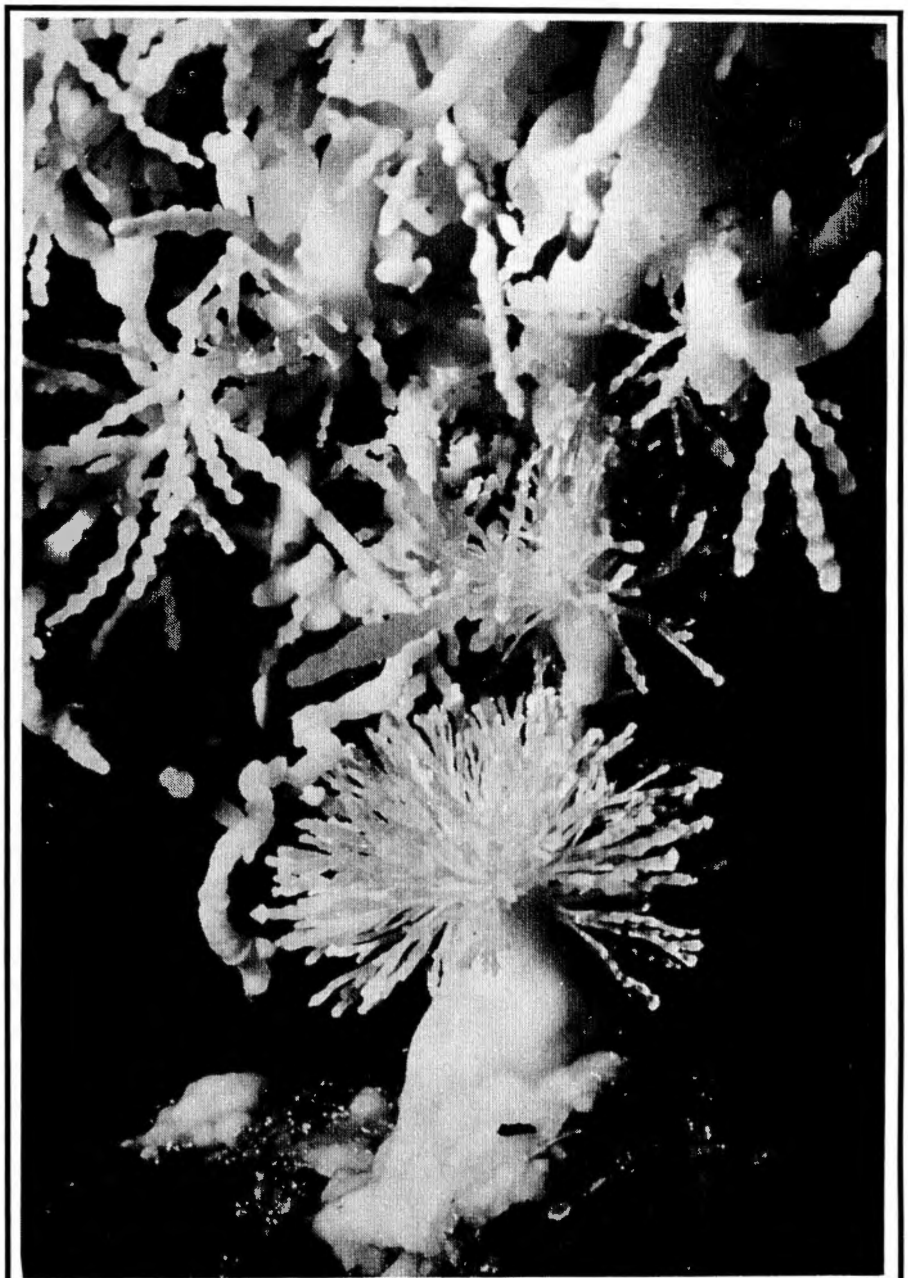
1986 ANNUAL REPORT



CAVE RESEARCH FOUNDATION

Cave Research Foundation Annual Report for 1986

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

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

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Cover Photo: "Sea anemone" with beaded helictite "tentacles" speleothem, Cave of the Winds, Colorado. *Photo by Cyndi Mosch Seanor.*

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CAVE CONSERVATION

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

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 Also, many of the processes that formed the cave passages we travel are no longer active in these areas.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

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

HIGHLIGHTS OF 1986

In March, 1986, Sarah Bishop and I met with National Park Service Director William P. Mott to sign a new long-term agreement between the National Park Service and the Cave Research Foundation. This agreement strengthens our already strong relationship and reaffirms our commitment to work as partners to support improved understanding and stewardship of the outstanding cave resources that occur in the national parks.

One element of the agreement that is new is the use of CRF personnel to assist the National Park Service with the evaluation and monitoring of cave sites proposed or included in the National Natural Landmark Program that is managed by the NPS. Volunteers from throughout the country will be needed for this new initiative of the Foundation, as well as the diversity of on-going projects.

CRF scientists are increasingly sought for their advice concerning a broad spectrum of cave science and management issues. Contacts established in 1986 are poised to lead the Foundation to other continents in our quest to explore and study the great cave of the world. Foundation expeditions to Colombia and the People's Republic of China are being planned for the not too distant future.

On the home front, cave restoration and interpretation projects continue to be strong, aided by cooperation with the National Park Service, the National Speleological Society, the American Cave Conservation Association and others. Efforts to package more of our collective knowledge into accessible forms are on track to produce a steady stream of products to document cave resources and to serve as aids to the management and interpretation of the caves in which we work.

The Foundation is strong and offers interested individuals a broad spectrum of challenging projects to further the understanding, protection and interpretation of caves. Anyone in search of an appropriate project should contact the Foundation directors for ideas.

Ronald C. Wilson
President, Cave Research Foundation

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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, Lincoln National Forest, Buffalo National River and Ozark-St. Francis National Forests have greatly contributed to the success of these projects. Their assistance is greatly appreciated. Other acknowledgements appear at the end of some reports.

SCIENCE PROGRAMS

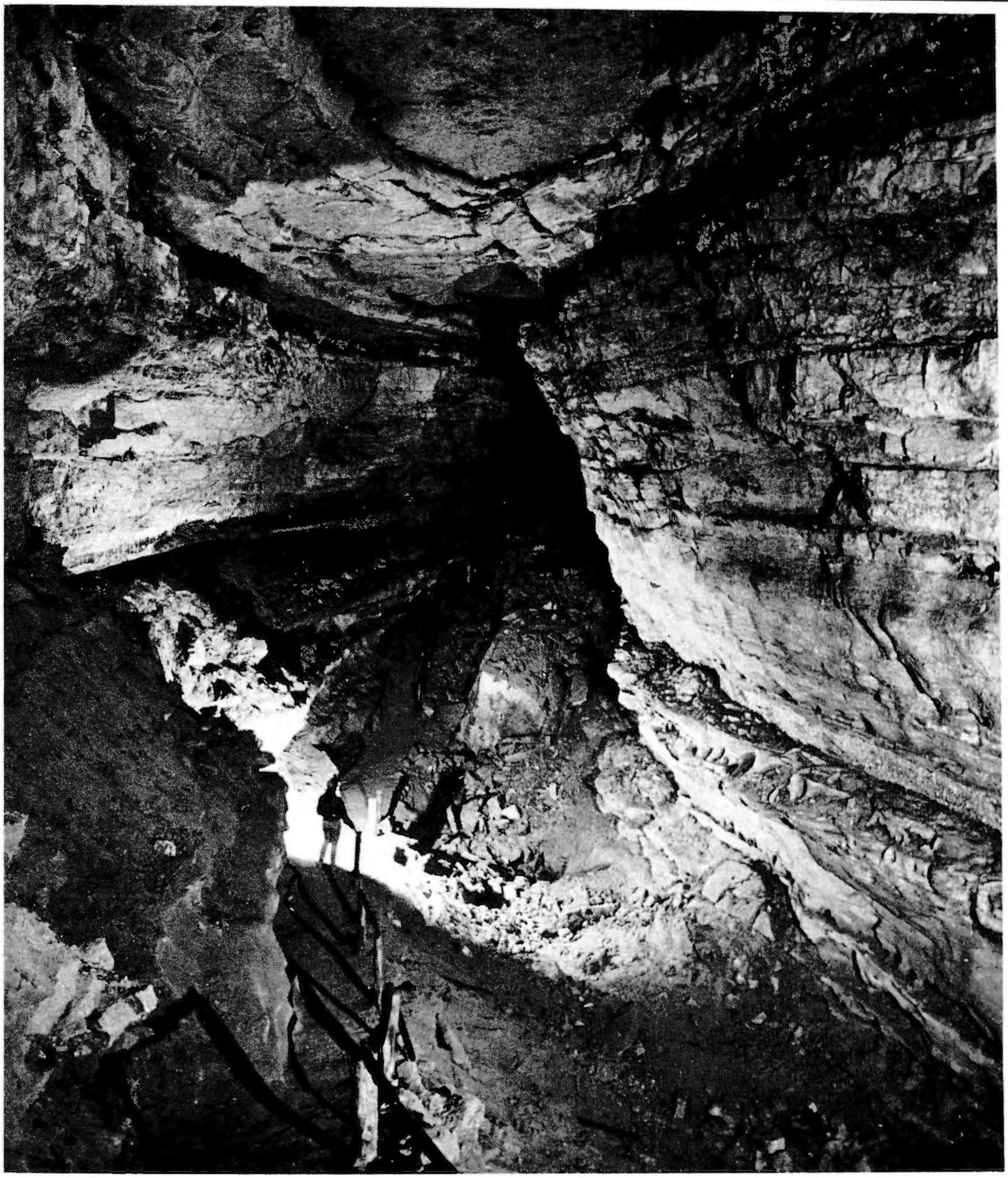

Figure 1: Upper-level passage in the Mammoth Cave System (Kentucky); typical of many of the large main passages in the system, it is a high, wide canyon partly filled with sediment and breakdown. This is Dyer Avenue in the Crystal Cave section, which was once under private ownership and open for tourists as late as 1961. Remnants of trail improvements are still visible. *Photo by Arthur N. Palmer.*

Cartography Program

Lilburn Cartography Project 1986

Peter Bosted

The cartography project at Lilburn Cave has two main goals. The first is to resurvey all the passages mapped in the 1960's and 1970's with improved sketching and detail. The original survey, led by E. Hedlund, mapped about 41,100 feet (12,527 m). Presently about 90% of this total has been resurveyed, with most of what is left being in the Yellow Floor Domes area. The second goal is to find and survey new passage. About 2000 feet (610 m) had been surveyed through the end of 1985, and about 2200 feet (671 m) of new passage was surveyed in 1986. From this it can be seen that the emphasis of the project is shifting towards the second goal.

There were a total of 14 survey trips in four expeditions in 1986. A total of 5600 feet (1707 m) was measured and 470 stations were set. These totals are down somewhat from previous years, reflecting the small number of expeditions and fewer cartographers per expedition. The total cave length is now over 41,100 feet (12,527 m), thus passing the old survey length. Hopefully this will provide some incentive for lots of work in 1987.

Most of the new passages found in 1986 were in the south end of the cave and in the Attic area. Both of these areas have a lot more potential. Nothing has been found that could lead to the hypothesized Great North Cave. On the other had, Cedar Cave (about 1 km N of Lilburn) needs to be pushed and mapped and could possibly connect with Lilburn.

Work on the inked draft of the cave is fairly well up to date. More detail needs to be added to areas that are more or less complete, and decisions need to be made about overlays in complex areas. Work is also being done on generating a 3D color computer graphics display of the cave.

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Mammoth Cave System Cartography

Scott House

1986 was a very good year for Mammoth Cave cartography. Several new projects were initiated as old goals were examined and revised. Following more modern cave cartographic standards a new series of system maps have been started at a scale of 1:600. The impetus for this new system was two-fold: a new series of tour trail maps were desired by the National Park Service and a remap of Unknown Cave was started at the same scale. Thus, this new map series is rapidly becoming a reality and it is hoped that this will be the new standard for detailed base maps of the system for some years to come.

The characteristics of these new maps is that they are generally 40 inches wide with variable lengths depending on the geographic area of the cave shown. The maps of Mammoth Ridge will initially be constructed with emphasis on the tour trails and later expanded to include all passages within the map borders. The scale of 1:600 (1" - 50") will be sufficient for most areas although insets at a larger scale will possibly be needed for some very complex areas (such as Emily's Puzzle). The maps are first drawn on mylar with pencil; later another layer of mylar will be inked for the final copy. These maps will be available as blueline prints or they can be photographically reduced for a variety of publishing purposes.

The first map "completed" at the new scale was the Frozen Niagara tour map by Scott House – this will later be redrawn to include more passages. In 1986 the tour trail map of Cleaveland Avenue was put into final form by Douglas Baker. This shows all passages from Thorpes Pit in Boone Avenue on the east through the Carmichael entrance and includes a large chunk of Main Cave inside the Violet City entrance. Pencil versions of the Cathedral Domes area tour trail map (by Scott House and Eric Compas) and the Kentucky Avenue tour trail map (by Michael Sutton) are in an advanced stage and nearly ready for inking. Together, these four maps will show all passages from the Frozen Niagara entrance to the Carmichael entrance. A new 1:600 manuscript is being contemplated in New Discovery with Tomislav Gracanin working on that.

Other caves within the park are also receiving cartographic work. A new map of Smith Valley Cave is being drafted by Tim Schafstall. And the small caves project is going to be producing numerous maps of smaller caves within the park.

In Flint Ridge five new 1:600 manuscripts are in progress. The titles of these are: Pohl Avenue, Brucker Breakdown, Turner/Mather Avenue, Swinnerton/Gravel Avenue and Northwest Passage. These maps are being done by Paul Hauck, Scott House and Michael Sutton. They will show essentially all passages from the Austin entrance out to the connection area. Additionally, Art Palmer is continuing work on a 1:600 map of Crystal Cave. Future Flint Ridge projects will include new maps of Colossal Cave. Final work on the Flint Ridge manuscripts is not as advance as hoped. This is due to the difficulties of closing major surface/subsurface loops to provide closed cumulative coordinates for the system. However, progress is being made and 1987 ought to see this completed for Unknown Cave.

Some new surveying techniques have been introduced. Among these are: use of 100-foot tapes, brunton compasses mounted on tripods of various sizes, better sketching techniques, new CRF waterproof surveying paper, and the practice of measuring rather than estimating whenever possible. Additionally, resurveying and resketching have been done where necessary. The oldest surveys in the Mammoth System are generally the poorest quality and they are typically of the most important passages. Much resurveying has been necessary to improve the quality of the survey net and to improve the quality of the sketch. Resketching is done where the survey net proves to be acceptable.

