dam No. 6 on the Green River, negotiating with the Environmental Protection Agency and a citizens committee to implement a farsighted 201 sewage plan for the Mammoth Cave watershed, protecting an off-park entrance to Mammoth Cave, negotiating with the National Park Service to improve the Master Plan, and meeting with the Central Kentucky Karst Coalition to further conservation aims.

Especially active in these efforts were Kip Duchon, Ed Lisowski, Ron Wilson, Cal Welbourn, Sarah Bishop, Bill Bishop, and Amos Hawkins. These individuals were supported by numerous Joint Venturers who pitched in willingly to help protect the caves.

Job Corps Removal Promised

At the start of 1979 Great Onyx Job Corps Center sewage lagoons were found to be leaking directly into the cave system. A series of such incidents extending through August, coupled with repeated breakins and vandalism to the cave, were reported in the newspapers. With editorial support, and protests by conservationists, patch-up measures were exposed as inadequate. In June a comprehensive article describing the Center as a menace to the resource was written by Bill and Sarah Bishop and published in the "National Parks & Conservation Magazine."

Near the end of June the National Parks & Conservation Association and CRF filed suit against the NPS to seek a restraining order against enlarging the Job Corps Center. At the first hearing, the government filed an affidavit agreeing to move the Center off Flint Ridge. In the course of the ongoing proceedings the judge ordered the NPS to produce a hitherto secret agreement to keep the Center on Flint Ridge, in direct violation of the intention stated in the approved Master Plan. At the end of the year the suit had not been resolved, although the NPS had purchased over 300 acres of land at the northwest corner of the park as a relocation site. Target date for this removal is summer of 1981. In August Supt. Amos Hawkins was transferred, according to one newspaper account, as Congressman Natcher's price for agreeing to relocate the Job Corps.

Lock and Dam No. 6

CRF representatives met with the Corps of Engineers and their consultants several times regarding the Corps' proposal to remove abandoned navigation Lock and Dam No. 6 on the Green River. CRF and the NPS have held in the past that the artificial pool, created in 1907, adversely impacted the aquatic habitats of the cave. In September CRF investigators found a dead specimen of the endangered Mammoth Cave blind shrimp in Roaring River in Mammoth Cave. The species was thought to be extinct. To biologists the species is the index to all similarly threatened species. At year's end, a CRF team was preparing an environmental statement on the impact of Lock and Dam No. 6, at the request of the Corps.

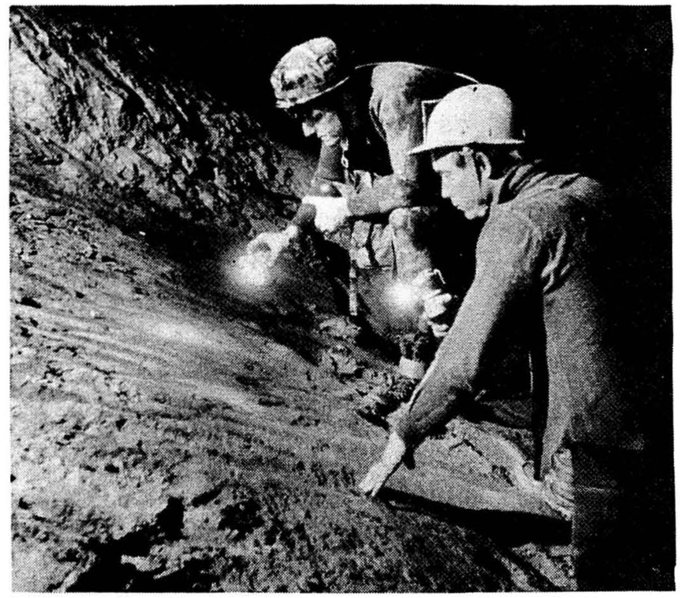

Figure 30. C.R.F. surveyors examine cave crayfish killed in Amos Hawkins River by presumed hydrocarbon pollution. Many of the crayfish crawled out onto the bank in an unsuccessful effort to escape the pollution. One of the several crayfish in the photo is centered in the beam of the carbide lamp. Photo by Pete Lindsley.

Regional Sewage Plan

In August a cave area citizens committee formally recommended the adoption of Alternative 2, a wastewater treatment plan that would provide maximum protection for Mammoth Cave as well as the region. CRF consulted with the EPA and the NPS to try to advance the knowledge of both groups about the importance of this plan to the protection of the national treasure that is Mammoth Cave. The NPS has signalled its willingness to participate "more than its fair share," but whether the EPA will select the best plan remains to be seen.

In both Lock and Dam No. 6 and the 201 Study, CRF's consulting has been based on more than 20 years of gathering scientific data on the cave. In relation to these issues the professional level of advice from CRF has focused nationwide concern.

Entrance Protection and Pollution

A hidden problem underlay the discovery of the connection between Mammoth Cave and Proctor Cave in Joppa Ridge. Hawkins River, the major underground trunk drainage, also connected to a cave entrnace located off park lands. CRF concealed the existence of this entrance while entering into negotiations with a friendly landowner to lease the entrance. A provision of the lease permitted CRF to erect a gate to control possible unauthorized entry and vandalism.

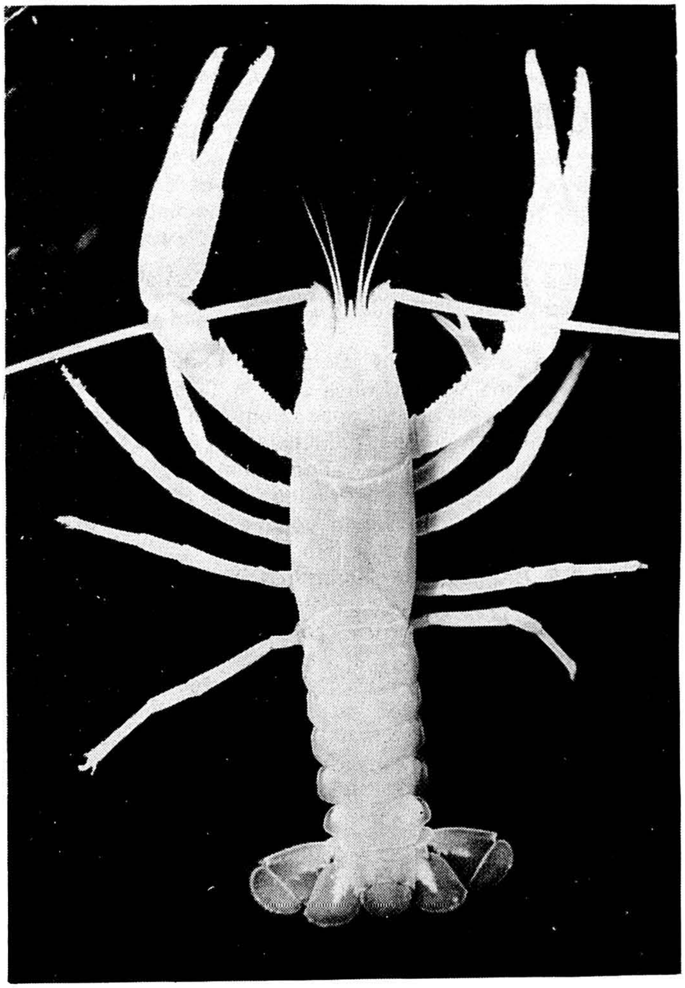

Figure 31. *Orconectesd pellucidus,* approximately natural size. Photo by R. Norton.

A related problem was the documentation of a hydrocarbon fuel spill that killed scores of cave crawfish in Hawkins River (Figs. 30-31). The source appears to have been a wreck of a tanker truck carrying diesel fuel on I-65 near Cave City in June. An attempt to identify the constituents of the pollution through analysis was inconclusive.

Master Plan Consultations

At the close of the year CRF held several meetings with NPS officials, both at Mammoth Cave and at Southeast Regional Headquarters in Atlanta. The subject was the implications and management problems of the summer's major discoveries. What were the implications for the proposed visitor staging area at Union City? Those consultations are continuing.

The Central Kentucky Karst Coalition invited CRF to discuss various matters of concern, including cooperative conservation efforts. This continuing dialogue promises a working cooperation in the months and years ahead.

Mammoth Cave—A good Master Plan in trouble

William P. Bishop and Sarah C. Bishop

In 1976 an imaginative and well developed master plan for Mammoth Cave National Park was published by the National Park Service. The plan was the result of over ten years of painful public airing of controversial proposals and ideas. The principle of protection to the one-of-a-kind underground feature of the park was firmly placed at the center of the plan. Facilities were to be moved to the periphery of the park, including a Job Corps Camp which the plan termed a "dangerous intrusion." But any plan spawned in controversy is sure to be difficult to implement. This one was no exception.

An idea that seemed good in 1965, the Job Corps Camp at MCNP has a fourteen year history of problems. By the early 1970s training projects in the park had been exhausted, and park managers were seeking alternative sites at other parks. Soon thereafter, the temporary dormitories were shown to be severe fire hazards. The sewage lagoons have overflowed, polluting the underlying caves, and corpsmen have entered and vandalized the caves of Flint Ridge. With all of this on the record, strong pressures must have been exerted to keep the camp in place. The local Congressman and an influential concessionaire exerted such pressures, and the NPS delayed all action over a period of seven years.

The winter of 1978-79 brought more examples of the "dangerous intrusion" of the camp, with sewage overflow and strongly worded safety reports. The National Parks and Conservation Association and others brought their own pressure to bear, and in early 1979 an internal task force report persuaded NPS Director, William Whalen, that the camp had to be closed. Congressman Natcher agreed, the corpsmen were moved to temporary quarters, and a new search for a site began. But the public meeting to discuss the possible sites was incredibly hostile; the citizens wanted the buffer of the park lands between them and the camp. No site outside the park would seem acceptable. And the NPS began "temporary repairs" to the old camp.

The Master Plan is a good one, and the removal of the Job Corps Camp is overdue. But the Master Plan is only as good as those who administer it. The dedicated work of two recent superintendents may be partly lost because their superiors lack the commitment made in the signing of the Master Plan for Mammoth Cave National Park.

Report on the New Melones Harvestman, *Banksula melones*

Barbara J. Martin

This report is based on a project sponsored by the U.S. Office of Endangered Species. Barbara J. Martin was partially supported by The World Wildlife Fund-Canada as the Biological Assistant on the project, D. Craig Rudolph was Principal Investigator and Steve Winterath was General Assistant.

The purpose of this 1979 project was twofold: 1. To search for new populations of *Banksula melones* along the Stanislaus River but above the highest proposed level of the New Melones Reservoir; and 2. To evaluate the success of the 1977-78 transplant of *Banksula melones* to a mine above flood level.

History of the New Melones Dam

The origin of this project, concerning the cave harvestman, lies in the somewhat tangled political history of the New Melones Dam on the Stanislaus River,a brief outline of which follows:

In 1944 Congress gave permission for the construction of a new dam on the Stanislaus River, to provide water resources and flood control beyond those already provided by the existing reservoir and dam. The area to be affected includes the upper Stanislaus River and its tributaries on the western slope of the Sierra Nevada Mountains in Calaveras and Tuolumne Counties, California.

The United States Army Corps of Engineers began construction of the New Melones Dam in 1966. Since then there has been a great deal of opposition from many conservation and recreation groups, principally the Sierra Club (an outdoor recreation group), the National Speleological Society (a caving organization) and the Friends of the River (a broad-spectrum organization including commercial rafting enterprises, conservationists, naturalists, etc.).

In 1971 T.S. Briggs of the California Academy of Sciences, who had been studying cave harvestmen of the area informed the Army Corps that one of the species, *Banksula melones*, was endangered by the dam. It was known from only two caves (Fig. 32) — McNamee's Cave, situated in a quarry eventually to be destroyed by quarrying activities, and McLean's Cave, a cave to be flooded by the new reservoir. He recommended the species for endangered status (endangered species are protected by law in the United States). He also suggested transplanting some harvestmen to a suitable habitat above flood level.

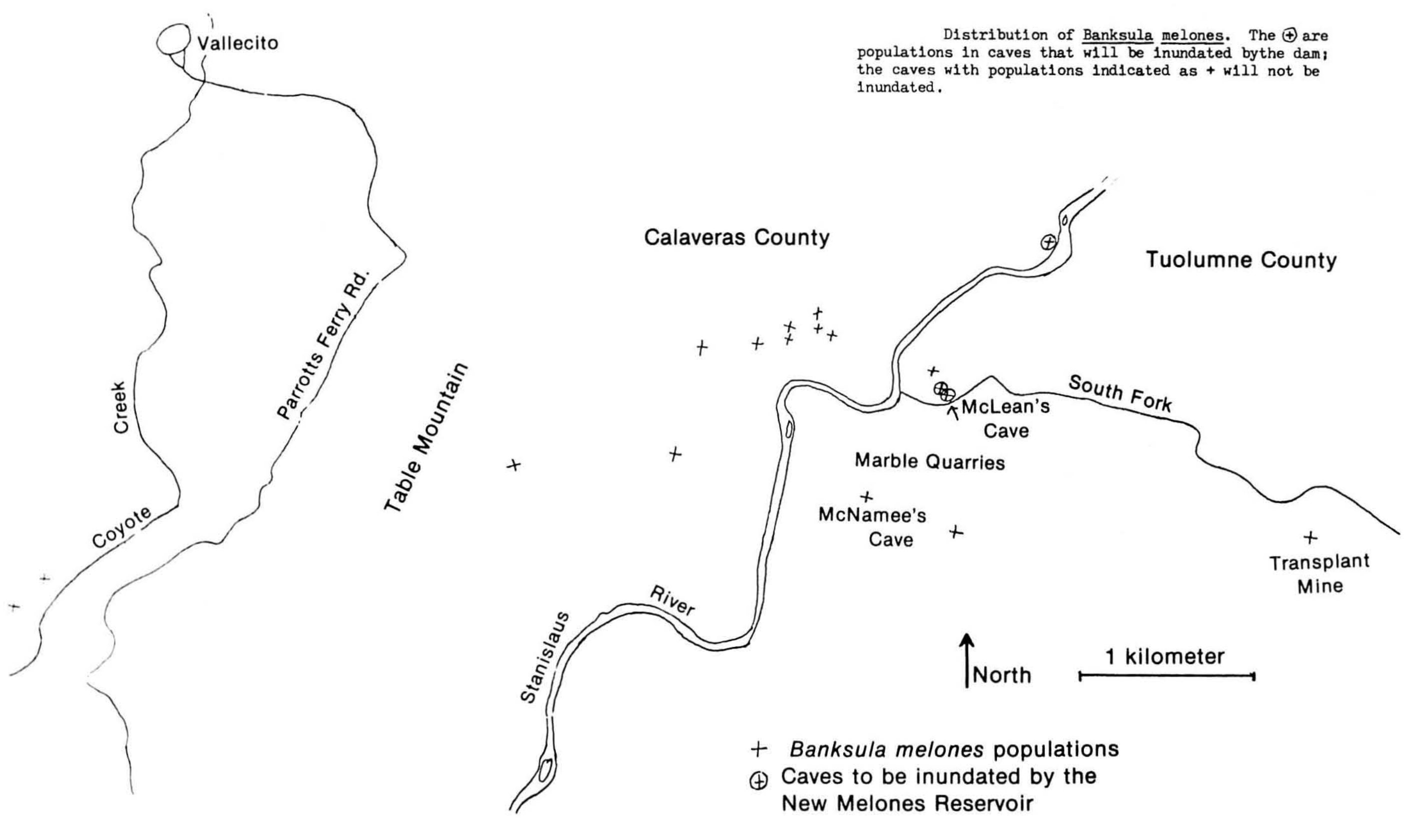

Figure 32. Distribution of *Banksula melones*. The (+) are populations in caves that will be inundated by the dam; the caves with populations indicated as ÷ will not be inundated.

In 1972 the Army Corps published an environmental impact statement which was considered inadequate by the groups in opposition to the dam. As a result the Army Corps contracted another group to evaluate the impact of the dam (McEachern and Grady 1978). The National Speleological Society, concerned about the number of caves to be affected, independently published an evaluation of the impact of the dam on caves and recommendations for management of the cave resources (Squire 1972).

In response to Briggs' suggestion to transplant the threatened harvestman, he was contracted by the Corps in 1975 to introduce some harvestmen to a relatively ecologically empty system—a 50-year old mine situated in limestone (Fig. 33). The introduction was presumed a failure when no *Banksula melones* could be found in the mine after several years.

As a result, the Corps funded a second transplant during the winter of 1977-78, which was much more thorough—an attempt to transplant as much as possible of the biota and habitat of McLean's Cave to the Transplant Mine (Elliott, 1978). This transplant was also deemed a failure when no specimens of *Banksula melones* could be found in the mine in May 1978. It was suggested by the contractor that a more fruitful approach to ensuring preservation of the endangered harvestman would be a search for other populations above the flood level. Due to the rugged nature of the terrain, there was a distinct possibility that undiscovered caves existed in the area which might contain *Banksula melones.*

With the completion of the dam and the imminent threat to *Banksula melones,* the Office of Endangered Species (United States Dept. of Fish and Wildlife) sponsored the 1979 project.

Biology of Banksula Melones

Banksula melones is a cave-restricted harvestman, recently described by Briggs. Nothing is known of its life-history beyond the fact that harvestmen are predators. Elliott successfully fed this species Collembola and Psocoptera, as did we on this project. From some experiments and observations we conducted it appears that *Banksula melones* probably goes through about four moults and reaches adulthood within a year of hatching, probably lives several years, and produces few offspring (one or two eggs per clutch).

This species occupies the same geographic area as a closely related species, *Banksula grahami,* although they do not co-occur in many caves. This genus, of which there are several other species in California, is a relict. Its closest relatives are cave species of the eastern United States.

Results of the 1979 Project

Field work was conducted along the Stanislaus River and the South Fork of the Stanislaus River from January 28 to April 28, 1979. Fifteen new populations of *Banksula melones* were discovered, most of which are above flood level (Fig. 33). Briggs is to confirm the identifications.

Numerous *Banksula melones* were found in a survey of the Transplant Mine (Table 6).

Conclusions

Banksula melones is under no immediate threat of extinction by the filling of the New Melones Reservoir, although it should be pointed out that its range is exceedingly limited—to the limestone area within a few square miles of the confluence of the South Fork with the Stanislaus River. Karst areas are a rabbitwarren of "holes," minute to massive passages and caverns, continually dissolving by water action. Probably very few of these mazes are accessible to man since connections to the surface large enough for entry are not common. The scenario for the Stanislaus area appears to be that the cave animals, among them *Banksula melones,* are found throughout the limestone ridges but are only sampled by us in the few places where there is external access (i.e., caves).

TABLE 6
Census of *Banksula melones* in the Transplant Mine

Adult Juven-ile Imma- Total

	Adult	Juven-ile	Imma-ture*	Total
Introduced July-Nov 1975	22	-	5	27
Introduced Nov-Feb 1977-78	26	-	26	52
Censused March 1979				
Site 1, March 21	11	1	5	
Site 2, March 21	12	5	5	92
March 24	5	0	1	
Site 3, March 21	41	0	6	

*There are two species in the Mine (and in McClean's Cave), *B. melones* and *B. grahami.* It is impossible to distinguish the two at very young stages, here called "immature".

†Site 2 was sampled twice: The animals caught on the first date were kept in containers so those censused on March 24 are new individuals.

The most recent transplant of *Banksula melones* seems to have "taken" at the present time. Two conclusions can be drawn from Table 6. The entire *Banksula melones* population was not sampled since one rarely does that in a single survey (see the second survey at Site 2—the specimens found on the first had been removed to live containers). Many more adults were found than were transplanted and a fair number of juveniles were collected. Therefore reproduction has occurred since the introduction a year ago and the population is presently increasing. No effort was made to estimate statistically the total population as the numbers are fairly low, so confidence limits would not give a particularly useful estimate.

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Toxicity of spent carbide waste to microbes in caves

Kathleen Hoey Lavoie

Anyone who has ever done any recreational caving has probably noticed deposits of grayish-white powder throughout the cave. This powdery material is spent carbide from acetylene-generating lamps that provide light for spelunkers. Conscientious cavers have always assumed that waste carbide is toxic and have been careful to dispose of it outside the cave.

Many people have wondered how this highly visible and all-too-common pollutant affects the natural inhabitants of a cave, but there have been very few scientific studies dealing with the biological toxicity of spent carbide. In 1955 Agagabyan showed that the waste carbide has bactericidal properties similar to slaked lime. A 0.5% solution of waste carbide killed several Gram negative species of bacteria within ten minutes of application, while Gram positive species were less affected.

Peck investigated the toxicity of the waste carbide to the blind cave beetle, *Ptomaphagus hirtus* Tellkampf. He placed eggs from this species in a culture dish containing cave mud and a pile of spent carbide waste. Most of the eggs hatched, but all the larvae died prior to molting to the second instar. Non-exposed control larvae developed normally. No mechanism was given for the observed toxicity, but Peck strongly advocated removal of all spent carbide waste from caves.

While these studies have shown that the toxicity of waste carbide is real, little attempt has been made to show the actual mechanism of the toxicity or the effect over time. My study was aimed at determining these mechanisms.

Cave organisms are dependent on detrital food material which enters the cave and is converted into useable food by the action of heterotrophic bacteria and fungi. The effects of large quantities of toxic spent carbide on the microorganisms of the cave substrate could ultimately affect the higher organisms which depend on the microbes and their by-products for growth and development.

The details of my methodology are not given here, and only selected results are discussed as this material has been accepted for publication in the journal, *Microbial Ecology*.

My laboratory study confirmed Agagabyan's earlier findings. I showed that a concentration of 1% spent carbide was highly effective in killing all three species of microorganisms tested within 15 minutes of exposure. Reducing the waste carbide concentration caused a corresponding reduction in the toxicity.

I then did a field study where I "dumped" fresh carbide waste on the mud bank of a small cave stream. This dump caused the death of 84% of the heterotrophic microorganisms in the mud within one hour of application as shown in Figure 33. The reduced population level was maintained over the next 36 hours, followed by a gradual rise in the population until the original numbers of viable microorganisms was reached after five days. This experiment and other results of mine suggested that the toxic effect of waste carbide was temporary and reversible.

When carbide is used to produce acetylene gas for light, the primary waste product is calcium hydroxide, as shown by the reaction:

CaC_2	+	$2\ H_2O$		C_2H_2	+	$Ca(OH)_2$
calcium carbide		water		acetylene		calcium hydroxide

A fresh aqueous solution of spent carbide has a pH of 11.3. In his experiment, Peck showed that the strong basic reaction did not extend into the substrate beyond one cm from the edge of the spent carbide. He noted that the basic reaction in one culture was neutralized after 15 days of incubation.

The drop in pH observed by Peck is due to the reaction of the waste carbide with carbon dioxide, according to the reaction:

$Ca(OH)_2$	+	CO_2	$CaCO_3$	+	H_2O
calcium hydroxide		carbon dioxide	calcium carbonate		water

The inert calcium carbonate which forms as the primary end product is chemically identical to the major component of limestone.

I did a laboratory study which showed that a 1% aqueous solution of waste carbide at pH 11.3 will reach pH 6.3 in 28 days if left undisturbed. The basic pH can be reduced in only four days if air is bubbled continuously through the solution. As a corollary, I also showed that the pH of the spent carbide is affected by its concentration. Based on these results, I believe that the time required for the waste carbide to approach neutrality in the cave environment would be greatly influenced by the type of sediment and the available moisture. The slowest neutralization would be on dry sand and the fastest on moist clay. These environmental factors and the concentration of the waste would also determine how widely the toxic effect would extend in a given area.

I now thought that the highly alkaline reaction of spent carbide waste was responsible for the toxic effect, but since commercially available calcium carbide is not highly purified, there was a chance that some other component of the waste could also be toxic. To examine this possibility, the effects of a "neutralized" solution (pH 6.3) and a fresh solution (pH 11.3) of the 1% waste carbide were compared using the most sensitive of the test microorganisms, *E. coli.* As shown in Figure 35, the toxic nature of the spent carbide was effectively eliminated when the pH was reduced.

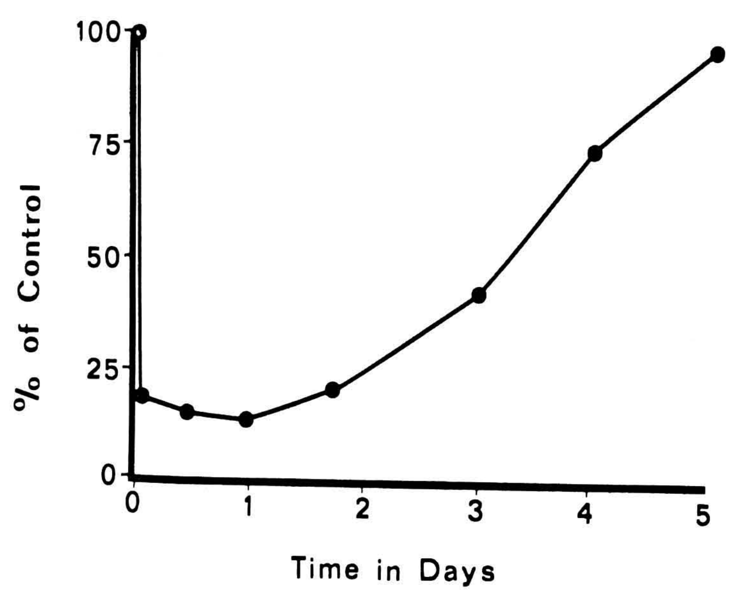

Figure 33. Initial depression of the numbers of heterotrophic microorganisms present per gram of cave sediment and the subsequent return of the population numbers after exposure to solid spent carbide waste.

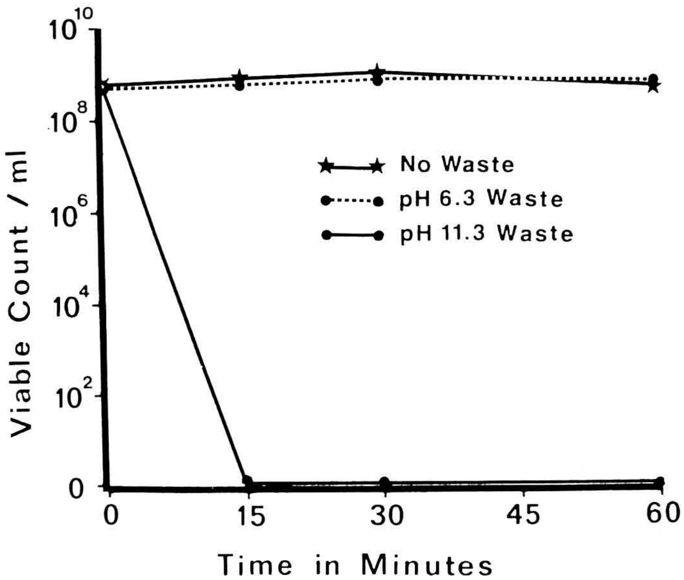

Figure 34. Loss of the toxicity of spent carbide to *E.coli* by reducing the pH of the solution. Comparison of 1% aqueous solutions at pH 11.3 and 6.3. Unexposed culture.

In summary, Peck has demonstrated that waste carbide is toxic to higher organisms while Agagabyan's and my study have shown the toxicity to microorganisms. I found that the toxicity to microorganisms appears solely related to the extremely alkaline pH of the waste (Fig. 34). The toxic effect is temporary (Fig. 33) as the pH is "neutralized" over time by atmospheric and substrate buffering. I have not determined whether the recovery of the population shown in Figure 34 represents a return to the normal bacterial flora or was the result of an increased in alkaline resistant strains. This offers an area for further study.

In this study I have shown that waste carbide is toxic as we have always thought, but the effect is temporary and localized. However, the long-term toxicity to higher organisms has not been established, and I believe we should continue to remove spent carbide from caves. Besides, it stays ugly in appearance.

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Broken-back Syndrome in *Amblyopsis spelaea*, Donaldson-Twin Cave, Indiana

James H. Keith and Thomas L. Poulson

A blind, depigmented fish was reported as early as 1820 by James Flint and named by DeKay in 1842 as *Amblyopsis spelaea.* In the tradition of the times, many doctors studied anatomy as an avocation. Three of them, Wyman, Tellkampf and Forwood, working independently, described the degenerate eyes of this fish. Based on these descriptions, Darwin ascribed the blindness to disuse and Louis Agassiz speculated that blindness was inherited and not an immediate effect of darkness on development. Recognizing this as "mere inference", Agassiz stated that only direct experiment could settle the matter." ...and here is a great aim for the young American naturalist who would not shrink from the idea of devoting his life to the solution of one great question." By the turn of the century Carl Eigenmann had answered this challenge. His classic studies of anatomy, variation and development of eyes in *Amblyopsis spelaea* confirmed Agassiz's inference. Eigenmann was also the first to adequately describe the rows of sense organs on the head and body (Fig. 35). We now know that these rows of neuromasts detect water movement caused by swimming prey or changes in flow over the head as the fish approaches an obstacle. Today the Indiana University Cave Farm where Eigenmann conducted his studies is included in Spring Mill State Park.