Several needs have been identified over the last two years. We need more people to be trained in cartographic procedures. A good opportunity for this exists in the small caves inventory project. It is easiest to learn proper cartographic procedures on a small cave before trying to work with a system like Mammoth. Secondly, the present CRF data reduction program does not work in a manner that gives cartographers the types of information they need to construct system maps. Loop closures and cumulative coordinates are the two biggest needs in that respect. Currently, we are reducing much of our data on hand calculators. A new program has been written for Apple][computers by Eric Compas. It allows both cumulative coordinates and loop closures and has allowed us to get caught up on a great deal of survey data work. However, few of our cartographers have computers. We need to improve our methods of distributing data within the cartographic community. Our present record-keeping system is somewhat haphazard at best. We also need a better distribution system for copies of maps. CRF has many maps on file but no formalized system for distribution. We need to coordinate our efforts with other groups in the area particularly in terms of sharing data. Lastly, we need to continue surface surveys to tie in various entrances accurately. This includes small caves which may fit on the manuscript maps.

Much needs to be done but with cooperation and hard workers we can produce maps that will show the cartographic community that Cave Research Foundation is capable of producing the finest cave maps in the world.

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Fitton Cave Survey Project

Pete Lindsley

Field work continued in Fitton Cave, Arkansas, with emphasis on completion of surveys in the major trunk passages. Seven expeditions were fielded in 1986 and the surveys in the major passages were 85% complete. The cartographers have been keeping the working maps up to date within a few months of the actual field work. Planning has started on the design of quadrangle sheets which will cover the area of the cave passages. A total of 12 quads is presently projected for the cartographic work in 1987.

A total of 240 survey points around the major survey loop in the cave - a 10,170 foot loop through the East Passage and Crystal Passage - were entered into a Macintosh based data base. Horizontal closure error is on the order of 13 feet; the total closure error in three dimensions resulted in an amazing 0.25% closure error! All the Fitton Cave Project participants deserve a pat on the back for this accomplishment. The long range cartographic goal of the Project is to achieve a 0.1% closure error along a precision base line through the major trunk passage loops. As the present Brunton - Suunto based surveys are linked to precision transit - theodolite based surveys it is expected we will approach the long range accuracy goal.

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

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Geoscience Programs

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

John C. Tinsley

Introduction

The objective is to improve understanding of rates and processes of hillslope erosion within the Redwood Canyon karst, Kings Canyon National Park. Volumes of eroded sediment are estimated on the basis of studies of the sedimentology and stratigraphy of sinkhole sediments. The karst contains about 60 sinkholes, many of which have intermittently trapped sediment eroded from hillslopes under a coniferous forest vegetation. The sinkhole sediments are composed chiefly of gravel, sand, silt and clay derived from the granitic and metamorphic wall rock comprising the canyon and from alluvial deposits of Redwood Creek and its tributaries. Of special significance to this study is the presence of a volcanic ash layer that forms a marker bed for these stratigraphic studies.

About 700 radiocarbon years ago, one of California's several volcanic centers erupted explosively in the Mammoth Lakes area in the southern part of the Inyo Craters volcanic chain, south of Mono Lake in east central California. The resulting plume of fine-grained volcanic ejecta, termed *tephra* or volcanic ash, drifted to the south and west across the Sierran crest, where it blanketed much of the southern Sierra Nevada, including the karst area in Redwood Canyon. The powdery tephra, identified by its distinctive trace-element chemistry as a product of the Deadman Dome vent, then was eroded from hillslopes, rivulets and gullies and was delivered to the sinkholes. What happened then depended on the nature of the sinkhole in question. Sinkholes containing open conduits in their bottoms apparently transmitted most if not all of the deposits of sediment and ash directly to the cave below, for these sinkholes preserve little if any record of the ash. Alternatively, a sinkhole floored with a permeable sediment plug composed of silt and sand effectively trap air- and water-borne sediment, including tephra; these sediments then become part of that sinkhole's sedimentary record and the water slowly seeps away. Deposits of non-tephra-bearing sediment continue to wash into sinkholes and bury the tephra deposits.

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

Methods

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

There are 65 sinkholes known in the Redwood Canyon karst; about 1/3 of these will be suitable for this study. Some of the sinkholes contain abundant deposits of granite boulders and cobbles, unyielding opponents to the soil auger as well as unsuitable media for efficiently trapping silt-size particles of tephra. Other sinkholes serve as principal inputs of water and sediment to the Lilburn Cave system. The open conduits commonly observed in these sinkholes are not capable of trapping tephra or most post-tephra sediments and estimated erosion rates in these drainage basins thus would be biased too low relative to reality. Only by comparing results from a number of sinkholes can we obtain estimates that are amenable to statistical analysis.

Results

Eighteen sinkholes have been examined and ten sinkholes have been augered as of 12/31/86. Hillslopes of less than 10% tend to retain at least part of the mantle of volcanic ash, which then becomes mixed with the soil owing to biological and physical processes. Slopes steeper than about 10% generally shed their ash mantle readily into the sinkholes and are more efficient contributors of sediment, especially coarse sediment, than their more gently-sloping neighbors. The tephra blanket apparently ranged in thickness from 1 to 5 cm thick in the Redwood Canyon area. Erosion rates of the soil mantle measured in this way range from 0.5 – 1.5 cm/yr.

During the 1987 field season, we plan to examine a large number of rather small, shallow sinkholes which have small drainage basins, in order to determine the minimum size required to obtain an unambiguous base to the tephra layer. We have discovered that the tephra layer typically is rather poorly preserved where gentle slopes and small drainage basins cause sedimentation rates to be low. Under these conditions, burrowing organisms tend to homogenize the stratification within the sinkhole and, where the base of the tephra is not clearly identifiable, unseemly degrees of uncertainty creep into the analysis. These refinements should enable us to identify the likely threshold of slope and drainage basin size below which the estimates of soil erosion rates and tephra thickness become unmeasurable.

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Kinetics of Calcite Dissolution in Carbonic Acid

S. Rosenfeld

Problem Statement

To understand the role of groundwater in karstification, it is necessary to have a satisfactory model to predict the dissolution of calcite by water containing carbon dioxide. A realistic mathematical model must reveal all significant mass transport and chemical reaction effects, and be in substantial agreement with data taken under a wide range of physical conditions. A study is now being performed which will combine all important chemical reaction and diffusion features for this system into a comprehensive model for calcite dissolution in natural aquifers. It is believed that enough features have been included in the developing model to allow a priori rate predictions in many physically important cases. At present there are no kinetic models for calcite dissolution that are fundamentally correct and contain enough features to provide accurate rate predictions. Prior studies using theoretical models have omitted important considerations; the results have been models that do not agree with rate data. Considerable data on this topic are found in the literature, so the study currently being performed has concentrated on construction of a model which substantially agrees with the data taken by others. A history of this problem shows the need for a more complete model.

Background

This study originated from a need to clarify a confusing assortment of contradictory theories and data resulting from several previous investigations. Work done by others has yielded kinetic rate data taken with a variety of methods and a wide range of hydrodynamic conditions. Mathematical modelling of calcite dissolution has been approached by empirical and fundamental methods. In each case the models can be shown to be in disagreement with data taken either by others or by their own respective studies. The interested reader is referred to a more thorough review article by Plummer et al (1979), which lists all but the most recent publications.

Scope

The model that is currently being developed is expected to define an upper limit for the karstification process in the turbulent flow regime. Furthermore, for the case of calcite dissolution far from equilibrium, the model appears to be in close agreement with observations. Closer to equilibrium, the rate is strongly reduced by inhibiting metal ions. However, these heterogeneous kinetic effects can only be examined after the diffusional and boundary layer chemical reaction effects are properly modelled. This study, then, is expected to provide a basis for future surface inhibition modelling efforts.

Methodology

A fundamental approach is being taken to solve this problem. Specifically, the method of Curl (1968) is being refined by successive addition of features to the model until the results produce accurate predictions for the data of other workers. Standard mathematical modeling techniques are being used to model mass transfer with chemical reaction in a turbulent boundary layer. Film theory is invoked to place the boundary layer diffusion equations in terms of mass transfer coefficients. A correction is being made to account for the observation that in solid-liquid systems the mass fluxes are observed to vary as the two-thirds power of the diffusivities, whereas traditional film theory invokes a direct proportionality.

Since the hydration of carbon dioxide in the boundary layer is known to be a slow step, this feature is being accounted for in the models in a manner similar to that used by Curl. In addition, the effects of carbonate, bicarbonate and hydronium ions are now being considered. These species participate in several fast boundary layer reactions, and these steps are assumed to be fast in comparison to the hydration reaction. At the interface, equilibrium of surface species is being assumed, as a first approximation. This assumption is necessary in order to separate the effects of boundary layer reaction and diffusion from the surface kinetic effects. The equations which form the boundary condition relationships at the interface are based on chemical equilibria and solubility relationships as well as charge and mass balances. An important feature of the model is its non-dimensionalization based on measured chemical activities. This considerably improves the accuracy of the model.

The system of equations which result from this model can be rearranged into terms of a single second-order nonlinear ordinary differential equation. If enough simplifying assumptions are introduced so that an analytical solution is possible, the rate predictions have been shown to differ from data. The complete system of equations is being solved for as many different physical conditions as for which data are available.

Preliminary results have been very encouraging (Rosenfeld, 1985). Figure 2 shows a comparison of the complete model with data taken by Plummer et al (1978). For this case of geochemical significance it is seen that the model provides good agreement with the data up to about 50% saturation, and provides a theoretical upper limit for the rate beyond that point. Further work is necessary to understand the kinetic steps which occur at the interface.

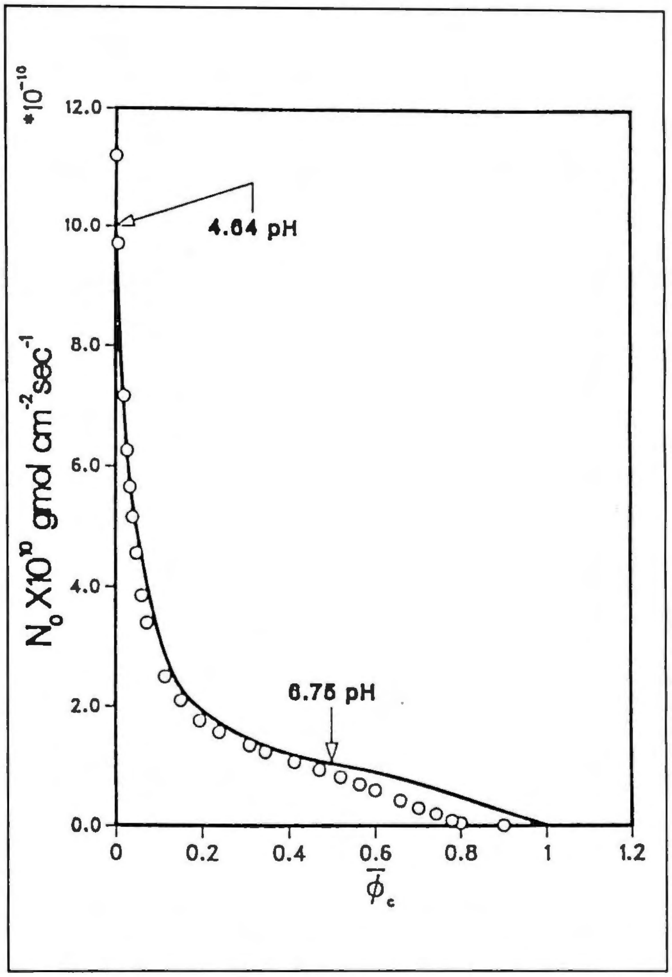

Figure 2: Rate data from Plummer et al (1978b), run 13.

References

Curl, R. L., 1968, Solution Kinetics of Calcite: *Proc. 4th Int. Cong. Speleology,* Yugoslavia, pp 61-66.

Plummer, L. M., T.M.L. Wigley and D. L. Parkhurst, 1978, The Kinetics of Calcite Dissolution in CO_2-water Systems: *Am. Jour. Science,* 278, pp 179-216.

Plummer, L. M., T.M.L. Wigley and D. L. Parkhurst, 1979, Critical Review of the Kinetics of Calcite Dissolution and Precipitation: in Jenne, E. (ed) *Chemical Modeling—Sorption, Speciation, Solubility, and Kinetics in Aqueous Systems, Am. Chem. Soc,* Washington, DC, pp 537-573.

Rosenfeld, J. H. 1985, Master's Thesis, Univ. of Michigan, Ann Arbor, MI.

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The Origin of "Trays" (Flat-Bottomed Popcorn) in Carlsbad Cavern

Carol A. Hill

In many parts of Carlsbad Cavern, such as in Left Hand Tunnel and the Big Room, sprays or clusters of popcorn and frostwork can be found, the composite mass of which ends in a flat horizontal surface. Often these flat-bottomed masses occur in tiers; that is, at different levels along a wall, in a stair-step-like manner. Such sprays of popcorn and frostwork have been informally called "flat-bottomed popcorn" by Guadalupe cavers for many years; recently, South African occurrences of this same speleothem have been formally named "trays" in the published literature (Martini, 1986). Tray speleothems have now been identified from four different caves: Carlsbad Cavern, New Mexico, USA; Cango Cave and Tabazimbi Mine Cave, South Africa; and the Grotte Andre Lachambre, France (Table 1).

Trays are characterized by the following features:

1. Maximum development of a tray is along its flat, bottom surface (trays seemingly "refuse" to grow further down). The elevation of that flat surface is controlled by the tip of bedrock pendant (Figure 2), or less often, by the tip of a stalactite. Where a number of stalactites terminate in trays, they can resemble elephant's feet.

Table 1: Description of Trays

Cave Name	Description of Trays
Carlsbad Cavern, New Mexico	Up to several meters in diameter. As individual masses or as masses arranged in tiers. Composed of aragonite frostwork along the periphery of the mass and calcite coralloids (popcorn) in central part of the mass. Occur on bedrock pendants and walls, and rarely on stalactites. Associated with condensation-corrosion features, "popcorn lines" and sometimes hollow stalagmites. Most are inactive and appear to be in the final stage of growth.
Grotte André, Lachambre, France	Approximately 6 - 30 cm in diameter. Composed of aragonite frostwork; no apparent build-up of calcite popcorn in the centers of the masses. Occur on bedrock pendants and walls. Associated with condensation-corrosion features and a "popcorn line". Appear to be in the initial stage of growth.
Cango Cave, South Africa	Up to 30 cm in diameter. As "elephant's feet" masses. Composed of coarse calcite crystals (spar up to 2 cm in length); no aragonite or popcorn. Occur on bedrock walls or as a secondary growth on stalactites.
Thabazimbi Mine Cave, South Africa	Up to several meters in diameter. Composed of aragonite frostwork along the periphery of the mass and calcite coralloids (grapes and coral) in central part of the mass. Occur on tips of chert pendants. Water actively dripping from grape coralloids in central part of the mass during some seasons. Associated with hollow stalagmites with axial channels left open by dripping or with floor frostwork surrounding a central zone of no deposition (Figure 3).

2. In the beginning of tray development, the speleothem may be composed wholly of frostwork, but as the form evolves, calcite coralloids (popcorn, grapes, coral) replace aragonite frostwork in the center of the mass while frostwork continues to build up at periphery of the mass (Figure 3). The coralloids are composed of fine-grained calcite which retains the morphology of the original aragonite frostwork. Cross-sections through the coralloids reveal that the branches feeding the coralloid tips are often hollow, cavities on originally occupied by aragonite needles (Martini, 1986).