Today these caves are a main attraction at Spring Mill. A boat ride for the public is operated from the karst window separating Upper and Lower Twin Caves (Fig. 36). Sightseeing boats are poled several hundred feet into Upper Twin Cave and then returned. Lighting is provided by a mantle lantern mounted in the bow of the boat.

In 1975 an employee reported that *A. spelaea* individuals were seen swimming oddly, and appeared to be injured or "bruised". A specimen was captured and sent to the Fish Hatchery Biologists' Laboratory in Genoa, Wisconsin. Examination showed that the fish was probably suffering from "Broken Back Syndrome", a condition which can be caused by trauma, vitamin deficiency, and exposure to pesticides. The vertebrae fracture and there is extensive hemorrhaging around the fracture area (usually the caudal area).

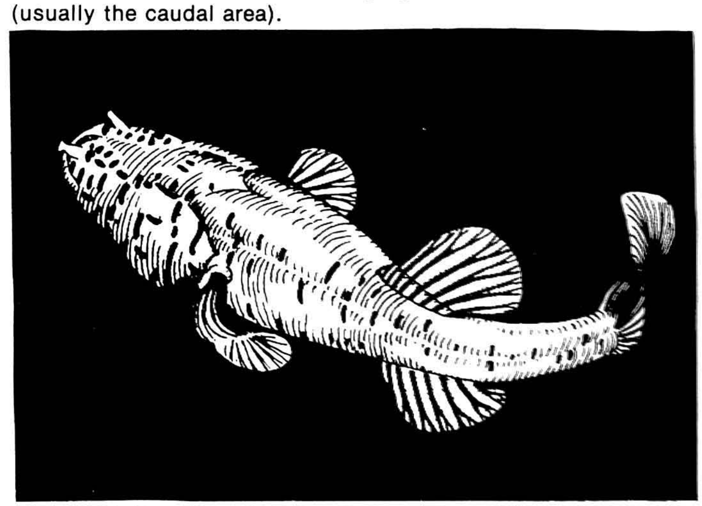

Figure 35. Drawing of *Amblyopsis spelaea* (½ size) by T. L. Poulson. The geographic range of this species is from southern Indiana to central Kentucky. Before siltation (see Lisowski and Poulson, this Annual Report) this predator and its prey of crayfish, shrimp, isopods, and amphipods used to be common in Echo-Styx Rivers region of Mammoth Cave. Now it is also threatened by hydrocarbon pollution in some areas of Mammoth Cave, and it is threatened by presumed pesticide pollution in Spring Mill State Park, Indiana as detailed in this report.

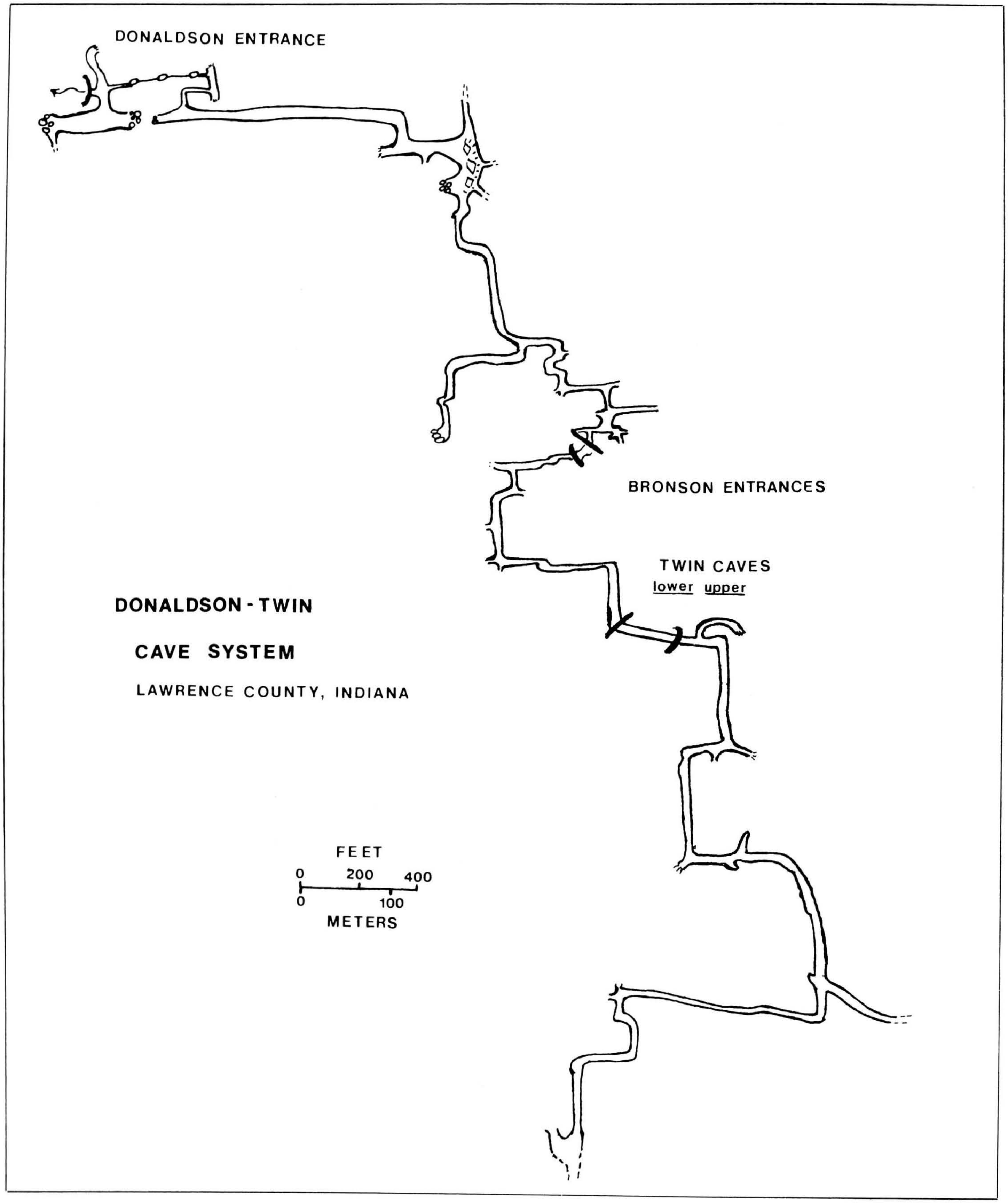

Figure 36. A partial map of the Donaldson-Twin Cave System in Lawrence County, Indiana. The same stream traverses all of the caves. A low dam between Upper and Lower Twin Caves divides the stream into two segments.

Table 7. Results from gas chromatographic analysis of water from Upper Twin Cave. Each peak represents a different chemical; the major peaks are capture curves for each peak: the numbers are dimensionless. The two highest values for each major peak are underlined, showing that most high values were in early summer.

	Date of Sample No.							
No.	6/17/78	6/19/78	6/24/78	7/12/78	*7/13/78	7/19/78	8/2/78	8/16/78
1	2118							
2	4608							
3	1458							
4	4220							
5	756	1171	951	613	366	548	458	444
6				641	478			
7	450		22460	31630	9929	2471	878	661
8			1531	1901	773	810	528	
9	1093	14400	7553	7474	498	1000	780	
10	768	624	6660	1386	130	753	584	654
11	936				130		382	586
12			893		103	1013	799	793
13			1117					
14	836	693	1950	809	376	1739	1367	2487
15						1287	699	1822
16	1242	230	7690	53310	11745	2197		2522
17				1220				
18	1912					704		
19	405		636	457		212	62	184

*The 7/13/78 sample was taken during flood conditions.

The persistence and timing of the Syndrome in the population suggested that pesticide contamination was a likely cause. In 1978 the Indiana Division of Fish & Wildlife made sufficient funds available to conduct routine water quality analyses in the cave system. Thirteen water samples were collected between May and September, 1978. These were taken both during normal stream flow and during floods. Samples were analyzed at the Indiana University Department of Geology using gas chromatography. Electron capture curves were generated for each sample and the area under each peak was measured. Comparison of the observed EC curves with existing curves of known organic substances was insufficient to identify the compound or compounds in the water. It can be stated only that halocarbons are present in the samples. Mass spectroscopy would have made identification a comparatively simple matter, but none of the available units were functioning during the sampling period.

Field censuses revealed that affected fish occurred in 1975, 1976 and 1977, and that they appeared in the summer and early fall months. Approximately 6% of the population was found to have the Syndrome each year. Two affected fish were penned in the cave and observed. There was no mortality after two months and the "bruising" began to vanish.

Table 7 shows the peak areas for 8 samples collected from June 1 through August 16, 1978. The relative area of peaks within samples gives clues to the chemical makeup of the water. Changes of area within peaks over time are proportional to the concentration of the compound in the water. Underlined maxima indicate that concentrations of substances peaked in late June-early July. A water sample taken in late September (not shown) contained almost no contaminants.

It is important to know whether the *A. spelaea* population was being adversely affected in any way by this contamination. to check this, Keith repeated the kind of census done by Poulson from 1958 to 1964. Size frequency are shown in Figure 37.

In Figure 38, censuses from two caves of the system are compared. On the basis of population size, there appears to be no adverse impact by pollutants. However, there is a slight increase in mean body length over time which, though not statistically significant, may indicate either a long-term decrease in reproductive potential or normal fluctuations in age distribution (Poulson 1969). The downstream segment contains slightly larger fish, which may be attributable to larger fish being washed downstream and over a low dam in the karst window.

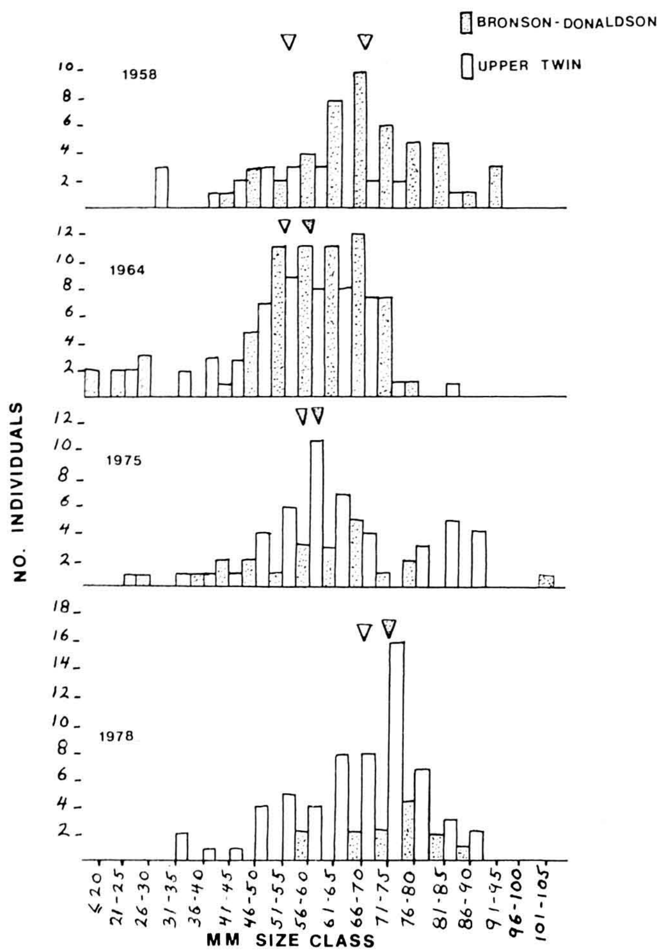

Figure 37. Size-frequency comparisons between Bronson-Donaldson and Upper Twin Caves. There is no difference in population size but a slight trend toward larger fish may indicate a decrease in reproductive potential in 1978.

As with many studies, this one has raised more questions than it has answered:

1) Are there one or more polluting agents in the cave stream? The fact is that it is halocarbon and its concentration pattern suggests a compound applied to crops. However, it should then be readily identifiable. Has it undergone chemical change while in the system?

2) Only 6% of the population was affected by Broken Back Syndrome at any time. Most of the affected fish were found in a stretch of cave stream only a few hundred feet long in Upper Twin Cave. There was no observed relationship between size and Broken Back Syndrome. Have these fish become "sensitized" to halocarbon pollution through previous exposure? Are the effects of this type of pollultion cumulative and repetitive? Does Broken Back Syndrome affect only the bone structure of the fish, or is the reproductive capacity affected as well?

3) What is the role of isopods, amphipods and crayfish in concentrating pollutants? Do they ingest and concentrate pollutants adhering to mud and detritus, or are the fish affected through the water?

4) The limits of the watershed are almost totally unknown. Discovering where the pollutants enter the system will be necessary in order to control their introduction or to study their behavior, once introduced.

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Impacts of Lock and Dam Six on baselevel ecosystems in Mammoth Cave

Edward A. Lisowski and Thomas L. Poulson

The recent discovery of a single dead shrimp downstream from the "shrimp pools" of the Roaring River passage is the first indication since 1967, despite repeated searches, that the species still exists. In view of the stresses that have been placed upon this crustacean by microhabitat reduction and altered flood regimes, the population level of this shrimp is most assuredly very small. The continued survival of this biologic relict depends on steps that will raise the population level so that the species will be able to withstand the vagaries of its limited and energy-poor refugium and to maintain a sufficiently large gene pool" (to allow adaptation to long term changes in its environment—*authors' note*).

...quotation from CONSERVATION STATUS REPORT ON THE MAMMOTH CAVE SHRIMP, presented by Dr. Raymond Bouchard, Chairman, Freshwater Crustacean Specialist Group, International Union for Conservation of Nature and Natural Resources to the U.S.F.W. Office of Endangered Species, 1979, recommending a status of "Threatened" or "Endangered".