3. Calcite deposition is maximal on the underside and toward the center of the mass and forms the rounded knobs of the coralloids. Water can be actively dripping from these coralloids, water which, according to Martini (1986), may be undersaturated with respect to calcium carbonate.

4. Popcorn, such as makes up centers of the trays, plots on the evaporation slope of a carbon-oxygen isotope graph (Hill, in press), indicating that the popcorn associated with the tray masses had an evaporative origin.

5. In two of the four caves (Carlsbad and the Grotte Andre Lachambre) the trays are associated with "popcorn lines", above which (on the ceilings and upper walls of the passage) there has been substantial condensation-corrosion, and below which (on the floor and lower walls) there has been a substantial build-up of frostwork, popcorn, and popcorn-frostwork trays.

6. In an area directly below the aragonite periphery of a tray, there can be a build-up of frostwork oon the floor (Figure 3) or even occasionally a hollow, aragonite "Christmas tree" stalagmite with the axial channel left open by dripping.

Because of the flat-bottomed nature of trays, it was first suspected that these speleothems form in a fluctuating water environment. This hypothesis has been shown to be untenable because: (1) the elevation of tray tiers differs from one tier to the next, (2) aragonite frostwork making up the tiers is never blunted or resolutioned as might be expected in an area of fluctuating water, and (3) cave rafts and shelfstone are never associated with trays.

Martini (1986) concluded that trays form under conditions of evaporation and undersaturation. According to Martini's model, slightly undersaturated solutions flow down a rock pendant and reach saturation by evaporation (Figure 3). Where evaporation of these thin films of water occurs, aragonite frostwork is precipitated (because evaporation increases the Mg/Ca ratio thus enhancing the deposition of aragonite). Water rises in the frostwork by capillarity and the growth of the frostwork is upwards and lateral, away from the tip of the rock pendant; thus, the remarkable flat bottom surface of the speleothem is created.

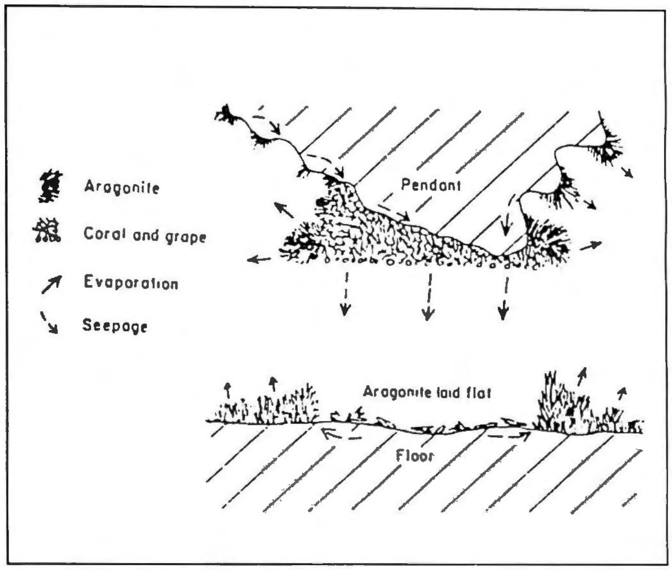

Figure 3: Idealized tray from Thabazimbi Mine Cave, South Africa (from Martini, 1976).

As frostwork trays continue to grow, undersaturated solutions move through the older aragonite in the center of the mass and redissolve this material (leaving hollow branches) until oversaturation with respect to calcite is achieved. Since aragonite is approximately 16% more soluble than calcite, there is a "window" where solutions can be undersaturated with respect to aragonite but oversaturated with respect to calcite. Furthermore, even though the deposition of aragonite is enhanced by a high Mg/Ca ratio, the MG^{++} ion itself is not incorporated into the crystal structure of aragonite; hence, when the aragonite redissolves, the Mg/Ca ratio decreases so that the deposition of calcite is favored. In this manner aragonite frostwork in the center of the tray is replaced by calcite popcorn and the original flat bottom of the mass is preserved.

Martini's model can be applied to the trays in Carlsbad Cavern. The slightly undersaturated water invoked by Martini is, in the case of Carlsbad Cavern and the Grotte Andre Lachambre, probably condensation-corrosion water. In Left-Hand Tunnel (Carlsbad Cavern), carbon dioxide, temperature and humidity are all higher on the ceiling (above the "popcorn line" where warm, moist, acidic air is moving out of the cave) than they are on the floor (below the "popcorn line" where cold, dry, less acidic air moving into the cave). Condensation water corrodes limestone and speleothems on the ceilings and upper walls and then seeps down the walls and to the tips of rock pendants. If the pendants hang below the passage "notch" (the maximum width of the passage which also corresponds to the level of the "popcorn line"), then the colder, drier air moving into the cave provides the evaporation necessary for tray growth.

References

Hill, C. A., (in press), Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico: *New Mexico Bureau of Mines and Mineral Resources, Memoir 44.*

Martini, J., 1986, The trays; an example of evaporation-controlled speleothems: *South African Speleological Association Bulletin,* Vol. 27, No. 1, pp 46-51.

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Geology of Lechuguilla Cave, Carlsbad Cavern National Park, New Mexico – Preliminary Observations

Carol A. Hill

Introduction

Lechuguilla Cave, located about 3 1/2 miles west and 1 mile north of Carlsbad Cavern, has been known for many years as a small cave which has a 90-foot vertical entrance drop and was formerly mined for guano (Jagnow, 1979). Recently, a team of Colorado cavers dug into a new section and extended the cave to a surveyed length of over 7400 ft and a depth exceeding 900 ft (Bridges and Glaser, 1986). On June 29, 1986 a geological survey of Lechuguilla Cave was made by a team of Cave Research Foundation geologists. This report discusses the *preliminary* findings of that survey, as noted the author.

Stratigraphy

The entrance to Lechuguilla Cave is at an elevation of 4640 feet. The cave is developed in the Yates Formation (Hayes and Koogle, 1958) and trends SW-NE, or approximately parallel to the reef escarpment. Abundant pyrite can be seen in the rock at the entrance of the cave indicating that the entrance may be developed in the upper, rather than lower, part of the Yates Formation.

The 90-foot entrance drop is probably developed entirely in the Yates Formation, as suggested by the orange-yellow siltstone exposed in the cave walls along the entire length of the drop and at the bottom of the drop. The cave may continue in the Yates to the top of the 150-foot drop, as suggested by the continuation of the siltstones all the way to the 150-foot pit and the abundant silt-sand on the floor of the Sand Dunes just before the 150-foot pit. A prominent bedding plane may possibly represent a basal unit of the Yates Formation. From the entrance down to the top of the 150-foot drop it is about 200-250 feet; that would make the thickness of the Yates Formation as exposed in Lechuguilla Cave comparable to that of the Yates reported elsewhere in the Guadalupe Mountains.

It is suggested that the cave, from the top of the 150-foot pit to the Rift, is developed in the Seven Rivers Formation. Hayes (1964) described the Seven Rivers Formation as a yellowish-gray dolomite along which beds of pale-orange quartzose siltstone can occur. The bedded limestone in this part of the cave is definitely silty and brecciated, more so than for other Seven Rivers exposures in other Guadalupe caves. Hayes (1964) described the Seven Rivers Formation as up to 600 feet thick where it thickens near the Capitan Limestone; possibly about 450-500 feet of the Seven Rivers is exposed in Lechuguilla Cave, making the depth of the cave from the entrance down to The Rift about 700 feet deep (approximately 200 feet of Yates and 530 feet of Seven Rivers).

The Rift cuts across Seven Rivers bedding planes, angles about 10° to the vertical, is 100+ feet deep, continues southward, and may possibly be developed at or near the intersection of backreef Seven Rivers beds with the massive Capitan Limestone.Hayes (1964) remarked that, in approaching the Capitan Limestone, the beds of the Seven Rivers thicken conspicuously and then the bedding planes disappear in the virtually unbedded Capitan; accompanying this change, the thin siltstone beds of the Seven Rivers become increasingly dolomitic and then either abruptly grade into limestone or pinch out. These stratigraphic changes were not specifically noted as The Rift was approached, but future detailed geologic mapping of the cave should indicate whether or not this is the case. (Note: there is also the possibility that The Rift may be developed along a fault – Bridges and Glaser (1986) reportedly found slickensides on rocks in The Rift).

Hydrology

It was not possible, on such a short reconnaissance trip, to define precise hydrologic routes in the cave, but the configuration of the 150-foot pit Colorado Room and other features (such as solution pockets on the walls of the Liberty Bell Room) suggest that Lechuguilla Cave developed phreatically as is typical of other Guadalupe caves. It is doubtful that the present cave entrance was a major spring outlet for water in the past because the passage leading to the entrance is too small. Perhaps future exploration will reveal a major spring outlet off of the 150-feet pit, or perhaps the main Lechuguilla paleospring has been destroyed by breakdown collapse. Bathyphreatic water may have ascended the 150-foot pit in the Colorado Room, but upon reaching the basal, confining siltstones of the Yates Formation, may have been diverted laterally along other, more diffuse avenues.

At the time of the reconnaissance trip, vadose meteoric water was profusely entering the cave due to a recent, abundant rain, and all the travertine was exceedingly wet (water was flowing *fast* down flowstone and dripstone surfaces). Water was pouring off all of the flowstone tiers in the Liberty Bell Room, down a steep flowstone cascade, and into the Lake Lechuguilla. The Lake had risen at least 2 feet from the time of previous exploration trips as documented by photographs taken by those earlier trips. Cascades of flowing water were followed to the bottom of the 150-foot drop; then the water abruptly disappeared in the floor just before the massive gypsum blocks were encountered. From that point on (all the way to The Rift) no water was seen or heard; perhaps the Seven Rivers Formation is capped by a relatively impervious section of the Yates Formation in this part of the cave.

Massive Gypsum and Native Sulfur

The scarcity of dripping water past the 150-foot drop has allowed for the preservation of gypsum blocks and rinds, especially in Glacier Bay where 25-30 foot high gypsum blocks overlie limestone and where sections of these blocks have slumped away from the main mass of gypsum, like icebergs along the leading edge of a glacier. Features seen in the massive gypsum include rims, lamination, possible replacement textures, drip tubes and commodes.

Giant "posthole" commodes, 8 feet or more across, occur in the gypsum blocks of Glacier Bay. These descend through the gypsum, and the extensions of these same holes continue downward 80 feet in the underlying limestone to the Land-Down-Under, a large room complex underlying Glacier Bay (Bridges and Glaser, 1986). Many of the gypsum blocks exhibit a marbly or brecciated texture, such as may be indicative of replacement gypsum. Other of the blocks exhibit a laminatedoverlaying-with Windy City. The sulfur is lemon-yellow, with crystals up to 1 mm long. The deposit occurs as a thin layer, 3 cm by 5 cm n diameter, overlying gypsum crust (J. Roth, pers. comm., 1986).

Carbonate speleothems in Lechuguilla Cave are stalactites, stalagmites, flowstone, popcorn and grape coralloids, coral pipes, helictites, cave pearls, shelfstone, cloud coatings, rimstone dams, rims and balloons. Sulfate speleothems noted were rims, coral pipes, crusts, flowers and possibly popcorn.

Carbonate dripstone and flowstone was seen from the bottom of the entrance drop all the way to the bottom of the 150-ft drop, but not beyond to The Rift. (Subsequent trips have found more travertine in the Land-Down-Under; Bridges and Glaser, 1986). The most spectacular flowstone occurs in the Liberty Bell Room where dark-red to orange to brown, vertical tiers of flowstone hang over solution pockets (5-6 ft in diameter) in the walls. These tiers look like bell canopies, but cannot actually be classified as such, as there is no lateral build-up of flowstone caused by a balance between evaporation and precipitation factors. Beautiful grape coralloids exist on the floor of the Liberty Bell Room, and below the ledge where the grapes are located, a colorful flowstone "frozen waterfall" cascades about 30 ft downslope.

"Sawtooth flowstone" (travertine with a high silt content) is an unusual flowstone subtype observed in Lechuguilla Cave. This flowstone was seen along wall ledges coming up the 150-ft drop in areas where a thin layer of silt overlays the limestone wall rock. Presumably in this location, the silt originated as material which flaked off the ceiling (possibly the basal unit of the Yates Formation) and settled onto wall ledges below. Gypsum blocks in Glacier Bay have a similar thin layer of silt covering them, silt which may also have drifted down from the ceiling and onto the tops of the blocks.

Popcorn occurs on the cave walls along the entire length of Lechuguilla Cave, from the upper levels all the way to The Rift. Most of the popcorn appears (from its fine-grained, moonmilk-like texture) to be composed at least partially of hydromagnesite, and many desiccated balloons hang from the popcorn nodules. Hydromagnesite is suspected to be the component of this popcorn and/or balloons because: (1) the bedrock (both the Yates and Seven Rivers) is dolomitic and thus high in magnesium and (2) because the high winds (in excess of 40 mph; J. Roth, pers. comm., 1986) in the cave create the evaporation factor necessary for the deposition of the mineral hydromagnesite. In many places where popcorn directly underlies gypsum rinds it has probably formed from solutions seeping out of the wall. In other places the popcorn has partially dissolved overlaying gypsum rinds and protrudes out and away from the rinds. In Windy City there is a rough indication of a "popcorn line" where corrosion has occurred above the line and popcorn deposition has occurred below the line; perhaps the popcorn here formed from condensation water as well as from seepage water.

Nests of cave pearls can be seen in the flowstone cascade at the bottom of the 150-ft drop. These are white and dark gray and are a few inches in diameter. The darker pearls in the nests are attached to the flowstone, whereas the whiter ones are unattached. (Later trips have found abundant cave pearls in the Land-Down-Under and in The Rift at White Pearl Hill and Black Pearl Pass; Bridges and Glaser, 1986).

True gypsum speleothems are hard to distinquish from solution features in the massive gypsum. Gypsum popcorn exists on the sides and tops of many of the gypsum blocks: whether these are some type of unusual solution feature or whether these are banded speleothemic popcorn caused by seeping water is not known and will not be known until one of the popcorn nodules is thin-sectioned. True gypsum flowers (extruded from the wall) were found near the junction of Windy City and The Rift, but most of the other "flowers" found up to that point probably formed as solutioned rims.

References

Bridges, R. A. and R. Glaser, 1986, Push at Lechuguilla or the Lech-A-Gorilla pushes back: *Rocky Mountain Caving*, Vol. 3, No. 4, pp 18-26.

Hayes, P. T., 1964, Geology of the Guadalupe Mountains, New Mexico: *U. S. Geological Survey, Professional Paper 446*, 69 p.

Hayes, P. T. and R. L. Koogle, 1958, Geology of the Carlsbad Caverns West Quadrangle, New Mexico-Texas: U.S. Geological Survey, Geologic Quadrangle 112, scale 1:62,500.

Jagnow, D. H., 1970, *Cavern development in the Guadalupe Mountains*: Cave Research Foundation, Columbus, OH, 55 p.