The label "Endangered Species" brings to mind The Snail Darter and this raises a red flag to developers and environmentalists alike. Unfortunately, the true importance of the Endangered Species legislation has not been properly stressed by the protagonists nor appreciated by the antagonists. To protect an endangered species is to protect its habitat, and to protect its habitat is to protect the entire ecosystem of which the endangered species is only a part. It is an historical accident that the legal clout needed to protect a habitat comes from the requirement to prepare a special section for the Environmental Impact Statement (EIS) if an Endangered Species is present. This slows the wheels of development because it takes a long time to document carefully environmental and economic impacts. It often turns out that cost/benefit analyses show that economic gains of proposed development are absent or marginal so that the burden of decision does not only rest on protection of the endangered species. So it is with the Mammoth Cave Shrimp. Lock and Dam No. 6 is no longer needed functionally for upriver navigation so the only economic reason for keeping it is the operation of a shallow draft sight-seeing boat on the water ponded behind the dam. Removal of the dam may not affect the sightseeing boat and any detriment to the business should be more than balanced by the revenues from potential canoe and fishermen outfitters when the Green River resumes its former free flow through Mammoth Cave National Park after the removal of the dam. The hydrologic and aconomic impacts are being covered in a report solicited by the Army Corps of Engineers now being prepared by Kip Duchon and Ed Lisowski. They will cover this in the next Annual Report. Here we concentrate on the impacts on the base level aquatic ecosystems in the caves of the Park, emphasizing the cave shrimp.

Background

The base level zone of horizontal drainage has, like the other ecosystems of Mammoth Cave, an unusually high number of species. This species richness is due to the high number of habitats, the high number of patches of each habitat, and the long time available for species to evolve in the cave and migrate in from other cave regions. In this ecological theater the evolutionary play has involved species isolated in caves locally, like the cave crayfish and shrimp, and those that have dispersed from other cave regions, like the three species of cave fish. Each has different requirements and each can find those requirements in such a huge system with its large number and variety of springs, backflooding areas, rivers, and streams. The spring-fish, *Chologaster agassizi,* does best in sinking streams and rocky spring outlets of underground streams; in years with large flood inwash of organic matter it can reproduce in the backflooded areas in the cave. The large northern cavefish, *Amblyopsis spelaea,* does best in large silt-sand-breakdown bottomed rivers where the food supply is low because it comes from distant karst valleys and the sinkhole plain. *Amblyopsis* may move up the lower reaches of tributaries fed by numerous vertical shafts that take local drainage off the caprock above the caves. These shaft drain streams have the most food, the greatest diversity of bottom types, and are the prime habitat of the small, southern cavefish, *Typhlichthys subterraneus.*

The three cave fish are each the top predator in the food web of, what we hypothesize to be, three separate communities, each with its own fish, amphipod, isopod, and flatworm species; there are only two crayfish with the cave adapted species occurring across all three communities. The Mammoth Cave shrimp appears to be unusual in that it has been found only in pools of an interface zone where all three communities come together, especially the Echo-Roaring River area of Mammoth Cave. They may occur in the adjacent deep water areas of Roaring River and submerged spring outlet of Echo River, but it will require SCUBA to check this. In any event, it is clear that they are doing best in an area which has never been the prime habitat for any species of the three fish-dominated communities. Unfortunately, this is partly conjecture based on indirect argument and historic records. If we had been around pre-1906 we could have investigated the situation directly but the area has now been so modified by the works and acts of man that we must use indirect methods of study until the major source of the problem, Lock and Dam No. 6 on Green River, is removed and the system returns again to its pre-1906 condition.

The interface zone in the cave is especially vulnerable because it is subject to impacts from all water sources up- and down-stream. These range from some as distant as the headwaters of Green River hundreds of miles away to some as close as the waterfall entering the Historic Entrance hundreds of feet away. Let us follow the extent of the drainage system by traveling upstream in one of the extensively interconnected underground networks that are still enlarging the cave. We start where Green River mixes with cave river water near the big springs: this is the interface zone which has the first of many tributaries draining vertical shafts and location of karst valleys. More join the major river as it extends headward under the Mammoth Cave Plateau. We continue out from under the plateau, under the sinkhole plain, where water enters from thousands of sinkholes and a few caves, to the sinking creeks, which are the eastern limit of the drainage network. Thus, pollution events that happen at different places upstream are focused downstream to the in-face area near the big springs. So far all upstream problems have been from point source pollution which, while having acute effects locally, is diluted by the time it reaches the interface area and disappears at the source as the impurity is removed. In contrast, most downstream problems have been from diffuse source pollution in Green River. This has widespread chronic effects and involves such large source areas that its effects are not diluted with backflooding into the interface area. Examples are brines, from oil field development, and silts, from backponding behind Lock and Dam Six. Such diffuse source pollution is often of a low level and not detected immediately. It is more insidious than point source pollution because it is harder to control and takes longer to reverse its effects.

Since upstream pollution can focus downstream, it follows that down stream pollution backflooding from Green River can spread upstream. When the Green crests, at levels as high as 50 feet above spring level, there is an immense hydrostatic head which acts like a huge plunger as it backfloods water into the spring mouth. The cave streams, and especially the rivers, have such a shallow gradient that a flood of 10 feet might back up water along miles of passage.

Impacts Related to Lock and Dam No. 6

Lock and Dam No. 6 was opened for operation at river mile 182 just downstream from the Park in 1906 and caused an immediate backponding of water which raised low water levels in the cave. The written accounts of many early visitors and explorers document the extent of this backponding in two areas. One of these, which is almost certainly the upstream reaches of River Styx, was discussed by E.A. Martel, the celebrated "Father of Modern Speleology." In 1913 he wrote:

> In his unpublished 1863 account, Stevenson (of London) recounts how he had a boat lowered from the window, and on which he followed a perilous watercourse for seven hours. Many years later, when Garvin's Pit (Gorin's Dome) was descended again, a boat was indeed found rotting on a mud bank at the edge of a rapid watercourse (6.5 km/hr) which could be the principal river of Mammoth Cave. Unfortunately, the dams on the Green River have raised the hydrostatic level, rendering impossible a new exploration of what has been named "Stevenson's Lost River." Thus the means has been eliminated of verifying the account of 1863 and of learning from whence comes this stream. This is deplorable!

The other impacted area, the Styx-Echo River area, has been routinely visited since 1838. A comparison of four maps graphically illustrates the extent of backponded water in this area. Stephen Bishop's 1842 map (in Bullitt, 1845) and Horace Hovey's 1882 map (in Packard, 1888) both show extensive areas of dry passage, particularly along the Great Walk and along Silliman's Avenue between Purgatory and Cascade Hall. These maps also show a dry passage, now known as Hanson's Lost River (the connection route between Flint and Mammoth Cave Ridges), taking off from Silliman's Avenue. In 1888 Hovey stated that "a rise of only five feet would completely cover this sandy walk" (the Great Walk). Later in 1909 he stated "the Great Walk for four hundred yards used to be admired but now its beautiful yellow sand is covered by back water from the rivers." Max Kaemper's 1908 map and Horace Hovey's 1909 map both show the Great Walk and Silliman's Avenue containing ponded water. Kaemper does not indicate Hanson's Lost River probably because its entrance was underwater, as it is many months of the year now, when he surveyed Echo River. However, Hovey, in 1909, does show it containing water.

The backponding of water in the cave reduces the habitat diversity in two important ways. First, ponded water replaces free flowing water. The River Styx, described as a "running stream" in October 1870 by Thompson and the Roaring River, described as one foot in average depth with a steady current in 1901 by Hay, are both now without appreciable flow. Second, the varied substrates of the base level streambeds become covered with a layer of silt. As silt accumulates there is less fine organic matter available to the cave food chains. After the immediate rise in water level there was a progressive increase in siltation and decrease in organic matter both of which seriously impacted the fauna, particularly the shrimp of the interface zone.

Before Lock and Dam No. 6 there was a rich fauna in the Styx-Echo-Roaring River area. In 1880 Hubbard described his first collecting trip to the base level streams in Mammoth Cave as follows:

> With this avenue the water system of the cave communicates at several points, forming pools known as Lake Lethe, The River Styx and similar Plutonic appellations. The floor of the cave is of fine sand....
>
> ....we began a search along here for blind fish and crawfish. The forms of several were soon seen floating like white phantoms in the almost invisible water, and we captured with an insect net several small specimens of both species of blind fish, *Amblyopsis* and *Typhlichthys,* which resemble each other closely, but want the ventral fin in the latter genus. We took also good specimens of the cave crawfish [*Cambarus* (*Orconectes*) pellucidus Tellk.] and, in addition, a gigantic female of *Cambarus Bartonii,* the common crayfish of the Green River, but which has quite often been found in the cave water.

Like the cave fishes, the crayfish have virtually disappeared from these areas since the construction of Lock and Dam No. 6. If tourism were to account for their rarity, then they would have recolonized these areas and increased their population densities after 1965 when the Echo River and All Day tours were discontinued. If anything, their frequency of occurrence has continued to decrease. Two Cave Research Foundation censuses of the fish and crayfish in the tourist trail areas between Charon's Cascade and the Fourth Arch in 1979 are typical of several from 1975 on. Only four *O. pellucidus* were observed during one and none during the other; no cave fish were observed during either census.

The main reason for the faunal decrease is the progressive increase in siltation and decrease in available organic matter. The silt covers everything and so decreases habitat diversity while the lowered organic matter decreases bacterial and protozoan populations which are the bases for the food chain in the cave waters. By the time of the French Expedition in 1928 we judge that siltation had impacted the Styx-Echo area since no fauna was found in the Styx and the area toward Echo was described as having "great banks of alluvial clay where one must walk carefully to avoid slipping...on which campodeids (bristletails) wander and *Neaphaenops* (beetles) run quickly." The only fauna discussed is near the Fourth Arch of Echo River. To paraphrase Bolivar and Jeannel:

> Lakes persist here and there in deep depressions and it is in these waters that one encounters the extraordinary animals that have made Mammoth Cave famous. There are crayfish in each pond and even crawling between ponds. Blindfish, both *Typhlichthys* and *Amblyopsis,* are rather more rare and still more rare is the Mammoth Cave blind shrimp *Paleomonias ganteri.*

Perhaps more important than siltation to the decreased abundance and more restricted distribution of animals was the association decrease in fine organic matter. An indication of the former abundance of organic matter is the former abundance of a mushroom that used to thrive in the organically rich sand-silt substrate. Ellsworth Call, in 1897, reported that a pale brown mushroom, *Coprinus micaceus:*

> ...thrives in the rich mud of the river banks, where sufficient organic matter is buried, and specimens have been seen with long and curled stipes of more than thirteen inches in length...and may always be found at the Third Arch or Landing on the Echo River...as well as in River Hall near Charon's Cascade (by Styx River).

Call also noted that larvae and adults of the small dung fly, *Leptocera tenebrarum,* which is "fairly common," can be found in the "decaying specimens" of *Coprinus* at these localities. In approximately 20 visits since 1963, Poulson has seen only one mushroom and in three visits during the summer of 1979, Lisowski saw neither mushrooms nor flies.

It is important to explain how the increased situation and decreased organic matter are interrelated and how removal of Lock and Dam No. 6 would reverse this impact. Siltation in the cave is increased as the result of two processes. First, cave waters from upstream traveling through the impounded area will deposit more of their sediment load as a result of greater quiescence. Additional sediments enter the cave via the Green River's backflooding. During non-flood condition, the Green River flows are clarified as they pass through Pool Six, depositing the heavier inorganic sediments, while on the other hand, the lighter organic debris passes through the impounded area. The inorganic sediments on the bottom of Pool Six are later scoured during flood turbulence which increases the suspended sediments of the water nearest to the bottom of the channel. The flood waters then force these heavily silt-laden bottom waters into the cave passages where the sediments are released due to the more quiescent conditions. Without Lock and Dam No. 6, there would be no such sediment trap and the backflooding waters entering the caves would be normal flood flows containing both inorganic and organic sediments in the bottom water. The normal pattern is important because seasonal flooding is the major way of recharging the nutrient pool that feeds the caves food chains.

The adverse impacts of reduced habitat diversity and food were exacerbated by changes in normal intensity and timing of backflooding into the cave. When Green River backfloods into the cave, water is forced miles upstream. Because of the increased Green River level, surface water now enters the River Styx Spring during the summer month where this occurred rarely, if ever, before the time of Lock and Dam No. 6. This summer flooding, which was aggravated by summer and fall releases from the Nolin Reservoir starting in 1963, adversely impacts the aquatic cave organisms in three ways. First, organic pollution, with attendant algal blooms, gives a temporary competitive advantage to the nontroglobitic, short-lived opportunists, which occasionally enter caves, at the expense of troglobitic, long-lived specialists adapted to the normally low food supply. This simplifies the community and so is called the paradox of enrichment. Second, during the summer, backflooding forces warm surface water into the cave streams. On May 30, 1960, Hendrickson observed an abrupt rise in temperature of Echo River from 54° to 70°F. Aquatic cave animals are physiologically less able to tolerate warm water than the cold water that is backflooded during normal floods in early spring. Third, increased summer-fall backflooding increases the likelihood that toxins will be washed into the cave when they are concentrated due to low flows in the Green River. Brown and Hendrickson both used high chloride concentrations, originating in oil field brines that were polluting the Green River, to trace surface water and to show that it does travel into the Styx spring and out of Echo River spring via the cave.

A further reduction in cave animal densities began after 1958 when oil field brines were first detected in the cave. This coincided with beginning of development of the Greensberg oil field upstream and may have involved hydrocarbon pollution along with the brine, since the concentrations of NaCl in the cave waters were well within the tolerance limits of any aquatic organism that has been studied. We do know that hydrocarbons have a deleterious effect because there was a large crayfish kill associated with gas smell and dollops of oil sludge in Amos Hawkins River in the summer of 1979. This Joppa Ridge master river drains into Roaring-Echo-Styx River area during high water and has its drainage basin under the sinkhole plain and the Interstate where the pollution may have originated in a tank car accident. Organic pollution may have a deleterious effect also. The Mammoth Caves Shrimp was last seen in the Golden Triangle-Eyeless Fish Trail area under Flint Ridge just before the first of a series of Job Corps sewerage lagoon overflows into that part of the cave, starting in the 1960s. All of these pollution events had a greater detrimental effect than in pre-dam times because the backponding and siltation had reduced the number and size of habitats that might have served as refuges and sources of recolonization for cave crayfish, fish and shrimp.

In addition to exacerbating pollution effects, the backponding and fall release of Reservoir water has a bad impact by compromising the reproductive success of the cave biota. When large flows are released from the Green and Nolin River Reservoirs in autumn, seasonally abnormal high water backs into the cave just at the time when the young of the year (cave fish, crayfish, and shrimp) are most vulnerable. The adults mate in the spring, probably synchronized by normal spring floods that renew organic matter in cave streams, and carry their eggs and developing young for three to six months. By fall, when the young are becoming self-sufficient, bacteria-protozoan-animal plankton populations have capitalized on the spring organic renewal and constitute the food supply for the young cave animals. In fall the water is normally low, clear, and quiet with the right kinds of food so the young cavernicoles have a fair chance of feeding and growing enough in their critical first year to cope with the lower food supply and greater rigor associated with the next winter-spring floods. Abnormal fall backflooding is intensified in wet summers, such as 1979, and so further disrupts and dilutes food supplies and increases the likelihood of the young being washed into unsuitable habitats. This is particularly critical for the shrimp which inhabit only the community interface zone.