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Fiume Vento Cave, Italy – A "Baby" Carlsbad Cavern

Carol A. Hill

Introduction

Fiume Vento Cave is located about 50 km southwest of Ancona, Italy, in the Apennines. It has a surveyed length of 21 km and is developed along two perpendicular joint trends. The purpose of my visit was to compare Carlsbad Cavern with Fiume Vento, the cave which Paolo Forti had described to me as a "baby" Carlsbad Cavern – in the sense that Fiume Vento is presently forming in a H_2S-rich environment and contains many of the same deposits and geomorphic features that characterize Carlsbad Cavern and other caves in the Guadalupe Mountains.

Cave Geomorphology

Geomorphologically, Fiume Vento resembles Carlsbad Cavern in its cave passage and karren forms:

Cave Passage Forms – The natural entrance of Fiume Vento is a small hole in a vertical wall of a dissected canyon. This entrance extends back into a joint chimney which opens up into the top of Ancona Shaft, a bell-shaped room 180 m high, 130 m long, and 120 m wide, a configuration closely resembling the Cave of the Madonna in the Guadalupe Mountains where a solutionally-enlarged joint, connected to a canyon-dissected entrance, expands into the huge, bell-shaped New Year's Eve Room. Large breakdown rocks occur on the floor of Ancona Shaft,, and, as in Guadalupe caves, this material fills but a small portion of the original solutional void. Boneyard is developed at the base of Ancona Shaft (as it is at the base of the New Mexico Room, Carlsbad Cavern), and the integration of space and rock is a few meters in width and depth.

Fiume Vento contains tubular spring shafts (like the Bottomless Pit, Carlsbad Cavern) and joint chimneys (like Dean's Drop in the Cave of the Madonna). The one spring shaft visited in Fiume Vento was a 20 m deep tubular pit developed along a fracture; this cone-shaped pit has a base large in diameter than its top. Hydrogen sulfide could be smelled as one descended the pit and the water table can be reached via this shaft. According to P. Forti (pers. comm., 1986), the pH of sulfide water ranges between 7.4 - 7.8 during the year.

Cave Karren Forms – Scallops are shell-shaped solution concavities on cave walls and ceilings which are ridged or crested on their upstream sides and more gently sloped on their downstream sides. The walls of Guadalupe caves often exhibit scallop-like markings, but these are usually not well-developed enough to determine the direction and velocity of past flow, and the marks (if any direction can be noted) often seem to point upward. Fiume Vento Cave displays these same kind of vertically-oriented scallop-like markings on its walls; these seem to grade into pitted surfaces on cave floors and larger scallop and dome shapes on cave ceilings.

Air scallops are concave pockets in cave walls and ceilings which resemble water-formed scallops, but which are much larger and which exhibit smooth, rather than sharp, crests. In Guadalupe caves these often truncate travertine material as well as bedrock and are believed to be condensation-corrosion (gas weathering) features. In Fiume Vento this same type of geomorphic form exists, some of which, according to P. Forti, causes bell-canopy-like shapes to form on stalagmitic travertine.

"Punk rock" is bedrock so highly corroded that it is soft and flaky rather than hard and crystalline. Upon undergoing corrosive weathering under air-filled conditions, the residue part of the bedrock is exposed, causing the surface of the rock to become dark brown and friable. Where the residue has flaked off cave walls and ceilings, it forms debris piles of dark silt on the floor. In Fiume Vento the silt is sometimes displayed as vermiculations (Figure 4).

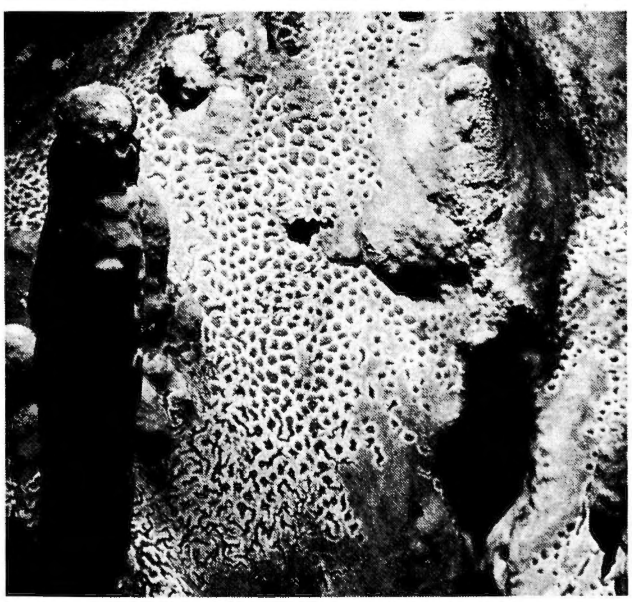

Figure 4: Leopard-skin mud vermiculations, near the pit in the Fiabilandia series of Fiume Vento. *Photo by Paolo Forti.*

Cave Deposits

Fiume Vento contains many of the same deposits as Guadalupe caves: gypsum blocks and rinds, montmorillonite-endellite clay and corroded speleothems.

Massive Gypsum – In Fiume Vento most of the gypsum deposits occur as crusts rather than as blocks. The only gypsum blocks seen were 2 - 3 m high; drip tubes were noted in these floor blocks, but there was not enough time to carefully inspect them for laminations, replacement textures or silt content. Gypsum crusts can be seen on the walls, floors, and ceilings in parts of the cave and appear to be actively forming by the replacement-solution process of Egemeier (1981). These crusts are up to 6 cm thick, macrocrystalline, and possess a high silt content, corresponding to that of the bedrock itself. Much of this replacement gypsum is removed by condensation-corrosion water during wet periods of the year (P. Forti, pers. comm., 1986).

The gypsum in Fiume Vento is similar to that in Carlsbad Cavern, only more (or most) of it appears to have formed as a replacement product of the limestone rather than as a solutional precipitate. The insoluble residue content of the Fiume Vento gypsum is visually high, whereas in the Carlsbad Cavern gypsum it is negligible (less than 0.1%; Hill, in press).

Endellite – Blue endellite occurs in Fiume Vento (near the massive gypsum blocks), and is apparently forming now (Bertolani and Rossi, 1985). The insoluble clay residue of the limestone is montmorillonite and this has altered to blue endellite and opal under acidic conditions. This same alteration process has been noted in Carlsbad Cavern: montmorillonite has changed to endellite and chert (rather than opal) (Hill, in press).

Speleothems – Very little popcorn build-up has occurred in Fiume Vento in connection with condensation-corrosion, but in the pit area, popcorn can be seen directly below a condensation-corrosion dome. Directional corrosion of stalagmites was seen near the 20 m pit, in a direction pointing *toward* the pit and hydrogen sulfide ascending the pit. This corrosion is apparently active because gypsum still lines the flanks of the stalagmite – if the process were not presently active, dripping water forming the stalagmite would have dissolved the gypsum away. Rim speleothem build-up around corroded stalagmites was not seen in Fiume Vento.

Another speleothem occurrence in Fiume Vento shed light on the "palm-stem" popcorn of the Carlsbad Cavern's Big Room (Lion's Tail and Jim White Tunnel). In Ancona Shaft "stalagmites en pile d'assiettes" have palm-stem projections along their bases, the angle of the projec-

Figure 5: "Palm-stem" development on a large stalagmite in the C-Room. *Photo by Paolo Forti.*

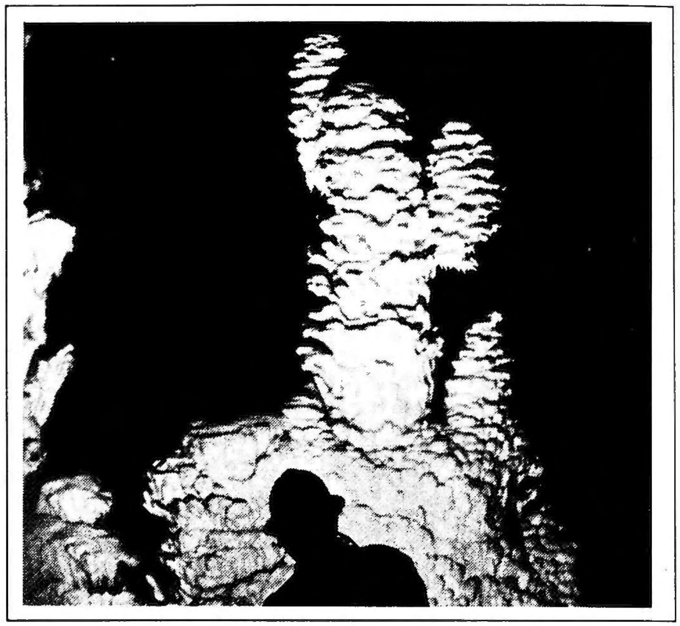

Figure 6: "Stalagmites en pile d'assiettes" (pile-of-plates stalagmites), Ancona Shaft. *Photo by Paolo Forti.*

tions varying with respect to the direction of ascending air flow (Figure 5). This suggests that the "palm-stem" popcorn in Carlsbad was also shaped by air flow. The top of "stalagmites en pile d'assiettes" exhibit a "pile of plates" morphology (Figure 6), which is attributable to the very high (over 50 m) ceilings, supersaturated solutions, and the fragmentation of dripping water during its falling (Hill and Forti, 1986).

Application to Speleogenesis Processes

Hill (in press) has proposed that Carlsbad Cavern and other caves in the Guadalupe Mountains dissolved via a sulfuric acid, rather than carbonic acid, reaction. Fiume Vento is a cave believed to be forming by this process *now* - not a half of a million years ago as is the case for Guadalupe caves).

A number of geomorphic features seem to characterize a sulfuric-acid speleogenesis: large rooms, boneyard beneath large rooms, spring shafts and fissure chimneys connecting levels. The pitted and scallop-like markings on cave floors and walls may be caused by replacement-solution where sulfuric acid directly attacks the limestone. Boneyard may be a form produced by sulfuric acid solutions dissolving limestone at or near the water table, or it may be a form caused or modified by condensation-corrosion processes (i.e. carbon dioxide liberated by the sulfuric acid-limestone reaction). Corrosion as seen on speleothems and walls may not only be a result of CO_2 corrosion, but as is the case of the directional corrosion on the stalagmite by the 20 m pit, may be due to H_2S-sulfuric acid corrosion. It is also possible that these same corrosional processes may play a part in the development of bell canopies, whereby the lateral shape is accentuated by corrosive air.

The source of hydrogen sulfide for the Fiume Vento cave system is not known. Oil is being commercially exploited in the Adriatic Sea, only 50 km east of the caves, and much natural gas exists in the region. Perhaps, as has been hypothesized by Hill (in press) for Guadalupe caves, H_2S was generated in a basinal setting and then this gas migrated into carbonate rock edging the basin to form sulfuric-acid caves.

References

Bertolani, M., G. Garuti, A. Rossi and M. D. Bertolani, 1976, Motivi di interesse mineralogico - petrografico nel complesso carsico Grotta Grande del Vento-Grotta del Fiume (Genga, Ancona): *Grotte d'Italia*, Ser. 4, Vol. 6, pp 109-144.

Egemeier, S. J., 1981, Cavern development by thermal waters: *Nat'l Speleo. Soc. Bull.*, 43(2):31-51.

Hill, C. A., (in press), Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains: *New Mexico Bureau of Mines and Mineral Resources, Memoir 44.*

——— and Paolo Forti, 1986, *Cave minerals of the world*: National Speleological Society, Huntsville, Alabama, 238 p.

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Preliminary Report on the Mineralogy of Cave of the Winds, Colorado

Cyndi Mosch Seanor and Carol A. Hill

Introduction

Cave of the Winds, located less than a mile north of Manitou Springs, Colorado, overlooks scenic Williams Canyon at an elevation of about 7300 ft (2225 m). The cave system is contained in a narrow ridge between Williams Canyon the east and Cavern Gulch to the west. It is one of the oldest commercial caves in the United States, having been shown continuously to the public since 1881.

Cave of the Winds is a three-dimensional maze cave, with over 9600 ft (2926 m) of mapped passage and 260 ft (79.25 m) of vertical relief (Fish, 1986). The longest passages are parallel corridors trending close to strike (N64°E). Most of the cave is developed along dip (about 10°SE), at the contact between the Ordovician Manitou Limestone and the Devonian Williams Canyon Formations, although some of the upper portions extend into the Mississippian Leadville Limestone. Cave development, as evidenced by many classic ceiling domes, is phreatic; large scallops (approximately 1 m in length), such as can be seen in Canopy Hall, are also probably phreatic features. The cave varies in temperature and relative humidity, from 53° F and 88% in the Whale's Belly to 56° F and 93% in Silent Splendor.

Speleothems

Carbonate, sulfate, and hydroxide speleothems exist in the cave. Carbonate speleothem forms that occur in Cave of the Winds are stalactites, stalagmites, coatings and crusts, flowstone, draperies, rimstone dams, shields, conulites, anthodites, helictites, cave pearls, spar ("rice" crystals) and moonmilk (classification after Hill and Forti, 1986).

Anthodites and Beaded Helictites – The quill and frostwork anthodites and the beaded helictites in Silent Splendor are among the most exquisite in the world. These speleothems are up to 30 cm long and 2 cm in diameter and are still actively growing. Most of these speleothems are composed of aragonite, either as individual needles (of frostwork) or sheaths of needles (in the beaded helictites), but some of the quill anthodites may be calcite. Many of the beaded helictites bifurcate at about 60° - this angle may be the 63°48' interface angle of aragonite. In all, about a dozen separate anthodite-helictite displays decorate the west wall of Silent Splendor; one of the most exotic, resembles a sea anemone with beaded "tentacles" (see cover photo). The west wall obliquely intersects dip and so the erratic speleothems grow exclusively on this side of the passage owing to solutions moving down dip.

"Button" Stalagmites and "Bird Bath" Conulites – In Silent Splendor, near the last anthodite-helictite display, are some button-shaped stalagmites 0.5 - 5 cm in diameter next to some tiny bird-bath conulites with curled-up edges (Figure 7). Hill and Forti (1986) described "button" stalagmites as a form of "embryo" stalagmite occurring under conditions of mud floors and low ceilings. Water drops, falling onto the unctuous clay, "ball up" and thus form the perfectly round, button shapes. A "bird bath" forms when dripping water makes a slight impression in clay or other soft material; the impression subsequently becomes lined with calcite so as to create the bowl-shaped speleothem. The relation of "buttons" and "bird baths" next to each other may reflect the force at which the falling water droplets hit the mud; those falling from a slightly greater distance hit the mud with greater force, forming the "bird baths", those that fell with less force form the "buttons".