The effect of Lock and Dam No. 6 has been to move the community interface zone upstream, which reduces its area due to narrower passages with steeper gradients (Fig. 39), and to increase siltation and decrease the amount of backflooded organic sediments. As the community interface zone is displaced upstream, certain habitats, such as riffles with flowing pools, are eliminated, and others such as the zone of quiet pools (e.g. shrimp pads) nearly disappear since the chert beds, in which pads are most common, are rare. Recall that this interface zone is important as the area between perennial downstream flow—which provides oxygenation and a low level of organic matter from the master drains of local valleys, vertical shafts, and the Sinkhole Plain—and the seasonal upstream flow—which provides moderate levels of organic matter from Green River backflooding in spring. We have already reviewed the evidence for the progressive and general restriction of distribution and abundance of cave animals in this interface zone starting in 1906. Now let us turn specifically to the shrimp.

The Mammoth Cave Shrimp

We believe that all of the impacts discussed have been especially hard on the cave shrimp and this is why we support its nomination for Endangered Species status. To explain why the shrimp is so vulnerable we will compare it to a related crustacean, the cave crayfish. Compared to the crayfish, the shrimp is more vulnerable to habitat degradation and pollution because it has a shorter lifespan, is more specialized by its reliance on interface habitats with lots of fine organic matter, and has a more restricted geographic range, being possibly limited to only a few low flow spring-cave river systems along the Green River in Mammoth Cave National Park. All of these shrimp characteristics make for relatively ineffective spreading of risk for reproductive failure, local extinction, and complete extinction.

An individual may spread its risk of reproductive failure over time by repeated reproductive attempts over a long lifespan. A population spreads its risk of local extinction across space if individuals are in different patches of a habitat or in different types of habitats: not all will be equally vulnerable to a local disaster and so some will survive to recolonize the impacted area. A species, that is a group of populations, spreads its risk of extinction over time and across space by having populations in different caves that are genetically adapted to those localities. This genetic diversity allows the species to persist even if most of its local populations go extinct. Some population(s) will be able to adapt evolutionarily to whatever catastrophe or secular change that caused the others to go extinct. And, once the surviving populations build up again, they are likely to emigrate and recolonize the areas where the rest of the populations went extinct. We will now show how these mechanisms of risk spreading are less developed in the shrimp than the crayfish.

The suggestion of microhabitat specialization for the shrimp comes from the nature of the locality where they were first discovered in 1901, and last seen in 1963, when fall releases of reservoir water extended the effects of backflooding and siltation. This "Shrimp Pool(s)" locality is described by Barr and Kuehne as follows:

> ...about 12 shallow basins scattered along a 100 meter section the floors of which feature scalloped pinnacles, fluted rock surfaces, and massive deposits of silts and sands. (As diagrammed in Figure 38) The pools lie approximately 3 meters above low water of Echo and Roaring Rivers (amongst remnants of a local chert bed). These pools attain a minimum depth between late October and early January (when the first heavy rains again flood the passage). The fishes *Chologaster* and *Typhlichthys* occur in the larger pools and *Amblyopsis* has been observed twice in a 13-year period (about 1950-1963). Isopods, amphipods, crayfish, and shrimp are the macroinvertebrates of widespread occurrence in the community. Microscopic examination of fresh samples of bottom sediments—silts and sands— has revealed several species of protozoans, notably ciliates, and occasional nematodes....

Hays caught the first specimens of the shrimp in these same pools in 1901. The only other localities, a pool near the Fourth Landing of Echo River and pools near the Golden Triangle Room of Flint Ridge, are similar to the Shrimp Pools in being left by backwaters of seasonal floods near, but above, the main channels of a baselevel river.

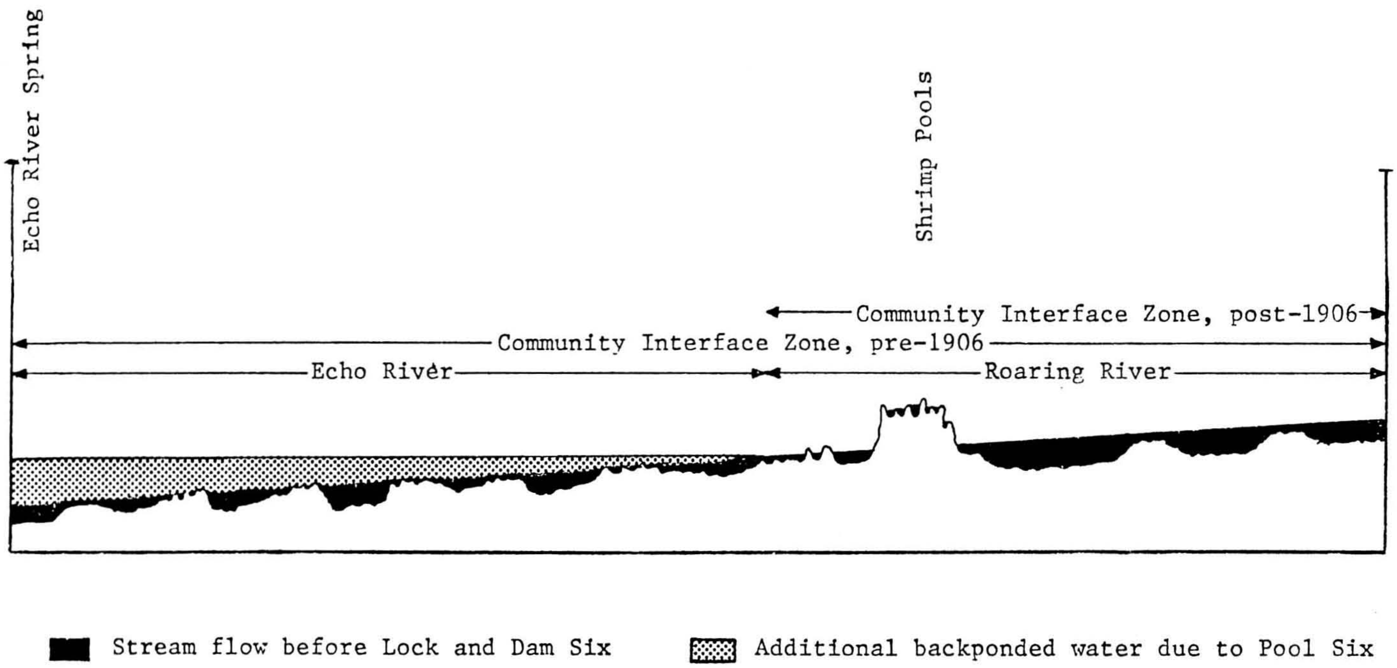

Figure 38. Profile of Echo and Roaring Rivers. The pre-1906 natural stream water, and the additional backponded water due to Lock and Dam Six are indicated on a schematic of Echo and Roaring rivers. The riffle and pool flow in Echo is now channel flow, and the community interface zone is now further upstream. The vertical axes represent the maximum flood crest of 54 feet.

Predation pressure, food habits, and the advantage of habitat selection argue against the flood pools being an accidental habitat for the shrimp, with the main habitat either in the deep rivers and/or the submerged spring outlets of the deep rivers. First, the adults and young are rarely vulnerable to predation by cave fish in isolated pools. Barr and Kuehne allude that fish are only in large pools, perhaps because they can avoid small pools, as the flood water recedes, whereas the shrimp do not avoid them. Bolivar and Jeannel note that of two pools, each with about 20 crayfish, one had 30 shrimp and the other no shrimp but three *Amblyopsis*. This suggests to us that the fish ate the shrimp in the second pool. The swimming habits of the shrimp (see Fig. 29) would seem to make them especially vulnerable to amblyopsid fish which detect prey by movement. Regurgitation of shrimp by both species of cave fish is direct evidence that fish do eat shrimp. Second, the still water away from the main channel provides protection while the floods are still in progress and allows the fine organic sediments to settle last, on the surface as a veneer, rather than being continually mixed with heavier silts on the bottom of the main channel. The organic veneer on pool bottoms provides a particularly propitious microhabitat for bacteria and protozoa which are the main food of the shrimp. Protection from predation and a favorable food supply allow shrimp to develop and lay eggs during the summer and allow the new hatched young to grow sufficiently before winter to cope with rising water levels and then floods. Body form and feeding habits are consistent with a need for quiet water and concentrated organic matter. Third, selection of pool microhabitats as floods recede is suggested by the location and limited number of pools in which the shrimp have been observed. In fact, they are only known for sure from three restricted areas, each in which it would be possible to remain in the pool by showing positive rheotaxis as water drained out of it during recession of high water. If shrimp use the main rivers, other than for dispersal to pool microhabitats, they will be found in the most quiet areas where there are few fish, probably under ledges in backwaters of the river or on ceilings of the submerged spring outlets. They will be found in small patches with few shrimp in between. All of this means that slow and painstaking search using SCUBA will be required to find them if they are present at all.

Before Lock and Dam No. 6 there were more patches of each habitat type thus spreading the risk of disturbance for all the cavernicoles and maintaining the biotic diversity known to have been present from the historic records. Pre-1906 the rivers were free-flowing with many patches of varied microhabitats including more pools that would be isolated by receding floods. In the river itself there were quiet pools, flowing pools, riffles, and perhaps even rapids with deep holes behind large rocks. Each of these had different substrates ranging from fine organic matter to silt, sand, gravel, rocks, and breakdown or bedrock. This former diversity of habitat was important for maintaining an overall community diversity but it seems to have been critical to spreading the risk of local extinction for the shrimp. The combination of specialized food and microhabitat needs with delicate body build and low mobility make the shrimp especially vulnerable. There had to be a diversity of habitats to be assured of encountering one of, what were even in the past, few and small patches of pools with fine organic matter isolated by receding flood waters. This way there could be recolonization from an unimpacted habitat patch if some local disaster, such as fish being isolated in a shrimp pool, caused local extinction. Now that the optimum microhabitats are reduced in size and density there is less effective spreading of the risk of local extinction. This scenario is summarized in Figure 39 which presumes no suboptimal refuge for the shrimp. Until we found a

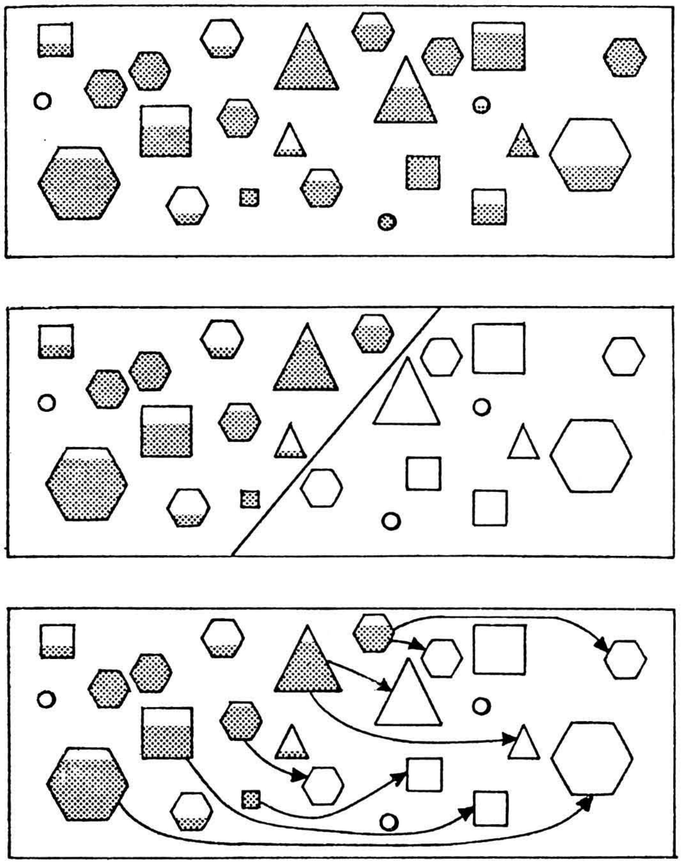

Figure 39. Spreading the Risk of Extinction. Each type of geometric figure represents a type of habitat for a different species, and the size of the figure represents the size of the patch. The area of the stippling is proportional to the number of individuals in a population in the patch. If a disturbance eliminates populations in some of the patches, individuals from other patches can recolonize. The "circle" species, e.g., the shrimp, has become extinct since all of its populations were eliminated by the disturbance. The habitat had few patches of small size compared to the "square" species, e.g., the crayfish, whose risk is spread by numerous and large patches.

single dead shrimp in 1979, we presumed that this was the correct scenario with no refuge sources for shrimp to recolonize the Shrimp Pools (if they are in fact still inhabitable by shrimp).

Both because of absence of shrimp in the Shrimp Pools now and fish predation, we think that the Roaring River upstream from the pools is a less likely last refuge for shrimp than the submerged spring outlet downstream. If they are in submerged springs then the area should have quiet water, excluding high volume springs like the Turnhole outlet for the Joppa Ridge river, and should be buffered against large temperature variation, excluding Green River cut-around entrances such as Styx River spring inlet which can get much colder and much warmer than normal cave stream temperature with winter or summer floods respectively. This leaves Pike spring outlet, but even it may be unsuitable due to siltation associated with backponding and periodic pollution from overflows of Job Corps sewage lagoons into the Eyeless Fish Trail tributary. There are spring outlets upriver of the backponding which have the right combination of low flow, buffering of temperature change, and deposition of fine organic matter but do not seem to have big cave passages with pool areas, left by receding floods, which are the optimum shrimp habitat. We do not really know that the shrimp is now or ever was restricted to the few interface areas in Mammoth Cave but the previous considerations and the biology of its closest relatives are consistent with such restricted distribution. All species in its family, Atyidae, tend to have very restricted geographic distributions, and the only other species in its genus, *Paleomonias alabamae,* has similar habitat requirements and is restricted to two hydrologically adjacent cave systems. So, both on a local and geographic scale the Mammoth Cave shrimp probably never had a very diverse gene pool and so always had limited genetic raw material for evolutionary adaptation to long-term changes in its environment. This would explain why it is now restricted to the relatively stable habitat of caves, that is, relatively stable until the intervention of man. Thus, the historic restriction in population size exacerbates the problem of low genetic variation in the species and means that there is little population level spreading of risk against long-term changes such as chronic pollution by silt or toxins. In contrast the cave crayfish spreads its risk quite effectively. *Orconectes pellucidus,* and its congeneric relatives, have wide geographic ranges and each species occurs in many caves of diverse ecologies. Within the Mammoth Cave system *O. pellucidus* occurs in many habitat types each of which has many patches.

Spread of the risk of reproductive failure by an individual increases as it lives longer and attempts to reproduce more often. This is the case for the blind cavefish and crayfish which are long-lived, slow growing, infrequent breeders, and have a low reproductive output of a few and large eggs at each reproductive event. Like the fish and crayfish, the shrimp do have few and large eggs relative to its body size. This gives the young a good head start in life because they hatch at a relatively large size. But unlike the fish and crayfish, the evidence for long life and repeated reproduction is equivocal for the shrimp. The indirect evidence includes the narrow and even size range for adults (18-22 mm) with rare medium size individuals (10-14 mm). Along with no censused young of the expected hatchling size (4-6 mm) and usually few but occasionally many of the adult females carrying eggs, this all suggests a high frequency of reproductive failure and so requires a long life with repeated attempts at reproduction if a female is to contribute at all to the next generation. Food is proverbially scarce in caves and so the narrow size range of adults could reflect very slow growth with any extra energy, above and beyond maintenance needs, going to production of eggs in rare years with a good food supply. As expected, with this logic, the number of eggs per female is quite variable. The disturbing thing about this scenario is that, until finding a *dead* individual in 1979, there had been 12 years without finding shrimp at all in the Shrimp Pools. This had been the only reliable locality for half a century. If the adults were long-lived they should have been observed. Thus all of the observations would be more consistent with a scenario of local extinction of a short-lived shrimp with poor powers of recolonization.

The major theoretical reason for expecting a short life is that adult shrimp are nearly as vulnerable to predation and flood damage as their young, unlike crayfish which escape these risks since they grow to be much larger. Theoretically the shrimp should mature and breed quickly so that they have some chance of leaving offspring before they are either eaten or killed by flood turbulence. The shrimp's reliance on bacteria and protozoa should allow fast growth because these prey are the most abundant in the food chain. If we were to design an exploiter of this food it would quickly convert the renewed food base into eggs as spring floods recede, seek quiet pools to lay and carry the eggs, and the young would hatch in the summer to give time to grow in the protected pools before rising waters in fall-winter subject these young of the year to predation and flood turbulence. According to this scenario, the rarity of medium sized and absence of young in collections is an artifact of sampling difficulties: the adults are difficult to see even when looking for them (Fig. 29) so the problems of finding the tiny and essentially transparent young should be formidable. All of this argument and conjecture should make it clear to the reader that we need detailed natural history data on the shrimp. This will come only from a combination of long patient nose-to-shrimp field observation, whether in small pools or with SCUBA in deep areas, along with quantitative data under controlled conditions. Someone should use field corrals and/or lab aquaria with females carrying eggs to follow the time course of gestation, hatching, growth of young, and longevity of adults.

Whether shrimp live only 1 or 2 years and reproduce once or live 5-10 years with several reproductive attempts, it is clear that shrimp spread their risks much less than crayfish and so are more vulnerable to the works and acts of man. Crayfish grow large enough to escape predation by fish, hazards of flooding, and isolation in drying pools between floods. Thus they are relatively invulnerable as adults and so can "afford" to wait for opportune times to reproduce. They can then invest little enough in each reproductive attempt that they can survive and iterate the process when good times return again. Thus they spread their risk of individual reproductive failure over a long lifetime, perhaps 25 years or more. Their broad habitat and food niches and ability to travel overland away from unfavorable areas give them a flexibility that allows them to do well under a variety of circumstances. Their occurrence in many patches of each habitat all over the cave, in many local caves, and in caves of many types over a wide geographic area all spread the risk of extinction on a population level and give a large gene pool which spreads the species risk of global extinction. They have the genetic variation required for effective response to new selective pressures resulting from long-term changes in climate, food supply, and perhaps even chronic pollution at low levels. Their long generation time is a disadvantage for fast evolutionary change, but this is compensated by a high degree of physiological and developmental flexibility which helps to explain their broad food and habitat niche.

Summary

Removal of Lock and Dam No. 6 will not matter much for the cave crayfish but may be necessary to save the cave shrimp. Removal, coupled with restricted fall release of water from the Nolin Reservoir, will prevent further summer-fall backflooding from the Green River when the newly independent shrimp are most vulnerable. Most important, removal of the lock and dam will restore free flow out of the cave and into the Green. This will wash out silt, restore habitat diversity, and increase the size and number of optimum pool microhabitats. This will make the shrimp population more stable by restoring the natural risk spreading mechanisms. In addition, restoring conditions needed by the shrimp will restore the overall habitat diversity and thus the biotic diversity of the entire interface zone at the border of downstream flows from vertical shafts, karst valleys, and the sinkhole plain with upstream backflooding through the springs from Green River during normal winter-spring floods. The restoration will make it convenient and useful for studying the three fish-dominated communities where they come together in the Styx-Echo-Roaring River area where it is also possible to interpret them to the public. But the restoration is *critical* for the cave shrimp. *Paleomonias ganteri* requires conditions which seem to be found only in the interface area with its quiet and organic veneered pools which are isolated each year by receding flood waters.

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Cave and Karst Inventories for federal agencies

Buffalo River Project, 1979

Calvin Welbourn, Principal Investigator

Seven expeditions were fielded during 1979 and over 50 new caves were added to our lists. Cal Welbourn led three expeditions, one of which was a week long and attended by the Arizona participants. Blore, Hinson and Lindsley led the other expeditions. Except for the February expedition, whch was held at Silver Hill, the expeditions were stationed at the Steel Creek Research Station at the west end of the Park. Our primary goal was to inventory caves located near the Park development sites, with less emphasis on the other good leads we had. The following sites were checked:

- Buffalo Point
- Ponca (Lost Valley, Big Bluff)
- Pruitt area
- Tyler Bend-Silver Hill
- Erbie
- Highway 123 crossing (Carver Bridge)
- Kyles
- Maumee
- Rush

In addition to entering the inventory data on the forms, several caves were surveyed and a few were photographed. Biological collections were made in selected caves and photo points were extablished in three caves. An important feature of each cave report form is a dual classification code that provides a measure of each cave's content and hazard rating. In this way CRF is able to make recommendations for the management of the caves visited.

An interim report to the National Park Service has already been submitted and a final report for our 1978-1979 field work is in preparation. The report will be ready for publishing before the end of November, the authors (Welbourn, Lindsley and Buecher) report. A key location map will be provided on the caves. Approximately 45 Joint Venturers of the Foundation participated in the project and over 100 Buffalo River caves have been inventoried to date.

Future work in the Buffalo River area is expected to continue during 1980. A proposal for the survey of selected major cave resources at Buffalo National River is presently in the works. In addition a proposal was submitted and a contract subsequently awarded to the Foundation for a cave resource inventory in the Sylamore Ranger District adjacent to the National Park at the downstream part of the Buffalo River. The Forest Service work will start December 1, 1979 and will continue with the survey of 23 selected caves during 1980.

Sequoia and King's Canyon National Park Project, 1979

Bruce W. Rogers, Principal Investigator

Since the signing of the C.R.F.-S.N.H.A. agreement on the 18th of May, progress has been made in several areas. Several days in June and July were spent in the library of the Park Service at Ash Meadows collecting data from Park files that pertain to the study. Also in July a library search of the Pacific Headquarters of the U.S. Geological Survey in Menlo Park, California, was completed with further collection of suitable materials. In late August we began a survey of the collection in the library of the San Francisco office of the California Division of Mines and Geology. A major acquisition was a complete set of Stanford Grotto of the National Speleological Society's Newsletter. The Stanford Grotto did much of the early cave exploration and study in the Sequoia region and wrote extensively.

Several individuals that were active in California speleology in the 1950's and 60's have been contacted. Their private libraries and personal recollections will aid in the historical and cave locational aspects of the study. We are also contacting former and current study groups familiar with the area, such as the N.S.S. Sierra Caves Task Force.

In addition to the literature search being conducted, several trips have been made to the Parks to undertake inventories of karst features. Trips to Clough, Soldiers and Blowing Fissure have been made. The trip to Clough and Blowing Fissure was in conjunction with Mr. Ken Cole from the University of Arizona. While no woodrat midden material suitable for dating was found in these two caves, other material was found in both Keyhole and Boyden Caves. The middens appear to span the late Pleistocene to Recent geologic time span and may be very helpful in reconstructing paleoclimates. A joint trip to Soldiers Cave was made with Dr. John Tinsley to both inventory the cave and collect data for Dr. Tinsley's U.S.G.S. Paleoclimate Project. Another cooperative trip to Lilburn Cave was made in July with other C.R.F. teams to inventory the cave and collect samples of sediment for the Lilburn Project. During another trip we inventoried Paradise Cave and reported a pair of nesting Canyon wrens at the entrance. Another small cave was located nearby. Named Pod Cave, for a large California Bladder Pod bush growing above the entrance, it was not entered due to lack of time and lack of suitable gear for vertical work. This may be the small cave reported by Fry in 1925 as having a fist-sized entrance. Since then two large blocks have fallen and the cave can be entered.

Preliminary lab work on samples collected during these trips has turned up two significant discoveries. Aragonite stalactites were located in another portion of Lilburn Cave and Sepiolite "mountain leather" has been identified from Soldiers Cave.

During the second quarter of this study further progress was made on the field compilation of data on karst features. An extended inventory trip was made to the Mineral King area in September. Parties located Empire Mine Cave, but did not enter the cave due to a shortage of suitable technical equipment needed to make a safe descent. Another party failed to locate Jordan and Glacier Plug Caves, but found that the karst area is much larger that previously expected with a possible swallet-cave-resurgent spring system of nearly 400 feet in depth. The area merits much further study. On the Monarch Creek drainage several small caves were located as well as a potential health hazard: an old pit toilet was found to be situated close to a possible karst stream pirating water from an upper meadow directly down to Monarch Spring. Confirmation of this connection is necessary before we recommend deactivating the toilet.

A dye trace was attempted from Eagle Lake Sinkhole to Spring Creek at Mineral King. No positive results were obtained. This may have been due to the low flow of the stream and/or the short observation time. A dye collector was left in the stream to collect any dye appearing over the winter.

Geomorphic and geochemical observations were made on the small travertine caves near Harry's Bend at Mineral King. A tentative age was deduced for the deposition and subsequent destruction of a large travertine barge across the East Fork of the Kaweah River. The timing of the deposition of the barge appears to have started during the late Wisconsin Glacial Advance and destruction was initiated in the Matthes Little Ice Age.

A return trip to Paradise Ridge succeeded in connecting Pod Cave with Paradise Cave. Some mineral specimens were collected and observations made on visitor impact to the cave.

Literature searches continued in several public and private libraries.

Publications, Advisory Presentations, Press Conferences, Talks, and Service

PUBLICATIONS

Bishop, William P. and Sarah G. Bishop. 1979. Mammoth Cave: A good Master Plan in trouble. National Parks and Conservation Magazine, *53*(7): 4-9.

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-Lexington section, Cumberland Chapter of the Sierra Club, Lexington, Kentucky; March.

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-Blue Grass Grotto of the National Speleological Society, Bowling Green, Kentucky; April.

SERVICE

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Interpretation and Education Program

Acquisition of knowledge and its communication at professional meetings and in the refereed scientific literature is only one of the Foundation's goals. Dissemination of information to the general public, students, cave managers, and governmental agencies is equally important. Book donations to schools and libraries, popular and interpretive slide talks, interpretive guides and training sessions, seminars, and written reports are all ways to interpret the cave resource to the public and to educate city and governmental personnel so that they can make more informed management decisions.

A recent example of an interpretive handout from a public lecture for Mammoth Cave National Park guides is the following excerpt from Art Palmer's STORY OF THE WORLD'S GREATEST CAVES: THE LARGEST, DEEPEST, AND MOST UNUSUAL.

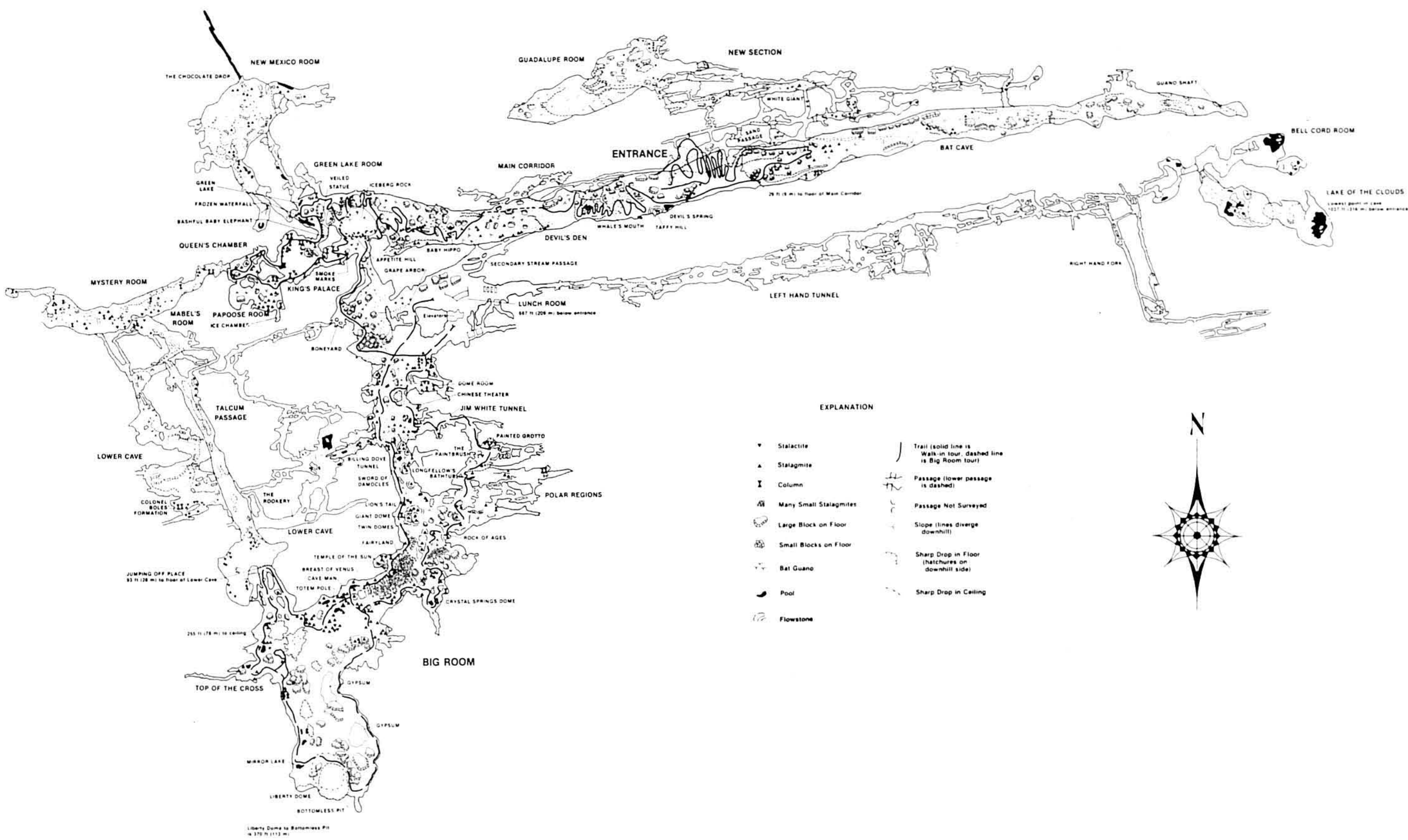

Figure 40. Carlsbad Caverns, New Mexico.