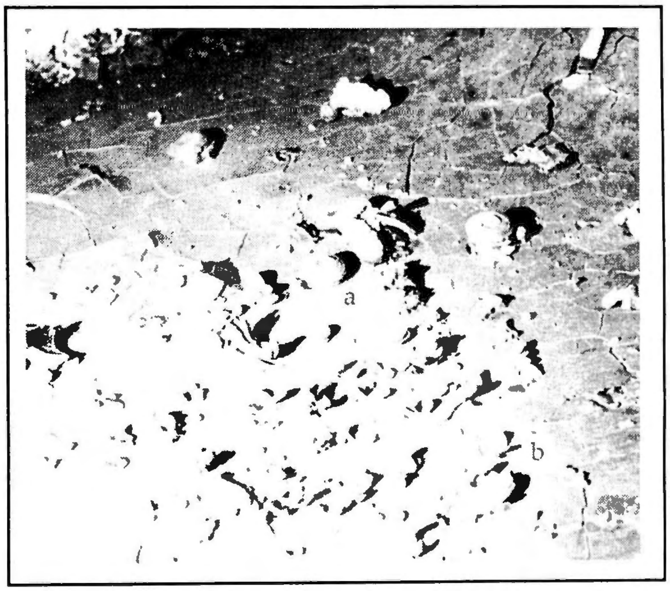

Figure 7: "Button" stalagmites (a) and "bird bath" conulites (b), Silent Splendor, Cave of the Winds. *Photo by Cyndi Mosch Seanor.*

Moonmilk – Moonmilk can be seen in many parts of the cave, including Manitou Grand, the Whale's Belly and Silent Splendor. The moonmilk in Silent Splendor has been analysed as hydromagnesite (P. Modreski, pers. comm. 1986).

The most unusual occurrence of moonmilk is found at the northern end of Silent Splendor where tiny beads overlie very smooth, transparent coatings and are aligned along parallel ridges (Figure 8). Davis (1985b) described these beads as "welts" which "stand out in relief as if applied by a cake-icing decorator". We call them "moonmilk tracks". Moonmilk tracks consist of one to three (but most often two) parallel ridges, usually straight but sometimes slightly curved. The distance between parallel ridges is from a few millimeters to less than a centimeter, a fact

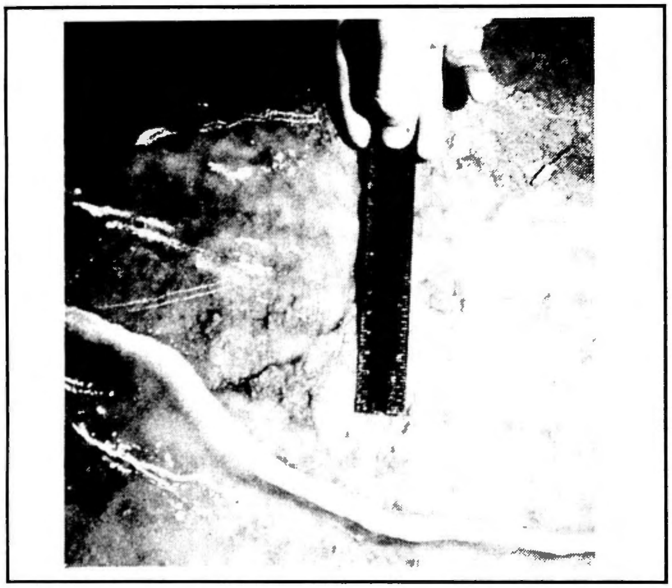

Figure 8: Beaded moonmilk tracks over a translucent, carbonate coating, Silent Splendor, Cave of the Winds. *Photo by Cyndi Mosch Seanor.*

which could indicate that the tracks were deposited by water droplets moving down the wall. (Curl, 1972, calculated that a droplet of water has a minimum diameter of 2.6 mm; he also showed a "large" droplet of water 0.7 cm in diameter). Inexplicable by this water-drop hypothesis is that the tracks, while usually vertical, may also trend in any direction, including the horizontal. Similar moonmilk tracks, up to 1.5 cm apart, have been observed by one of us in California Caverns, California.

D. Davis (pers. comm., 1985) hypothesized that the moonmilk tracks represent material that oozed forth along scratches made by bats. However, the lack of evidence of habitation by bats (no bones or guano below the tracks) in this chamber, and the lack of good bat-roosting sites on the smooth coatings make this interpretation questionable. Single-line moonmilk tracks have been observed by one of us in the Grotte André Lachambre, France – a cave which was recently (about six years ago) blasted open and which shows no evidence of bat inhabitation. The exact mechanism by which these tracks form remains elusive.

Sulfate Speleothems – Mirabilite occurs as cotton in Canopy Hall, very near the cave entrance, and gypsum occurs as needles, small flowers and cotton in Silent Splendor. The gypsum cotton in Silent Splendor has grown substantially over the past three years since the passage was first entered - this growth may reflect the drying out of the passage due to air flow in and out of the enlarged entrance.

Limonite Boxwork – Mud-covered limonite boxwork occurs in Silent Splendor and in other areas of the cave. The fins are 1 to 5 mm thick and extend up to 30 cm from the wall.

Other Features

Mud Folia – Mud folia has been described by Davis (1985a) in Snider Extension as "delicate, sinuously horizontal, interleaved sloping ribs up to a foot or more long, one-half inch (1.27 cm) wide and one-eighth inch (.32 cm) thick". Calcite folia are known from a number of caves, but only in Cave of the Winds is this form known to be composed of mud.

Mud Vermiculations – Vermiculations are thin, irregular, discontinuous deposits composed of incoherent material (usually mud) which are found on the walls, ceilings, and floor of caves (Hill and Forti, 1986). Small patches of tiger-skin vermiculations have been identified on the walls of Silent Splendor Passage.

Unusual Impressions in Mud – Davis (1985a) described curious markings in mud in Snider Extension, and suggested that the markings represent "ancient frost crystal impressions". Observations of these crystal impressions and their relationship to other features in Snider Extension are listed in Table 2; these same relationships are shown pictorially in Figure 9. Another feature, the "scratch" marks have been attributed by Davis (1985a) to the "claws of swimming animals". While these features are referred to as "scratch" marks, their exact origin is still uncertain. The following interpretation of the peculiar markings in Snider Extension is offered:

1. When the water table was at or above the level of Snider Extension, the mud slowly settled out of suspension and onto the top of bedrock projections. These projecting mud ledges became further modified into cone-shaped "canopies" as the water channeled down into the mud during its descent.

2. During the last glacial period (Wisconsin; 20,000 YBP), freezing of the mud banks in Snider Extension produced the hair-line "scratch" marks. Shrinkage cracks in the mud formed after the "scratch" marks as the mud dried out.

3. "Curtains" of condensation ice crystals (such as are pictured in Hill and Forti, 1986, Plate 11) grew downward in the Snider Extension fissure until they reached the mud walls in the lower part of the passage. These crystals pressed into the mud, forming the crystal impressions and mud curls around the impressions. This model is supported by an important observation made by H. DuChene (pers. comm., 1986): the crystal impressions do not start until the crawlway opens up into the fissure part of the passage.

4. As the climate warmed at the beginning of the present interglacial period, the ice crystals melted and the fossil impressions were left intact.

Acknowledgements

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Table 2: Sequence of Events with Respect to the Crystal Impressions in Snider Extension, Cave of the Winds

Feature	Characteristic of Feature	Environment during Formation
1. Mud	Brick-red clay with greenish-yellow inclusions.	Subaqueous.
2. Mud "canopy" ledges Mud folia	Cone-shaped, "canopy"-like ledges.	Subaqueous-subaerial Formed when water drained down the mud banks.
3. Scratch marks	Straight to slightly curved, semi-parallel grooves. 1 - 5 grooves (2 and 3 most common). Usually vertical, but at any angle, including the horizontal. Tiny surface "scratches" and deeper grooved "scratches" penetrating to a depth of 6 mm. Extend up to top of mud banks and "canopy" ledges, but not above passage "notch" (maximum passage width) and into mud folia.	Probably subaerial; marks would probably not survive refloodings.
4. Mud shrinkage cracks	"Scratch" marks displaced along mud cracks; i.e. mud cracks came after scratches. Mud cracks sealed by crystal impressions; i.e. mud cracks came before crystal impressions.	Subaerial. Formed as passage dries out.
5. Crystal impressions	Tabular or bladed, several hundred in number. Hexagonal (120° and 90° angles) with one long axis, symmetrical hexagonal, curved, striated (parallel to longest axis). Maximum impression 12 cm long, 1 cm wide, 2 mm thick. Mud sometimes curled back along sides of impressions; mud curls most usually in the downward direction. Smaller crystal impressions (1 - 2 mm, triangular to rectangular "hillocks") on surface of larger impressions.	Subaerial. Crystals press into the mud to form impressions and curls of mud surrounding impressions.
6. Calcite-aragonite	Calcite-aragonite crystalline material lines mud and vugs in mud. Mud has spalled out of the mud banks along shrinkage cracks to expose the calcite-aragonite.	Late-stage subaerial. Form as drusies in open spaces within mud.

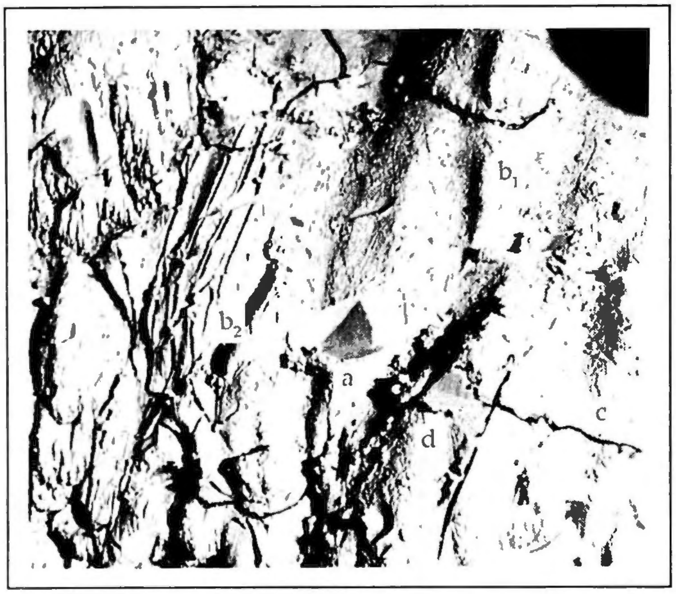

Figure 9: Crystal impressions (a), "scratch" marks (b_1, b_2), and shrinkage cracks (c) in mud, Snider Extension. Note the hair-line "scratch" marks (b_1) covering the surface of the mud and the mud "canopies" (cone-like mud shapes in the left side of the picture), and the deeper "scratch" marks at b_2. Also note how the "scratches" have been offset by the shrinkage cracks but are overlain by the crystal impressions, and how at (d) a crystal impression has sealed the mud crack. *Photo by Cyndi Mosch Seanor.*

References

Curl, R. L., 1972, Minimum diameter stalactites: Nat'l Speleo. Soc. Bull., **34(4)**:129-136.

Davis, D. G., 1985a, Mysteries in mud: ancient frost crystal impressions and other curiosities in Cave of the Winds: *Rocky Mountain Caving,* Vol. 1, No. 3, pp 26-29.

Davis, D. G., 1985b, Observations: lowest part of Cave of the Winds: *Rocky Mountain Caving,* Vol. 2, No. 2, pp 10-11.

Fish, L., 1986, The program Groaning wrote: *Rocky Mountain Caving,* Vol. 3, No. 4, p. 29.

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

Udden, J. A., 1918, Fossil ice crystals: *Univ. of Texas Bulletin, No. 1821, 28 pp.*

Lithologic Controls on Karst Groundwater Flow, Lost River Groundwater Basin, Warren County, Kentucky

Christopher G. Groves and Nicholas C. Crawford

Introduction

The Lost River Groundwater Drainage Basin in Warren County (Figure 10), is a karst drainage system encompassing 143 square kilometers developed within the Mississippian St. Louis and Ste. Genevieve limestones. Near the contact between these two formations lie two bedded chert units, the Lost River Chert bed within the Ste. Genevieve and the Corydon Chert Member of the St. Louis, which appear to be perching layers to shallow karst groundwater flow. The Lost River Chert is a fossiliferous, bedded replacement chert occurring with white sparite in a zone which varies from 3 to 7.5 meters thick throughout the study area. The chert zone within the Corydon

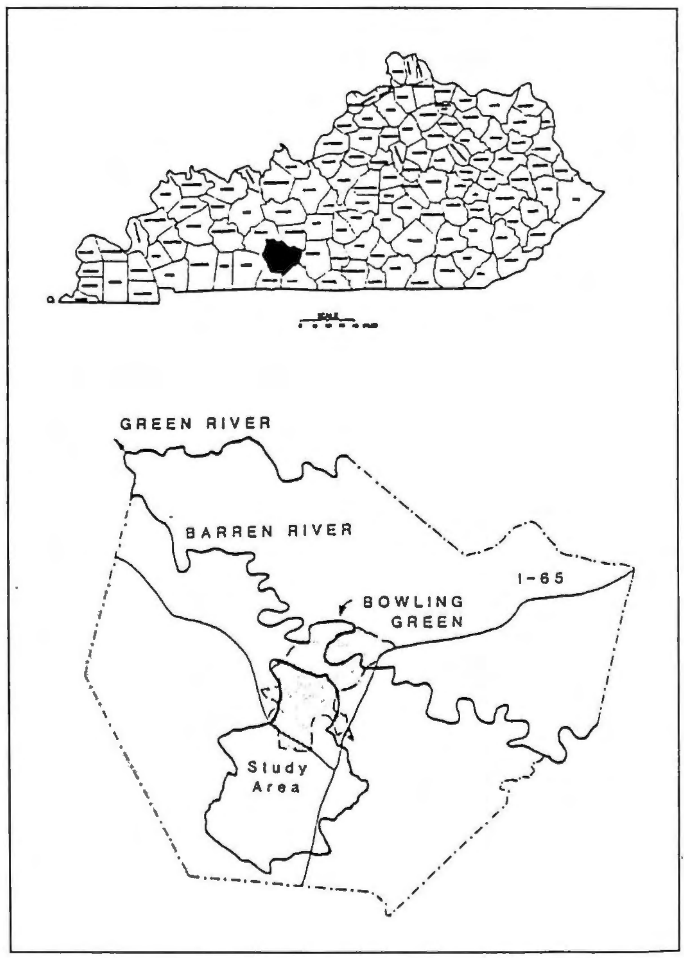

Figure 10: Location of study area.

Member of the St. Louis is a dolomitic zone containing profuse spherical, irregular, and lenticular chert nodules. A complete section of this zone has not been found within the study area, but it reaches a thickness of at least 7.5 meters. Groundwater may be seen flowing at or near the tops of these chert layers in various cave streams and at springs and swallets. Outcrops of the cherts are difficult to find at other locations throughout the basin. Crawford (1981) observed this and hypothesized that the two chert-confining units should be a preferred zone for cavern development. Other investigators, however, who have studied the effect of lithologic heterogeneity on groundwater flow and cavern development within the same part of the stratigraphic column in Kentucky (Palmer, 1981; Quinlan and Ewers, 1981; Wells, 1976) have assigned a very minor role to the importance of these layers. It was the purpose of this research to study the relationship between the chert layers and groundwater flow within the Lost River Groundwater Basin.

Hypotheses and Research Design

This project tested the following hypotheses:

Hypothesis #1: The Lost River Chert Bed and the Corydon Member are perching layers throughout the basin and are the dominant influence in the control of the vertical position of shallow karst groundwater flow within the Lost River Groundwater Basin.