The largest cave rooms: It is not clear which is the largest cave room in the world; but the largest by far in the U.S. is the Big Room of Carlsbad Caverns, New Mexico (Fig. 40). Carlsbad is a gigantic spongework cave, but there seems to have been no major source of water to form it. Water seeps in from the surface but is *depositing* limestone (as stalactites, etc.) instead of dissolving it. The cave is located in a ridge of limestone next to extensive layers of "rock salt," such as gypsum, which is *very* soluble, even in water that has dissolved all the limestone it can. Here is a *possible* theory for the origin of the cave:

a. Deep below the water table, limestone was replaced chemically by gypsum, where fresh water descending from the surface mixed with "salty" water.
b. As the water table dropped, the gypsum "blobs" in the limestone were dissolved by fresh water, creating irregular rooms. Some limestone was also dissolved.
c. The cave is now above the water table. Vadose water is still removing remnants of the gypsum, but also depositing limestone as stalactites and stalagmites.

Literature, The Arts, and Photography

In addition to giving lectures and slide talks, and writing popular articles and guide books, CRF supports artists working on cave-related matters. One of the first of these was Donald Finkel, a Theodore Roethke Award-winning poet, who has published two book-length poems with the Mammoth Cave System as a background: *Answer Back* (Atheneum, 1968) and *Going Under* (1978). Sheldon Helfman, a well-known American painter, has painted nearly a hundred watercolors in the MCS (See Fig. 41). And Jean Truel, a French painter of note, has painted 19 large watercolors and oils in Mammoth Cave and 23 in Carlsbad Caverns.

Barbara McCleod has composed words and music for several original ballads on our caving, including the award-winning *Grand Kentucky Junction.* The Composer in Residence at Washington University, Robert Wykes, is composing music with CRF support on a Mammoth Cave theme for the 1981 International Speleological Congress. Richard Watson has published a novel based in part on Flint Ridge caving, *Under Plowman's Floor* (Zephyrus, 1978). And those enigmatic Flint Ridge cavers, Erg Noswat and Ergor Rubreck have produced a parody of a parody, *Maws* (Speleobooks, 1976). From the beginning of work in Flint Ridge, we have had the participation of excellent photographers. James Dyer and William Austin won many awards at photo salons, and their *Man Underground* sequence is still one of the best photographic evocations of our kind of caving. More recently Art Palmer and Pete Lindsley have produced award-winning photographs. Lately, Mark Elliott, Jim Goodbar, Tom Gracanin, and Lynn Weller have been especially active. Dave DesMarais and Roger Brucker continue to produce high quality work. One of DesMarais' photographs was used on the cover of *The Longest Cave* (Knopf, 1976), and many of Brucker's photographs were used in that book and in *Trapped!* (Putman, 1979). These books are in the realm of CRF's social history contributions to interpretation.

Cave Drawing

More drawings were made of the Flint-Mammoth Cave system during the July Fourth expedition of 1978. A methodical program interpreting a comprehensive number of sites does not exist. Each study is rather a consequence of fortunate pauses while accompanying survey parties, or made during tours especially recruited from those willing to share a piece of "beautiful cave." Casual as this might seem, the quality of the drawings seems to improve.

Preferred materials are: small water color paper, compact enough to transport flat and remain clean, semi-moist water colors, in a small pallet box, which quickly deposit a moderately permanent tone on the paper, and a rapidograph pen with a #1 point and a diluted ink or a fine pentel pencil for thin lines that allow much definition on a small surface. Light, a critical commodity for photography, is less problematic for these studies. A carbide lamp, plus a candle or occasionally a Coleman lantern will do. Fifteen to thirty minutes are allowed for each drawing, after which time one must move about to warm up again. During that time of communion with the cave, increasingly dilated eyes develop a comprehension of the surrounding form and surface.

The prime challenge of how to draw a cave persists. Imitation of light is often too laborious to practice at the site. Frequently an adumbration of forms coded with tonalities that explain what is near or deep is a more comfortable expedient. The eyes probe the surface like fingers seeking purposeful recesses. With the accumulation of reciprocal choices the paper gets scribed with the contours of particular voids. Such gesture drawings express the movement of observed surfaces and avoid compiling an inventory of every bewildering visible edge. In these studies distortion becomes an inevitable virtue as it convincingly implies the perspectives of the meandering cave. Some ambitious drawings condense 180° sweeps from side to side up and down onto an 8½"x11" surface.

That weekend three drawings were made in a passage which drops off from Emily's Avenue, three studies were made in Proctor's Cave, and four in an old tourist cave with many flowstone formations at its mouth and occasionally within (Fig. 41).

Poetry, GOING UNDER

Donald Finkel, poet-in-residence of the Washington University English Department, has received a prestigious award from the American Academy and Institute of Arts and Letters in New York City, Finkel received the $2500 Morton Dauwen Zabel Award for his contribution as a "poet of progressive, original and experimental tendencies." Finkel's most recent work is a double-volume paperback consisting of two poems entitled *Going Under* and *Endurance* published in 1978. The form of these two long poems (for the second, turn the book upside down) employs a collage technique which calls on a variety of verse forms and voices. *Endurance* is concerned with the story of Ernest Shackleton's attempt to land a transcontinental expedition on the coast of Antarctica and his ordeal after the ship was destroyed; *Going Under* deals with cave exploration in the Mammoth Cave System. As the author explains it:

> Employing the characters of Stephen Bishop and Floyd Collins as guides, I intended the poem as an exploration of the experience of caving itself. Following them through their personal histories and their respective caves, I wanted to sketch out a kind of memory map, not only of a region, or an era, but of a mysterious passion. The individual passages of the poem were to me like passages on Stephen's map, some of which went (and still go), some of which pinch off, some of which are difficult of access, and some of which are gloriously easy, walking cave. In one sense, the poem is essentially linear, to be read in sequence, at least at first. Thereafter, however, the image I wanted most to sustain was that of a complex interlocking system, like Flint/Mammoth/Joppa, all parts existing simultaneously, though all the connections have yet to be discovered.

Figure 41. Watercolor by Sheldon Helfman.

Novel, UNDER PLOWMAN'S FLOOR

Novel, *Under Plowman's Floor*. Richard A. Watson. Two of the reviews of Red Watson's book (Zephyrus Press, 1978) give a good idea of what was intended by the author.

1. Watson was for more than twenty years among a small group of cavers who led exploration of the Flint Mammoth Cave System in Kentucky, now the world's longest as the result of their efforts. His vast practical experience and probing turn of mind have combined to produce a thoughtful and richly detailed novel of undeniable authority and verisimilitude.

2. *Under Plowman's Floor* is the story of an ordinary quiet, contented man who becomes intensely devoted to cave exploration. While he lives a routinely satisfactory external life, his vital inner life merges with the inner world of the cave.

We follow this man from his first trip underground, through his metamorphosis into an expert long-distance caver, through the peak of his career as director of a caving group exploring one of the most demanding caves in the world. We see him begin solo caving, driven by an inner need, at the age of fifty-five. Some thirty years after his first caving trip, he reaches a goal and a death alone underground that make him into a legend.

This is not an ordinary story. Yet, as the reader comes to feel the hopes and aspirations of this caver, and the excitement and joy of this kind of exploration, what might ordinarily appear to be an incredible obsession is accepted as natural and fitting.

One finishes this novel with a kind of answer to the eternal question, Why climb that mountain, Why explore that cave?

History and Social Science

The Mammoth Cave system is one of only a few caves in the world with a written history of nearly 200 years of continuous exloration and commercial exploitation. A catalog of names in the cave and artifacts provides further documentation. In the Saltpetre studies, these lines of evidence allowed re-creation of the nitrate extraction technology, thus confirming the efficiency of nitrate recovery discussed in the written history. A 25-year program of taped interview with old-timers provides yet another source of information. It helped in the writing of TRAPPED! about the famous cave explorer Floyd Collins. Caves were important to the economy in Floyd's time and he met his end in Sand Cave searching for a new entrance to commercialize. The current tourist industry is no less important to the regional economy, and the whole history, especially the least documented period from Floyd's time to the present, would repay study by someone with expertise in rural sociology and economics.

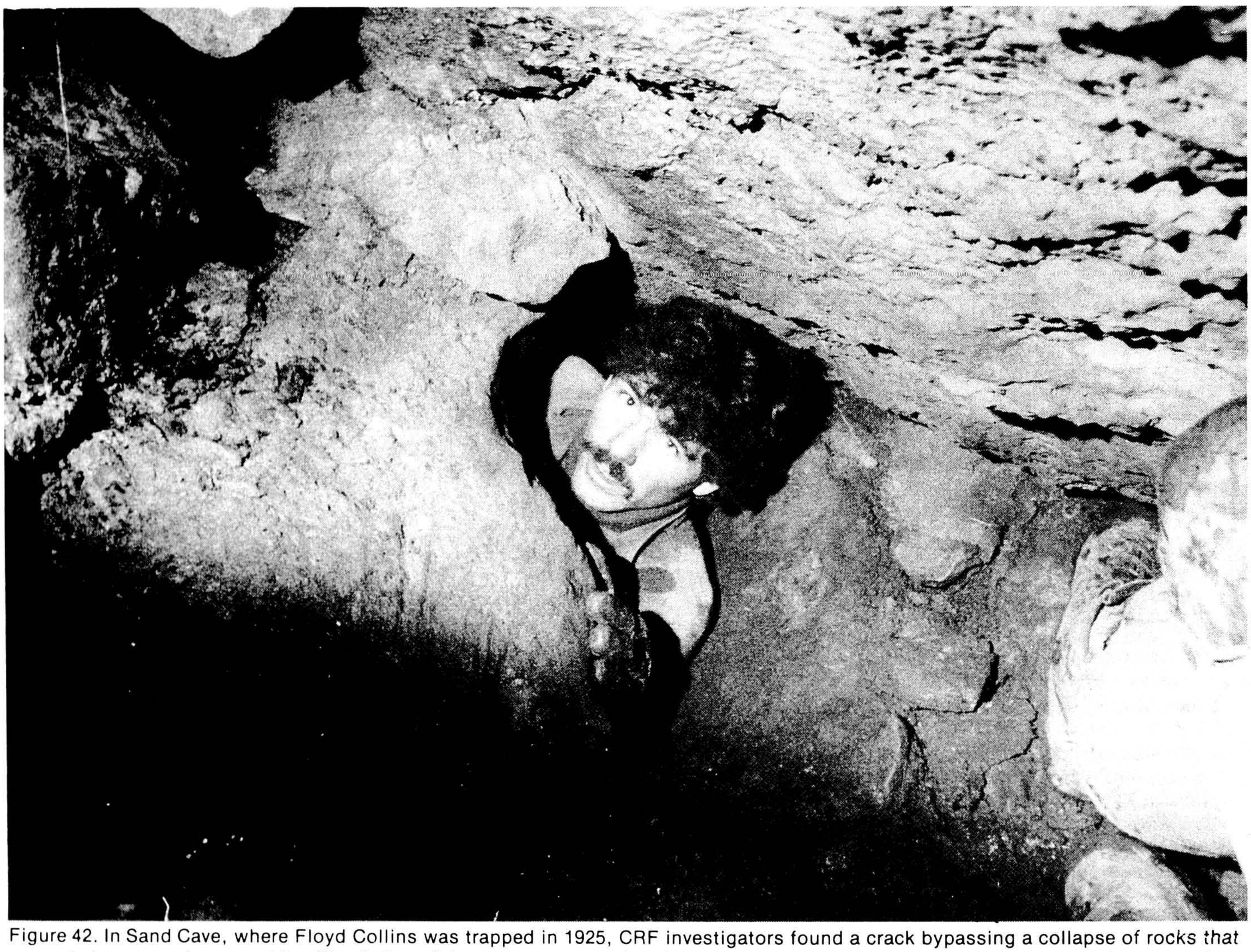

Figure 42. In Sand Cave, where Floyd Collins was trapped in 1925, CRF investigators found a crack bypassing a collapse of rocks that prevented rescuers from reaching Floyd. One of the most controversial of the rescue workers, Johnnie Gerald, always claimed that they could have reached Collins, and the authors of *Trapped!* conclude that he was right. Photo shows Tom Brucker in the nine-inch crack.