Hypothesis #2: Influence on shallow karst groundwater flow by the two cherts is limited or nonexistent. The gradient of groundwater flow and its vertical position within the stratigraphic section are influenced primarily by other factors.

Hypothesis #3: Groundwater flow is affected by a combination of responses to the perching effects of the two layers and other influences.

In order to test these hypotheses, two structure maps of the basin were prepared, one having the top of the Lost River Chert Bed as datum (Figure 11), and the other the top of the Corydon Member. Field data were collected by transit leveling of surface outcrops, surveying of cave outcrops, and geophysical well logging, and a few points were added from existing geologic maps. A contour map of the water table (at or near which shallow karst groundwater flow is assumed to take place) for the shallow karst aquifer beneath the study area was also constructed, primarily from existing water level data (Figure 12), and compared to the chert structure maps. The maps were contoured from the raw data and compared using a combination of SURFACE II and DISSPLA computer graphics packages. Upon comparison, the amount of area

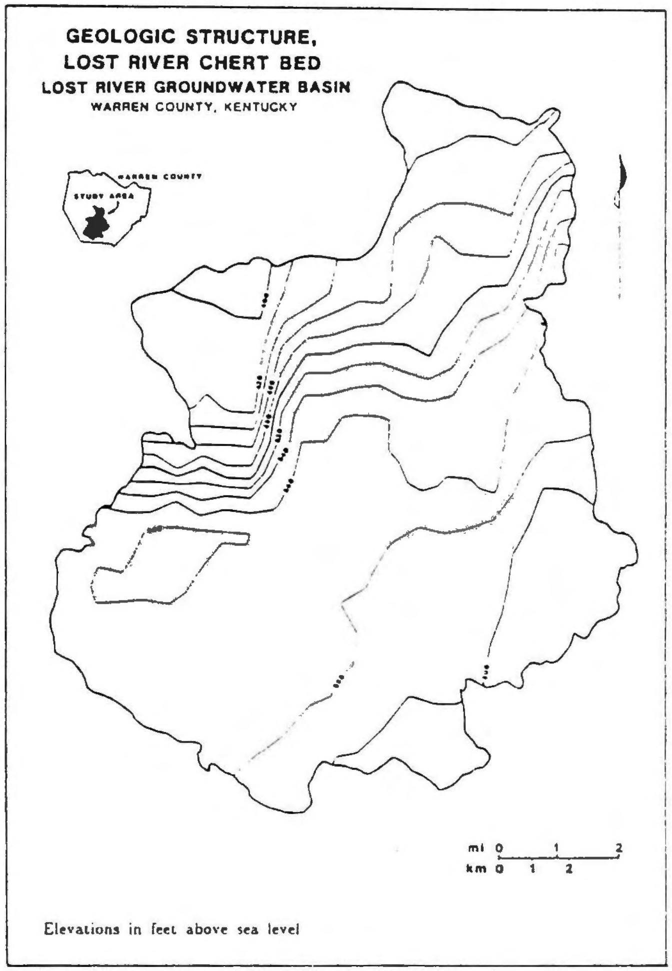

Figure 11: Geologic structure of the Lost River Chert Bed, Lost River Groundwater Basin. Top of Corydon Chert Member occurs 40 feet below top of Lost River Chert Bed.

that corresponds between each of the chert layers and the water table was expressed as a percentage of the total area within the basin, then the percentages for the two chert layers were summed. The percentage of area within the basin over which groundwater flow is correlated to the chert beds was then used to accept or reject the appropriate hypotheses. Accepting correlation for locations where the water table is within 6.1 meters above or below the top of one of the chert layers, the following range values were used as criteria:

> *70% correspondence*: acceptance of hypothesis #1. Resistant chert beds are the dominant influence on the vertical position of shallow karst groundwater flow.

> *30% correspondence*: acceptance of hypothesis #2. Chert beds have little or no influence on the vertical position of shallow karst groundwater flow.

> *30% but < 70% correspondence*: acceptance of hypothesis #3. Mixed influences are responsible for the vertical position of shallow karst groundwater flow.

Results

The water table was compared with the chert beds by comparing elevation differences at 88 evenly spaced "nodes" throughout the study area (Figure 13). It was found that 42.6% of the nodes show a correlation between the water table and the Lost River Chert Bed, and the Corydon Member correlates with the water table over 40.7% of the Basin. Summing these quantities shows that the water table correlates with bedded chert layers over 83.3% of the basin, and therefore hypothesis #1 is accepted: the Lost River Chert Bed and the Corydon Member of the St. Louis Limestone have a dominant influence on the vertical position of shallow karst groundwater flow within the Lost River Groundwater Basin.

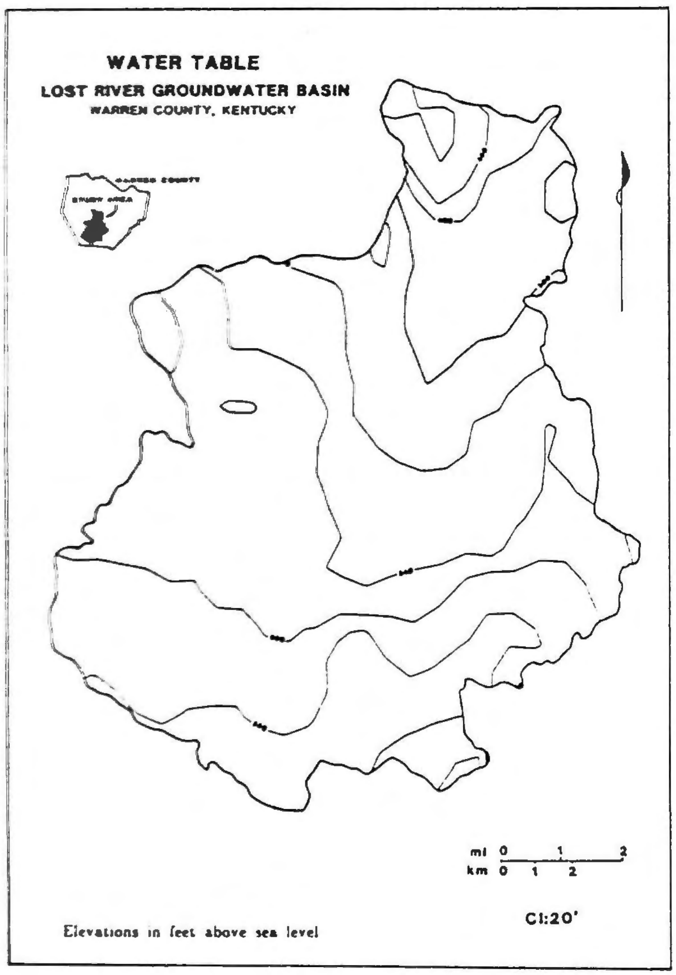

Figure 12: Water table, Lost River Groundwater Basin.

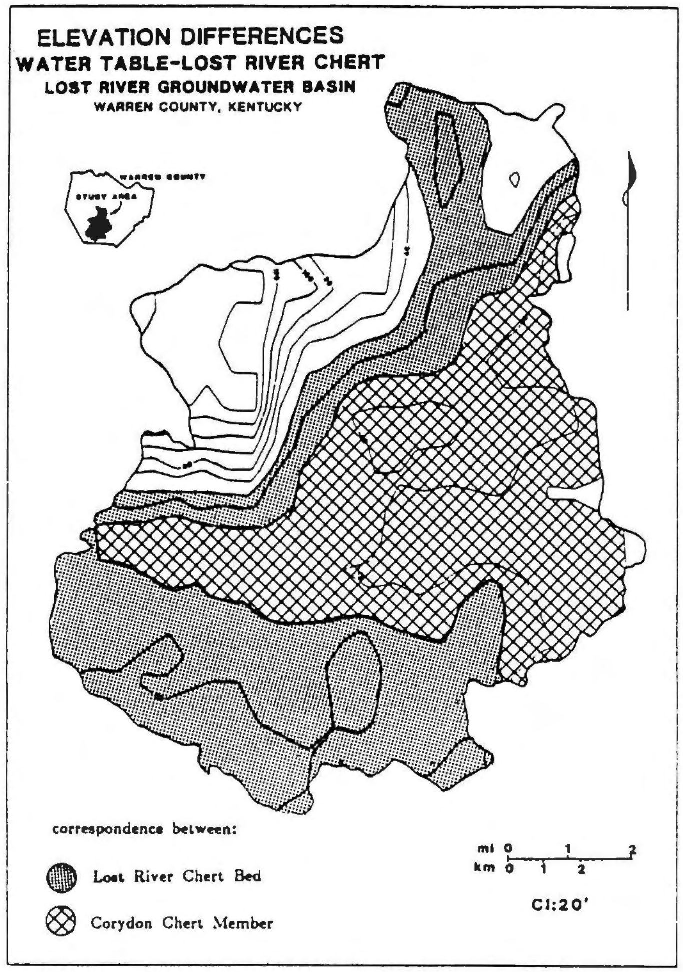

Figure 13: Elevation differences between water table and Lost River Chert Bed. Shaded areas show correlation between water table and chert beds.

References

Crawford, N. C., 1981, Karst hydrogeology and environmental problems in the Bowling Green Area; *Report of Investigations #3*: Center for Cave and Karst Studies, Department of Geography and Geology, Western Kentucky University, 21 p.

Palmer, A. N., 1981, *A geological guide to Mammoth Cave National Park*: Teaneck, New Jersey, Zephyrus Press, Inc., 196 p.

Quinlan, J. F. and R. O. Ewers, 1981, Hydrogeology of the Mammoth Cave region, Kentucky: in Roberts, T. G. (ed.), *G.S.A. Cincinnati 1981 Field Trip Guidebook*, Vol. 3, pp. 457-506.

Wells, S., 1976, Sinkhole Plain evolution in the Central Kentucky karst: *Nat'l Speleo. Soc. Bull*, 38:103-106.

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Gypsum Replacement of Limestone by Alternating Open and Closed Systems in the Vadose Zone, Mammoth Cave, Kentucky

A. N. Palmer

Vadose seepage into many of the passages in Mammoth Cave enters through tiny non-solutional fissures only a fraction of a millimeter wide, but the water immediately becomes very aggressive and has etched the walls to depths of more than a centimeter. Clearly the water is absorbing CO^2 from the cave air to achieve this renewed aggressiveness. This is common in many caves.

The PCO_2 of the cave air at Mammoth is very low, however: an average of 0.0005 atm in the dry upper levels where such seepage is common – not much higher than that of the surface atmosphere (0.00035 atm), and much lower than the measured soil PCO_2 (0.003 - 0.01 atm). Considering that the seepage must have passed through some soil as it infiltrated, it must start its journey at a fairly high PCO_2. The traditional view of dripping vadose water is that it partially degasses when it enters the low-PCO_2 cave atmosphere, depositing carbonate speleothems. How then can the minor seepage absorb CO_2 from the cave atmosphere?

Water that dissolves limestone under CLOSED conditions be greatly depressed in its concentration of CO_2. For example, if water at $PCO_2 = 0.003$ atm reaches saturation entirely under closed conditions, its equilibrium PCO_2 plummets to 0.000045 atm!

It is unreasonable to assume that such vadose seepage operates under totally closed condition, but the vigorous uptake of CO_2 as it enters the cave shows that much of its history is under at least semi-closed conditions. For instance, a lengthy plug of water in a narrow capillary tube will have very little contact with a gas phase and will approach closed conditions.

Using a few conservative values that do not overstate the case, this is how the water would evolve as it passes from the soil into the limestone and finally into the cave:

In soil:

$PCO_2 = .003$ atm;
pH = 5.1 (if from CO_2 only); no carbonate content.

In the vadose zone in the limestone, water under closed conditions approaches:

$PCO_2 = 0.000045$ atm; pH = 8.85;
saturation value with respect to calcite = 32.2 mg/1;
$Ca^{++} = 3.14 \times 10^{-4}$ mol/1; $HCO_3^- = 5.96 \times 10^{-4}$
$CO_3^= = 1.61 \times 10^{-5}$ (assuming only calcitic limestone).

Upon reaching the cave, the water shifts toward:

$PCO_2 = 0.0005$ atm; pH = 8.17;
saturation with respect to calcite = 71.8 mg/1;
$Ca^{++} = 7.04 \times 10^{-4}$ mol/1; $HCO_3^- = 1.4 \times 10^{-3}$;
$CO_3^= = 8.29 \times 10^{-6}$.

This may not appear significant: but note that the $CO_3^=$ decreases almost two-fold when the water enters the cave. One of the major questions in cave mineralogy is how gypsum replaces limestone to form a curst on cave walls. Most of the gypsum we see on cave walls is an evaporite deposit, petrographic evidence shows that much of it has actually replaced limestone bedrock. Why does this replacement take place right at the cave wall, rather than at the site where the gypsum is first taken into solution?

Two reactions can be stated that achieve the desired result:

[1] $CaCO_3 + 2H_2O + SO_4^= \Longleftrightarrow CaSO_4 \cdot 2H_2O + HCO_3^-$

[2] $CaCO_3 + 2H_2O + SO_4^= \Longleftrightarrow CaSO_4 \cdot 2H_2O + CO_3^=$

Let's examine #2, the simpler of the two. Only the active participants in the reaction are shown. Other components are assumed to be invariate. The origin of the sulfate is oxidation of pyrite in the surrounding bedrock, possibly augmented by solution of primary gypsum incorporated within the limestone during primary deposition. (Microscopic examination shows that both are valid sources.) According to thermodynamics, the equilibrium coefficient (K) = approx. 5400. In other words, the reaction will go to the right (gypsum replacing limestone) only when $[SO_4^=] / [CO_3^=] > 5400$. At lesser ratios the ratios the reaction tends to go the other way.

Normal vadose drip water goes in the wrong direction: its sulfate/carbonate ratio *decreases* as it enter the cave. But notice from the preceding analysis that the vadose seeps decrease in $CO_3^=$ as they enter the cave, and thus show promise of favoring gypsum replacement. Using the same PCO_2 values as above, Table 3 shows how the sulfate/carbonate ratio changes as the water goes from (ideally) closed vadose conditions to open conditions at the cave wall.

More precise calculations of the equilibria can be made but the general trend is clear.

Under the conditions stated in this example, a dissolved gypsum content of only 0.0035 moles/liter (about 0.2 cubic cm per liter) is needed to bring the sulfate/carbon-

Table 3: Sulfate/carbonate ratio changes from closed to open conditions.

Closed Vadose Conditions in Limestone Bedrock (initial $PCO_2 = 0.003$, final = 0.000045 at calcite sat.)				**Open Conditions in Cave** ($PCO_2 = 0.0005$)		
gypsum mol/1	pH	SI_{gypsum}	SO_4/CO_3	pH	$SI_{calcite}$ approx.	$SO_4^{=}/CO_3^{=}$ approx.
.001	8.61	-1.65	140	7.61	-1.0	1300
.002	8.52	-1.22	380	7.53	"	3300
.003	8.47	-1.28	400	7.45	"	4500
.004	8.43	-1.17	420	7.40	"	6500
.005	8.39	-0.68	1318	7.35	"	8000
.006	8.36	-0.57	1675	7.44	"	10,000
.007	8.34	-0.49	2034	7.49	"	11,000
.008	8.33	-0.42	2387	7.44	"	13,000
.009	8.31	-0.36	2725	7.29	"	27,000

ate ratio above the critical value of 5400 needed for gypsum to replace limestone at the cave wall. Note also that the water does not need to be saturated with gypsum: with a saturation index (SI) of about -1.2, the water is less than 10% saturated with gypsum.

Is this a valid process? The replacement of limestone by gypsum occurs in the very places where this process would be most likely to operate – where minute amounts of water seep into the cave by capillary flow through tiny pores and fissures. A more thorough investigation is underway.

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Siliceous Crusts on Cave Walls

Margaret V. Palmer

Siliceous crusts are fairly common features replacing the limestone in cave walls, but this is apparently the first time they have been recognized and identified. Previously they were thought simply to be oxidized weathering rinds. The crusts in Mammoth Cave are white, composed of very finely crystalline quartz (as shown by X-ray diffraction), and form on limestone bedrock only. The crust thickness is 0.3 - 1.5 cm. It forms primarily around shafts that intersect lateral passages. The crust is a moist paste near water sources and grades laterally to friable powder in dry areas. The source of the silica appears be sandstone of the Big Clifty Formation and other clastic rocks,fragments of which occur in the shafts and overlying sinkholes. Siliceous sediment in the cave, derived from the same rocks, can serve as a local source for silica in passages that penetrate deep beneath cap-rock.

Most of the water samples show supersaturation with respect quartz, but none are supersaturated with opal. Precipitation of quartz is very slow at normal surface temperatures, and it is more likely that the microcrystalline quartz in the cave walls was first deposited as opal and then recrystallized to quartz. Evaporation would be necessary to allow opal to precipitate, and this process is apparently common because of gypsum deposits similar areas, despite the high relative humidity of 90 - 97% in the passages observed.

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ECOLOGY PROGRAM

NATURAL HISTORY OF ARTHROPODS OF CARLSBAD CAVERNS EMPHASIZING *RHAPHIDOPHORIDAE* OF THE GENUS *CEUTHOPHILUS*

Diana E. Northup and Rebecca Kuper

Introduction

Censusing of arthropods using pitfall traps was carried out in three areas of Carlsbad Cavern (CACA hereafter) during 1985 and 1986. CACA has provided an interesting study site because two (possibly three) species of camel crickets of the genus *Ceuthophilus* co-occur in areas with differing amounts and types of food resources, and with different patterns of species dominance. Additionally, the camel crickets inhabit areas deep within the cave, and may travel to the surface for food only rarely. One of the three CACA species, *C. longipes*, is highly cave adapted, and may be a true troglobite.

The three study areas being used for this research in CACA are Bat Cave, Sand Passage and Left Hand Tunnel. Bat Cave, a bat guano community dominated by *C. carlsbadensis*, is located approximately 50 - 100 feet (15 - 30 m) below the surface. It represents the food rich area of CACA. Species richness is high with various micro-arthropods (mites, diptera, coleopteran larvae, pseudo-scorpions, fleas and collembolans) and numerous larger arthropods (*C. carlsbadensis* and *C. longipes*, psocopterans, tenebrionid and other adult coleopterans including *Rhadine sp* carabids, and tineid guano moths (Bailey, 1927; Barr and Reddell, 1967; Welbourn, 1975a, 1975b, 1976). Bat Cave receives some daylight from a shaft to the surface at the back of Bat Cave, and some artificial light during the day from lights in the "Main Corridor". *Ceuthophilus longipes* co-occurs with *C. Carlsbadensis* here, but in low numbers. Sand Passage is located approximately 90 - 105 meters below the surface and some horizontal distance from the entrance. It is likely that fauna of this section makes the journey to the surface to feed only rarely. The area is moist, but lacks much standing water. There are numerous sandy (hence the name) areas suitable for oviposition. This represents a food-poor area and as yet the exact nature of food sources is unknown. The area is dominated by *C. longipes; C. carlsbadensis* is rare in this area for most of the year. Species richness appears low. Besides the two camel cricket species, *Rhadine* beetles and diplurans occur in fairly large numbers. Left Hand Tunnel represents an area of moderate food resources. This area is located 229 meters below the surface and is directly off the CACA "Lunch Room". The two camel cricket species co-occur here in somewhat equal proportions, with *C. carlsbadensis* occurring in slightly higher numbers. The area itself is dry (no standing water for one to two hundred meters) and food poor, but its proximity to the Lunch Room and various trash containers provides a reliable food source. Species richness and composition is similar to Sand Passage; however, *Rhadine* beetles and diplurans are not as abundant as in Sand Passage.

Methods

In order to gather data for analysis of species evenness, pitfall trapping is ongoing in all three study sites. The 16-oz (454 g) pitfall traps are Solo plastic cups with Solo cozy cup inserts. Twenty pitfall traps are buried to their rims in the substrate in approximately the same place each time in all three areas. At each visit, *Rhadine* beetles and adult crickets are marked (a color scheme indicating location and time of year has been worked out), cricket head capsule width and ovipositor length for adults and subadults are measured, body length is measured for juveniles, and all species are counted and released.

The data collected from these censusing trips are currently being analyzed using the Hill's N2 (Hill, 1973) index to provide a measure of species evenness as well as descriptive statistics on cricket species distribution (spatial and temporal). Between cricket species, differences in head capsule widths are being examined to determine species-specific and possibly site-specific age class differences. Descriptive statistical analysis will also be performed on the distribution of other species. Results are expected to provide information concerning mortality patterns, sex ratios, reproductive cycles and species evenness.

Observations in Sand Passage reveal predation by C. carlsbadensis on C. longipes. Members of the latter species were observed fighting over food. Dissection of crickets from this area showed what looked like sand grains and an occasional cricket part in the crop. Studies are being undertaken to further elucidate the diet of crickets inhabiting this area of CACA. *Rhadine* carabids were also observed eating juveniles in the traps, although the rhadines themselves were never seen being eaten by the camel crickets. Descriptive analysis of the census data collected to date appears to show a continuous pattern of reproduction as evidenced by the presence of juveniles during all census periods. There is one particularly finely-grained sandy area in which copious quantities of juveniles are found ("hordeville") and which may therefore be an oviposition site.

Observations in Left Hand Tunnel demonstrate a similar pattern of camel cricket predation as seen in Sand Passage. *C. carlsbadensis* always eats *C. longipes*. Observations of mating and activity rhythms were made in Left Hand Tunnel to further elucidate cricket natural history. To gather information on mating habits, a fish tank was set up in Left Hand Tunnel and pairs of crickets place in it were observed, using red lights, at different times of the year. Mating was observed only during late November. Behavior observed during these studies included some choice behavior on the part of female crickets, no significant male-male interactions, and copulations which lasted approximately five minutes. In addition to the mating studies, an activity rhythm study was conducted which showed more nocturnal than diurnal activity.

Preliminary analysis of census data from Bat Cave shows a strong dominance of this area by C. carlsbadensis. In contrast to the situation in Sand Passage and Left Hand Tunnel, young camel crickets in Bat Cave are found in low numbers. There is a rather indistinct pattern of seasonal reproduction. Dissected camel crickets from this area show large amounts of guano and some evidence of cricket parts and possibly beetle parts in the crops, and some parasitism by horse hair (Nematomorpha) worms. Also in contrast to the other areas, evidence of predation in the traps was never seen in Bat Cave.

References

Bailey, V., 1928, Animal life of the Carlsbad Cavern: *Monographs of the American Society of Mammalogists, No. 3,* Williams and Wilkins Company, Baltimore, Maryland.

Barr, T. C. and J. R. Reddell, 1967, The arthropod cave fauna of the Carlsbad Cavern region, New Mexico: *The Southwestern Naturalist,* **12**:253-274.

Hill, M. O., 1973, Diversity and evenness: a unifying notation and its consequences: *Ecology,* **54**:365-389.

Welbourn, W. C., 1975a, Arthropod fauna of the guano in the Bat Cave portion of Carlsbad Cavern: *Cave Research Foundation 1975 Annual Report,* pp 57.

———, 1975b, Survey of the cave fauna of the Guadalupe Region, Eddy County, New Mexico: *Cave Research Foundation 1975 Annual Report,* pp 56.

———, 1976, Arthropod fauna of the guano in the Bat Cave section of Carlsbad Cavern: *Cave Research Foundation 1976 Annual Report,* pp 35.

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ARCHAEOLOGY AND ANTHROPOLOGY PROGRAMS

In Memorium - Tribute to a Special Friend

On September 27, Christine Hensley-Martin, Karli White and Patty Jo Watson placed a floral wreath on the grave of our very good friend, John L. Thomas, who died suddenly of a stroke on July 13, and is now buried in the Logansport Cemetery. A special memorial has been prepared for him there, to which our Shell Mound Project is contributing (see *CRF 1977 Annual Report* and subsequent years for summary accounts of the Shell Mound Project and its relationship to Mammoth Cave System archaeology). The stone reads:

John L. Thomas
1919 – 1986
Postmaster – Grocer – Friend of Community
He never met a person or a bargain he did not like.
Erected by the Friends of John L.

We are proud to be among the large group of John L. Thomas' friends, and are deeply saddened that he is no longer at the center of life in the Big Bend, as he was for many decades. He was such an integral part of our archaeological research in Butler County that it is difficult to imagine continuing without him. But our other friends there - especially Waldemar and Ethie Annis, Kathleen Thomas, Tim Thomas and his family, and Gordon and Francis McKee – are also immensely kind and supportive so, of course, we <u>will</u> continue, with John L.'s memory in our minds and heart.

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CRF ARCHAEOLOGICAL PROJECT – 1986

Patty Jo Watson

This was a year of considerable activity with respect to papers, symposia and reports, all of which are briefly described below. Except for the Cave Archaeology course (June 8 - 15), only one fieldtrip to the Big Bend was undertaken.

While in the Big Bend/Logansport area on Sept. 27 - 28, three shell mounds were visited: Bt 5, Bt 10 and Bt 11. There is a recurring problem with vandalism at all of these sites, but it is especially acute at Bt 11, previously relatively undisturbed. This mound (approximately one mile south of Bt 5, the Carlston Annis mound, where we have focussed most of our research) is now owned by Mr. Maitland Rice, who does not want people trespassing on the mound nor digging in it for relics. Unfortunately, it is impossible to mount a 24-hour guard at the site, so the vandals can sneak onto the site from the river and dig at night, leaving at dawn. If they persist, however, they will be caught and prosecuted as Mr. Rice is now both annoyed and vigilant.

Cave Archaeology 1986

From June 8 to 15, CRF archaeologists with the strong support of CRF President Ron Wilson led 10 students through the fieldtrips, lectures and exercises that make up the Western Kentucky University Cave Archaeology course (offered through the Center for Cave and Karst Studies, Department of Geography and Geology, WKU, in collaboration with Mammoth Cave National Park).

George Crothers was the teaching assistant, with Mary Kennedy coming in for the last three days, and Ron Wilson providing paleontological as well as general natural historic information in addition to being chief guide for the trip through Jaguar Cave, Tennessee.

Meetings and Conferences

CRF Archaeological Project personnel participated in a wide variety of scholarly meetings throughout 1986. On March 8 - 9, Valerie Haskings, Christine Hensley-Martin and Pat Watson presented papers in a Kentucky Heritage Council conference at the University of Louisville on the Late Paleoindian and Archaic periods in Kentucky prehistory. We were delighted that Waldemar and Ethie Annis, owners of the Carlston Annis shell mound, were able to come for part of the session. Valerie Haskins' paper will be published in the conference proceedings volume, the paper read by Christine Hensley-Martin is to appear in the *NSS Bulletin*. Valerie's research at Prewitts Knob has been greatly aided by grants from CRF and from the Kentucky Heritage Council (see her account in this same Annual Report).

On April 27, George Crothers, Valerie Haskins, and Pat Watson took part in a symposium entitled "Cave Archaeology in Eastern North America" at the Society for American Archaeology's 51st Annual Meeting in New Orleans. Crothers and Haskins presented papers, and Watson was a session discussant (see separate article in this report).

On May 8, Pat Watson gave a presentation at the Third USA-USSR Archaeological Symposium (Smithsonian Institution, Washington, D.C.) entitles "Archaeobotany and Geoarchaeology at a Late Archaic Shell Heap in Western Kentucky". During June and July she went on a lecture tour to Jordan and Israel, where she discussed archaeology in general and Mammoth Cave area archaeology in particular, both informally and in lectures under the general sponsorship of the U. S. Information Agency.

In August, Pat, Red and Anna Watson, together with several other CRF members, officers and JVs, attended the 9th International Speleological Congress in Barcelona, Spain. Pat Watson delivered a paper on "Cave Archaeology in the Eastern Woodlands of the United States".

On October 18, Pat presented another paper, "The Beginning of Field Agriculture in the Eastern Woodlands", during the Keynote Symposium at the Midwestern Archaeological Conference in Columbus, Ohio.

All of these papers make important reference to the archaeological remains in the Mammoth Cave System as well as to the results of work by the Shell Mound Archaeological Project.

On November 7 - 8, respectively, George Crothers and Charles Hall presented papers at the Southeastern Archaeological Conference meetings in Nashville, Tennessee. Crothers described one of the more unusual artifacts from Big Bone Cave, Tennessee (a large and carefully mended gourd bowl), and Hall summarized the results of his research at Bugtussle Rockshelter (work partially subsidized by a CRF Research Grant).

In December, Christine Hensley-Martin completed and successfully defended her M. A. thesis on a topic that stemmed from our Shell Mound Project research: *A Reanalysis of the Lithic Industry from the Read Site, Butler County, Kentucky (15 Bt10).*

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Short Abstracts of Papers Presented at the 51st Annual Meeting of the Society for American Archaeology

Patty Jo Watson

The Society for American Archaeology held its 51st Annual Meeting in New Orleans, Louisiana on April 27, 1986. During this meeting, seven papers were presented by archaeologists whose research have been, in part, aided by the resources of the Cave Research Foundation. A short description of the session (as taken from symposium papers) is as follows:

> *Earlier research in the dark interiors of caves in the mid-south of the United States had demonstrated prehistoric mining for gypsum and cathartic minerals. Research during the last decade has added significantly to our knowledge of prehistoric cave use in eastern North America. The papers of this symposium demonstrate that caves were used during various periods for the extraction of an expanded suite of minerals, for particular forms of mortuary activities, and for ritual sanctuaries. Research on surface sites and ethnographic analogies offer insights for the prehistoric use of caves and cave minerals.*

Short Abstracts of Paper Presented

1.) Cook, Della Collins (Indiana). *Prehistoric Mortuary Use of a Pit Cave in Southeastern Indiana.* Human remains recovered from a pit cave in Harrison Co., Indiana, comprise a demographically complete sample, because both sexes and all ages are present in expected frequencies. There is no evidence for intentional disarticulation or other processing of remains. Egalitarian access to this mortuary site is indicated. Rapid dental wear and rarity of dental caries date these remains prior to the advent of food production. Findings are compared with those from similar pit cave mortuary sites elsewhere in the Ohio Valley.