TRAPPED! tells the story of Floyd Collins

Roger W. Brucker

In November, 1979, G.P. Putnam's Sons Inc., New York published *Trapped!* by Robert K. Murray and Roger W. Brucker (335 pp.). The book tells the story of Floyd Collins' entrapment in Sand Cave and the subsequent attempts to rescue him. The story became one of the most sensational news stories of modern times. The narrative reconstructs the event and places it in the social context of the 1920s. The authors made considerable use of CRF's oral history tapes, recorded by James Dyer, Micky Storts, Robert Pohl, and others in the 1950s and 60s, and interviewed scores of people with memories of the event and times. CRF Joint Venturers opened and explored Sand Cave for the first time since 1925. The book, sold nationally, has drawn a great deal of critical acclaim. Excerpts from selected reviews are printed below:

> The death of Floyd Collins in Sand Cave may no longer be a large part of American folklore, but it is one of the very largest parts of the lore of American cave exploration, and this interesting and well-researched book will help secure it in that place.
>
> William Mixon, *Windy City Speleonews*

> The story is skillfully told so as to illuminate the history and development of the Kentucky cave region. And finally the event is discussed in the light of its appeal to American society in the 1920s. The result is not simply a moving treatment of one man's agony, but excellent social history as well.
>
> Nelson Dawson, *Louisville Times*

> And it is a penetrating analysis of how the plain facts of any celebrated event can be distorted into a mish-mash of truth, myth, and legend.
>
> Ernest Cady, *Columbus Dispatch*

> ...a splendid, vivid, bone-chilling, fear-of-tight-places book that succeeds on a number of levels. It is an exciting narrative of the 16 day rescue effort....On another level, Murray and Brucker provide a superb analysis of how legends are made. They examine the media hype and hucksterism and explore the psychological chords, often antithetical, struck in the American people by the plight of Collins.
>
> Michael Heskett, *Houston Chronicle*

> They have left nothing unexamined, from the nature of the press coverage to the story's after life, in a ballad, many bad poems—and one superlative poem. They have reviewed novels and movies firmly or precariously based on the story, and even the TV dramas it has spawned.
>
> Donald R. Morris, *The Houston Post*

> Amply illustrated with photographs and diagrams, *Trapped!* is good deductive history. Scholarly but not pedantic, the book refrains from lapsing into technicalities. In fact, so well told is Collins' plight that armchair claustrophobes doubtless will squirm in discomfort.
>
> Charles Davis, *Peninsula Herald*

The legend of the Mammoth-Dixon Cave connection

Duane De Paepe

There are persistent old Mammoth Cave guide stories about the location of a supposed "connection" between the trunk terminus in Dixon Cave and Mammoth Cave. It has long been recognized that geologically the two caverns are part of the same system, now sealed from each other because of the breakdown collapse at the rear of Dixon Cave.

Some guides relate that the Methodist Church in Mammoth Cave is the location where the two caves meet, and indeed the character of the large breakdown truncated alcove passage lends credence to this theory. Yet another idea is that the terminus of Pensacola Avenue is the point of connection and an engraved "Saltpetre Manufactory" inscription at the end of that passage can be tantalizingly interpreted as showing the way to the early Dixon Cave mining operation. Finally, the collapse that opened the Historic Entrance to Mammoth Cave is also regarded as the place where Dixon joined Mammoth Cave.

The legend involved both caves and originated during the saltpetre mining era. The vehicle by which the story has transcended generations of cave enthusiasts was Ebenezer Meriams' (1844) exquisitely documented story in the *New York Municipal Gazette.* Meriam was a witness and participant in the circa 1812 nitre recovery venture, and as such had furnished invaluable primary annotation for the modern saltpetre researcher. His account states:

> The ancient mouth of the Mammoth Cave, is a quarter of a mile from its present one. The mouth of 'Dixon's Cave' was originally that of the Mammoth. 'Dixon's Cave' is, so far as it goes, of immense size. Laborers digging for Saltpetre earth, at its extremity, have been heard within ten feet of the Mammoth Cave. The proprietor intends to connect them at some future period.

Many years later, pioneer speleologist Horace C. Hovey (1882) wrote, concerning the Historic Entrance to Mammoth Cave:

> ...the ancient outlet of the subterranean region before us was through what is now known as Dixon's Cave. A small opening on our left as we stand facing the present entrance, points in the direction of Dixon's Cave, but the guides say there is no opening through, although persons in one cave can make themselves heard in the other, as was proved by the miners in 1812, whose picks could be heard...

From the foregoing accounts it appears that the terminus of Dixon Cave is at the Historic Entrance to Mammoth Cave. In order to prove this, saltpetre investigators during July, 1979 tried to make an acoustical connection, similar to that experienced in 1812. This was attempted from inside Dixon Cave, at the top of the trunk terminus breakdown slope, and simultaneously at various locations in and around the Mammoth Cave Historic Entrance; including inside the "small opening on our left" mentioned by Hovey. This effort was supplemented by a radio direction finder. A basic tenet to the experiment was Meriam's belief that the Dixon Cave mining sounds "have been heard within ten feet of the Mammoth Cave."

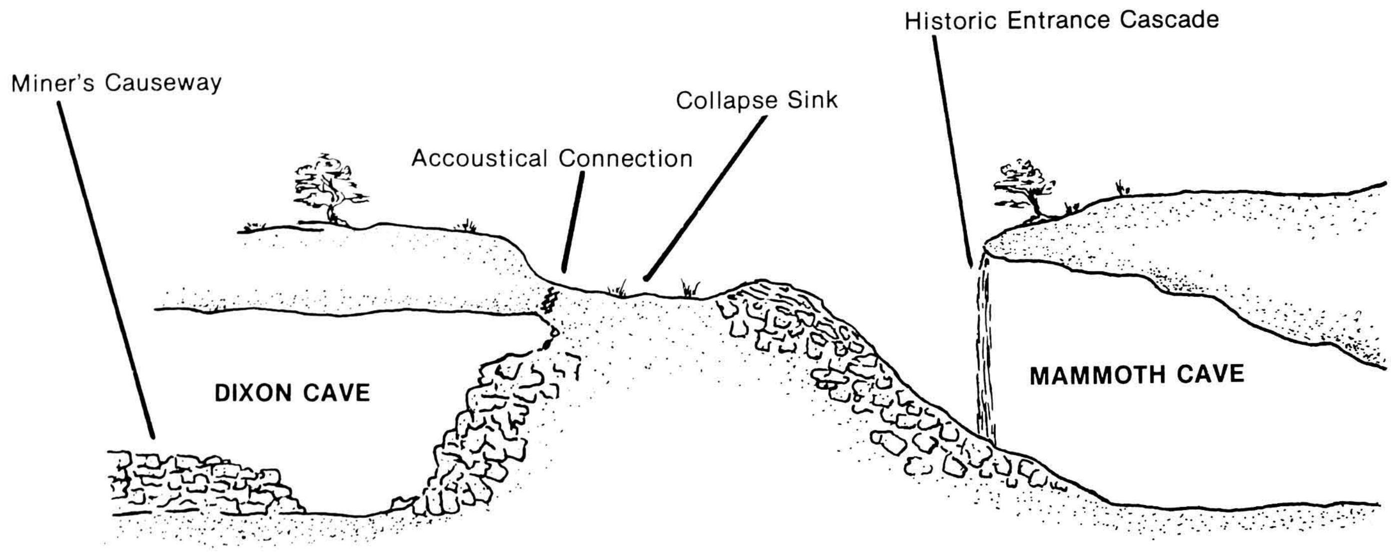

Figure 43. Diagrammatic model of the Mammoth-Dixon Cave connection. Drawing by Duane DePaepe.

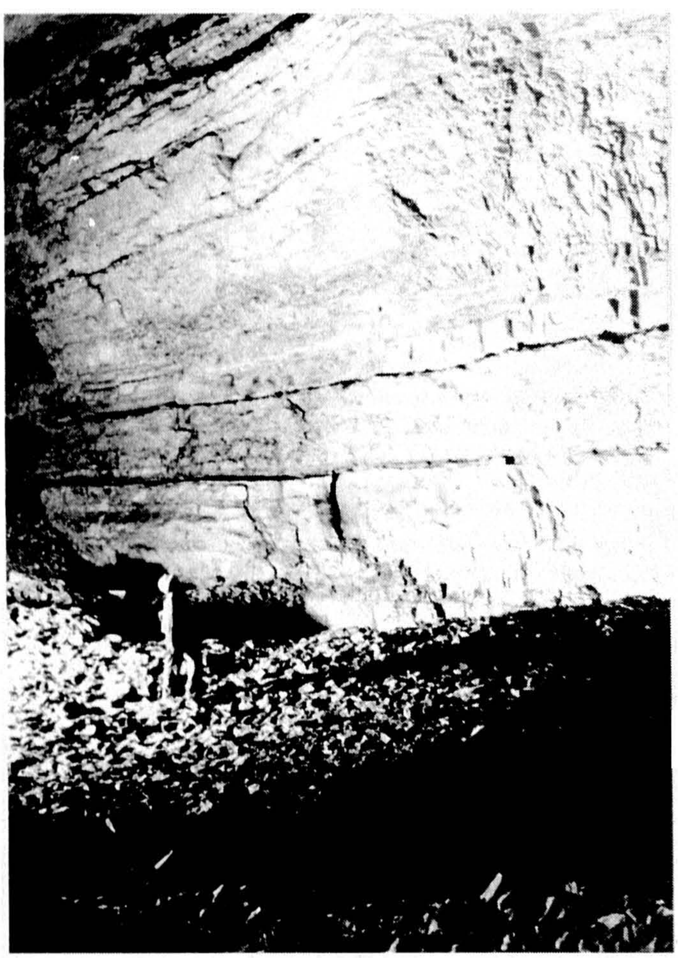

Figure 44. Dixon Cave breakdown sorting and excavation by circa 1812 saltpetre miners. Photo by Duane DePaepe.

After an interval of trial and error, the shallow collapse sink above the Mammoth Cave Historic Entrance (Fig. 45) transmitted clear sounds of hammering from within Dixon Cave. The exact location was quickly determined. Coded rock hammering signals could distinctly be exchanged and vibrations felt underfoot on the surface.

The Meriam's account was dramatically verified. From this we can also assume the accuracy of his statement that the saltpetre operation owners planned to connect the two caverns. From all of the early reports, it is evident that the Wilkins-Gratz saltpetre venture was an efficiently run business operation. It realized considerable profits after covering the initial capital investment for the elaborate works and labor supply. It followed that the Mammoth-Dixon connection be constructed in order to realize further expansion. However, the end of the War of 1812, and the resultant collapse of the saltpetre market, obviated profit incentive for connecting the two caves.

The entrance vestibule in Dixon Cave was where that cave's initial mining took place, and where the leaching vat complex and minimal leach water supply was located. Probably two boiling furnaces, similar to those at Mammoth Cave, were located on the surface, just outside the entrance. Despite the intense human effort in sorting breakdown (Fig. 46), the search for nitre deposits convenient to the entrance processing facilities eventually produced diminishing returns. But if the back end of Dixon Cave were connected to the Historic Entrance of Mammoth Cave, the Mammoth Cave leach water cascade, boiling furnaces, and surface labor force could be made directly available to recover nitrates in the rear of Dixon cave. In all probability, the Dixon Cave log leaching vats, stationed near the damp entrance with exposure to seasonal elements, were in an early stage of deterioration. This factor, and likely smaller capacity boiling furnaces, could have made the connection plans even more attractive. It may be further theorized that the construction of the elaborate "miners' causeway," near the terminus of Dixon Cave, was the initial phase in a plan to combine the recovery facilities of both caverns.

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- -Chicago Academy of Sciences, Chicago, Illinois, February.

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- -Fairborn, Ohio Explorer's Post, November.
- -Lion's Club, Yellow Springs, Ohio, October.
- -Indiana Cave Capers, Marengo, Indiana, Banquet Speech, June.

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Translation Program

translations program: *Richard A. Watson*

A. Miotke

During March of 1979, Franz-Dieter Miotke and Richard A. Watson spent three weeks in Hannover, West Germany, working intensively on two translation projects:

1) They translated Miotke's booklet, *Karstmorphologische Studien in der Gizial-Uberformten Hohenstufe der "Picos de Uropa", Nordspanien.* Jb. d. Geogr. Ges. Hannover, Sonderheft 4. 161 pp.
   It will be published in England.
2) They put together a first draft of a book by Miotke titled *Geomorphology of the Mammoth Cave Region,* Karst Theory and Practice Using as an Example the Origin, Evolution, and Interrelationships of Erosion Surfaces, Landforms, and Caves in the Central Kentucky Karst.

This book is based on the following:

Miotke, F.-D. (1973 *Der Zentral-Kentucky-Karst.* Habilitationsschrift, Hannover: Technischen Universität Hannover, 603 pp.

Miotke, F.-D. (1975) *Der Karst im Zentralen Kentucky bei Mammoth Cave.* Hannover: Jahrbuch der Geographischen Gesellschaft zu Hannover für 1973, 360 pp.

Miotke, F.-D. and A.N. Palmer (1972) *Genetic Relationship between Caves and Landforms in the Mammoth Cave National Park Area.* Hannover: Geographisches Institut, Technische Universität Hannover, 69 pp.

Miotke, F. D. and H. Papenberg (1972) "Geomorphology and Hydrology of the Sinkhole Plain and Glasgow Upland, Central Kentucky Karst, Preliminary Report", *Caves and Karst,* Vol. 14, pp. 24-32.

Papenberg, H. (1973) *Verkarstung und Karstformen in Ihrer Beduetung fur die Landschraft im Zentralen Kentucky [USA].* Staatsexamensarbeit, Hannover: Technischen Universität Hannover, 263 pp.
(Miotke supervised Papenberg's work, which is equivalent to an American M.S. thesis.)

This work will be published in the United States when Watson finishes editing the text and Miotke finishes preparation of the illustrations. It will be a major presentation of Miotke's theory of karst based in part on his work in the Mammoth Cave Region, and will be about 300 pp. long.

B. Jean Truel:

Jean Truel, Pientre des Gouffres. Paris: Arte-Adrien Maeght, 1979, 32 pp. This booklet contains color reproductions of Truel's paintings, including two of Carlsbad Caverns and one of Mammoth Cave. It also contains short articles on Truel by Norbert Casteret, Richard A. Watson, and Claude Chabert, plus an interview with Truel by Jacques Chancel.

Since 1962, Jean Truel, a major French painter, has painted only the interior landscapes of caves. He worked in Mammoth Cave in 1974 (19 paintings) and in Carlsbad Caverns (23 paintings) in 1976, with some assistance from CRF. His paintings sell from $850 to $2500 each. He expects to work in Mammoth Cave again in the summers of 1980 and 1981 under CRF auspices. His paintings can be seen at the Astro Mineral Gallery in New York, and will be on exhibit at the 1981 International Speleological Congress in Bowling Green, Kentucky.

Support for the 8th International Congress of Speleology

In addition to being a cooperating organization for the Congress, about half of the 48 persons involved with the Congress organization are affiliated with CRF.

As part of the Publicity Department Roger Brucker designed the logos.

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Cultural: Richard A. Watson

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Mammoth Cave: Arthur Palmer
Hydrology: James Quinlan

Map Salon: Ernst Kastning

Photo Salon: Karen Kastning

Still others are on our regular information list and not currently active. These include the Chairman, Rane Curl; the remainder of the Steering Committee, William Halliday and Bro. G. Nicholas; the President, Russell Gurnee; and the coordinator of the Science Program Committee, John Thrailkill.

The
CAVE RESEARCH FOUNDATION

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Richard A. Watson

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Steve G. Wells, Guadalupe Escarpment Area
David DesMarais, California Area
W. Calvin Welbourn, Special Projects
William P. Bishop
Arthur N. Palmer
Patty Jo Watson
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