2.) Crothers, George M. (Tennessee). *The Prehistoric Exploration and Utilization of Big Bone Cave, Tennessee.* Big Bone Cave in central Tennessee contains a variety of perishable archaeological remains in its remote passages. Preliminary research has accomplished three goals: 1) identifying the extent of exploration, 2) documenting the variety of remains and 3) dating the period of aboriginal activity. Results of this research are presented in comparison to other known archaeological cave sites in eastern North America and a gypsum mining hypothesis is discussed as a potential explanation for the extensive utilization of this cave.

3.) Faulkner, Charles H. (Tennessee). *Petroglyph Caves in the Southeastern United States.* Four petroglyph caves in Tennessee and West Virginia and a cave with mud glyphs in Virginia are described. Petroglyphs in one Tennessee cave may date as early as an associated terminal Archaic chert quarry, while two caves contain Southern Cult motifs. Torch charcoal associated with the Virginia mud glyphs dates in the 11th century A. D. While ritual marking of cave walls may occur in earlier periods, this activity appears to be largely a late prehistoric phenomenon in eastern North America.

4.) Haskins, Valerie A. (Washington, St. Louis). *The Archaeology of Prewitts Knob, Kentucky.* Prewitts Knob, near Mammoth Cave National Park, contains a commercial cave and 15 small pits. Three have yielded human skeletal remains. One radiocarbon date indicates the bones are more than 2500 years old. Therefore, some activity on Prewitts Knob was contemporaneous with exploration and mining in the Mammoth Cave System. Remains from all pits are similar; some bodies may have been disarticulated prior to deposition. Results of the osteological and archaeological research to date, and preliminary interpretations on the prehistory of Prewitts Knob are presented.

5.) Munson, Cheryl Ann (Indiana), Patrick J. Munson (Indiana) and Kenneth B. Tankersley (Indiana). *Middle Woodland Quarrying and Use of Aragonite from Wyandotte Cave, Indiana.* Wyandotte Cave in southern Indiana was utilized during the Terminal Archaic through Middle Woodland periods for the extraction of a variety of minerals. Aragonite, a relatively rare form of speleothem material that occurs in this cave, was extensively quarried during the Middle Woodland Period. The quarrying activities are described, the microscopic and chemical "fingerprints" of Wyandotte aragonite are presented, and artifacts of this material are identified from surface Middle Woodland sites in the Midwest.

6.) Tankersley, Kenneth B. (Indiana), Patrick J. Munson (Indiana) and Cheryl Ann Munson (Indiana). *Prehistoric Selenite Mining in the Mammoth Cave System, Kentucky.* Selenite crystals occur in dry clay fill deposits in numerous locations in Mammoth Cave and Salts Cave. Evidence for prehistoric mining is numerous and extensive at these locations. "Lost John," an Early or Middle Woodland miner who was crushed to death by a falling boulder in Mammoth Cave, was digging for these crystals. This paper documents the evidence for, and extent of, selenite mining and entertains possible prehistoric uses of these crystals.

7.) Turner, Kenneth R. (Alabama). *Mortuary Caves in Alabama.* Of the several mortuary caves within the Cumberland Plateau in Alabama, the majority are described in published reports as expressions of the Copena mortuary complex, although some are recognizable only as early or late Middle Woodland. In Alabama, unlike other regions, no mortuary caves derive from the Late Archaic. For several dental health characteristics, the skeletal remains from these caves are intermediate to Archaic and Mississippian series from the same region. Morphologically, the mortuary cave skeletal series are more similar to Mississippian series, implying a relationship unlike that inferred farther north.

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Mortuary Uses of Caves at Prewitts Knob, Kentucky †

Valerie A. Haskins

Prewitts Knob is situated in karst terrain in Barren County, Kentucky, southwest of Cave City and approximately twelve miles from Mammoth Cave National Park.

Sinks and small caves, or pits, are scattered across the surface of the Knob. Crystal Onyx, a commercial enterprise, is by far the largest, but fifteen other pits are known to date. Three of these - Crystal Onyx, the Pit of the Skulls (Hemberger, 1985), and Roger's Discovery - have yielded human skeletal material and provide the setting for important archaeological research regarding the physical remains of a Late Archaic/Early Woodland population.

All but on of the pits have been surveyed by the Cave Research Foundation (CRF) using compass and tape. Maps of Crystal Onyx and the Pit of the Skulls, prepared by CRF, are completed; the remaining maps are in preparation.

The specific objectives of this study are to: 1) provide quantitative study and comparison of intra-site and inter-site variability in the skeletal remains from the three caves in the following categories: age, sex, diet, pathologies, and mortuary processing techniques; 2) determine whether the chronologically positioning of each of the cave sites is sequential (episodic) or contemporaneous, regarding each other as well as the surface sites; 3) relate the osteological and chronological variation to other known sites in the Mammoth Cave Area.

Crystal Onyx Cave

Cleon Turner discovered the cave (15Bn20) in 1960; he lowered himself approximately 95 feet on a rope down the main shaft, and saw the human bones scattered at the base of the shaft.

When Turner commercialized the cave, he built stairways, placed gravel in the paths, installed electrical lights, and moved the bones to a display pit area. To my knowledge, the bones had not been disturbed since he placed them there 20 years ago. I removed them osteological analysis; my preliminary results indicated that at least 18 individuals are represented from the bone pit display area. However, a number of human fetal and infant bones have now been analyzed, suggesting that the actual minimum number of individuals is much higher, perhaps as many as 30. Apparently, men, women, children, and infants were all deposited in these pits. One radiocarbon date from the cave indicates that the bones are more than 2500 years old (680 B. C. ± 95.) Therefore, at least some of the activity on Prewitts Knob was apparently contemporaneous with the well-documented aboriginal exploration and mining in the nearby Mammoth Cave System (Watson *et al.*, 1974.)

The Pit of the Skulls

In June, 1981, the Pit of the Skulls (15Bn51) was discovered explored by two local cavers, Michael Hennion (CRF) and Roger Kline, who observed a number of human and non-human animal bones at the bottom of the shaft. Hennion and Kline collected several of the remains, as well as a nondiagnostic chert biface. After mapping and retrieving skeletal material from the pit, Jan Hemberger (University of Louisville, KY), analyzed the bones and reported her findings (1982, 1985.) He observations on five of the individuals recovered from the pit include evidence of artificial cranial deformation, extranormal mastication, and dismemberment. I am completing analysis of the remainder of the skeletal material, and thus far, I estimate that at least fifteen individuals are represented. Again, men, women, children and possibly fetuses are included in the assemblage.

Roger's Discovery

The initial goal of the CRF archaeological expedition to Roger's Discovery (15Bn55) on July 7, 1983 was to survey the pit and to determine whether any bone, human or non-human, was present. Roger Brucker noticed a human molar lying on a ledge inside the pit. Hence, the ledge was named Brucker Ledge, and the pit Roger's Discovery. Further investigation yielded a large quantity of human and animal skeletal remains. The faunal identifications were made by Ronald Wilson; the human identifications were made by both Wilson and myself. Several bags of dirt (a total of 63) were removed from the ledge and taken back to Washington University for flotation. Although the material is not yet completely analyzed, it appears that the individuals deposited in this re similar in skeletal and dental structure to the others in Crystal Onyx and Pit of the Skulls.

Summary

Research at Prewitts Knob over the past year has greatly expanded our knowledge regarding the prehistory of the Knob in particular, and regarding methods of processing and disposing of the dead in the Late Archaic - Early Woodland cultural periods in the central Kentucky karst region in general.

Although the bone deposits have been disturbed, they offer an opportunity to study a larger population of *individuals* than previously available from the Early Woodland period in the Mammoth Cave area. Isolated burials, such as that mentioned by Carstens (1980), and the naturally desiccated "mummies", such as Lost John and Little Al (Meloy, 1980; Watson et al., 1969; and Watson (ed.), 1974), present some information regarding individuals, but few population studies have been available. Louise Robbins (in Watson (ed.), 1974) discusses the human skeletal material excavated from the Salts Cave Vestibule, but much of that material has been calcined and presents little available data to the condition of the bones. The Crystal Onyx, Pit of the Skulls, and Roger's Discovery human skeletal collections provide an opportunity to study a larger number of individuals from three separate, but nearby, cave localities.

A number of interesting pathologies have been noted thus far. The most striking is a femur which shows evidence of osteomyolitis, a suppurative periosteal reaction. A few fractures are evident, as well as numerous dental caries and abscesses.

Cultural practices can be inferred from evidence on the bones. A few skulls exhibit signs of artificial cranial deformation. The most unusual evidence of cultural practices, however, can be observed on a distal right humerus of a young adult female. Similar to the markings on a female innominate from the Pit of the Skulls, the humerus appears to have been disarticulated and/or defleshed prior to disposal in the pit.

The original Pit of the Skulls study by Hemberger (1985) produced some important results. Only scanty documentation is available for the prehistoric technique of using pit shafts for burials. The cut marks on the left female innominate indicate that at least one individual was disarticulated prior to deposition in the pit. Also, the crania that exhibit signs of artificial occipital deformation and extranormal mastication were both males.

Similarly, some of the bones recently removed from Crystal Onyx, such as the female humerus, appear to have been processed by disarticulation and or defleshing. Thus far, none of the bones from Roger's Discovery suggest disarticulation, although the analysis fro. this cave is incomplete.

We have observed a number of subadult, juvenile, infant, and possibly natal bones and teeth in the samples identified to date. It appears that there are no restrictions on the ages of the individuals being thrown into the pit. Also, the possible prenatal and/or natal bones may indicate that aborted fetuses or pregnant women were being disposed of in this manner.

Chipped stone recovered from surface investigations suggests that the Knob was being used as a lithic reduction and/or hunting area, possibly in the same temporal span as when the aborigines were depositing their dead in the pits. The discovery of the chert outcrop on the Knob flank suggests that the chert composing the lithic scatter on the surface was locally obtained.

Conclusion

It is believed that the results of the final analysis of the skeletal remains and lithic debris from Prewitts Knob will make a significant contribution to our understanding of the use of this distinctive karst feature by prehistoric peoples, and also towards our knowledge regarding the processing and disposal of the dead during the first millennium B. C.

Acknowledgements

Many thanks are owed to the vast number of CRF personnel who have been involved in a multitude of tasks for this project, from field work through analysis.

Funds for the Prewitts Knob Archaeological Project have been provided by a CRF Karst Research Fellowship, the Kentucky Heritage Council, and a Grant-In-Aid-Of-Research from Sigma Xi, the Scientific Research Corporation. Further radiocarbon dates obtained from these funds will be presented as soon as they are available.

References

Carstens, K., 1980. Archeological Investigations in the Central Kentucky Karst. Unpublished Ph.D. dissertation, Department of Anthropology, Washington University, St. Louis, MO.

Hemberger, J. M., 1982. A Preliminary Report on the Pit of the Skulls (15Bn51). MS on file, Department of Anthropology, Washington University, St. Louis, MQ.

_________, 1985. Preliminary Findings at the Pit of the Skulls (15Bn51). *Woodland Period Research in Kentucky* (Polack et al., eds.), The Kentucky Heritage Council.

Meloy, H., 1981. *Mummies of Mammoth Cave.* Micron Publishing, Shelbyville, IN.

_________, H. and P. J. Watson, 1969. Human Remains: "Little Alice" of Salts Cave and other mummies. *The Prehistory of Salts Cave,* Kentucky, by P. J. Watson et al., Illinois State Museum Reports of Investigations, No. 16.

Robbins, L. M., 1974. Prehistoric People of the Mammoth Cave Area. *Archeology of the Mammoth Cave Area* (P. J. Watson, ed.), Academic Press, New York.

Watson, P. J. et al., 1969. *The Prehistory of Salts Cave, Kentucky.* Illinois State Museum Reports of Investigations, No. 16.

_________, P. J. (ed.), 1974. *Archeology of the Mammoth Cave Area.* Academic Press, New York.

† Portions of this report have been submitted for publication in the following volume, under the title:

Haskins, V. A., (in press). Prehistory of Prewitts Knob, Kentucky: Preliminary Analyses and Interpretations. In *PaleoIndian and Archaic Period Research in Kentucky,* (David Pollack et al., eds.), the Kentucky Heritage Coucil.

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Cave Archaeology in Eastern North America †

Patty Jo Watson

Cave archaeology is not an aberrant pursuit followed by fringe types unable to secure or come to grips with a decent above-ground site. As is the case with underwater archaeology, cave archaeology is still archaeology. The remains are underground rather than on or in the earth's surface, but the basic techniques applied to them are the same.

The prehistoric people who went into caves were not weird or peculiar, either. They were perfectly normal aborigines in close touch with their physical environment and the natural resources it provided. They noticed cave entrances and utilized them frequently and freely to gain access to the world underground. Using simple but effective illumination techniques, they went wherever they pleased and stayed as long as they liked. The prehistoric inhabitants of the North American midcontinental karst region were the best cavers in the world for a period of several millennia (until ca. A. D. 1950).

Principles or Tenets of Cave Archaeology

There is a series of significant dichotomies that deserve attention for those unfamiliar with karst landscapes or features. First, sites may be either rockshelters or caves. That is, they may be under overhangs or in little bedrock pockets, or they may be in real caves: deep, dark passages and passage-complexes a few hundred meters to several hundred kilometers long. The Mammoth Cave System is the world's longest cave at 1500 km and is still growing. Real caves in the Eastern Woodlands are found in the mid-continental karst region of the U. S. that stretches from southern Indiana to Tennessee/Georgia and Virginia. This region contains several of the longest and largest caves in the world, as well as thousands of lesser caves. The first people to live in this area began exploring caves at least as early as 2500 B. C. according to ^{14}C dates from Jaguar Cave in association with the prints of moccassined and bare human feet along a mud-floored passage an hour's journey from the entrance.

Other important contrasts with respect to cave archaeology are the following:

- dry vs. wet caves
- vertical vs. horizontal caves
- sediment vs. rocky substrates.

Each of these has important implications for the archaeological record contained in or on it, and each also has important implications for methods and techniques appropriate to documenting that record.

Finally, we should take special note of the preservation potential in dry rockshelters and caves, which is not only significant in absolute terms, but also is spectacular relative to preservation conditions normal to the Eastern Woodlands. Dry caves and rockshelters preserve everything, from the most delicate of vegetable-fiber textiles to entire human bodies. This can be wonderful, of course. How many opportunities does one have in Eastern North American archaeology to examine 3000-year old vegetable-fiber moccasins that look as though you could slip them on and walk off in them? There are drawbacks to this incredible preservation, however, because it means that you cannot seriate objects or materials by appearance. Hemlock needles in Cloudsplitter Shelter that look as though they blew into the breakdown last winter radiocarbon date to 9000 B.C. Lying on top of them are cucurbit seeds that date to 600 - 700 B.C. Fragments of cane torch material and wood in Salts Cave that look as though they were dropped a few months ago are 3000 years old, and scattered on the cave floor among them are pages from a newspaper with a 1942 date clearly visible at the tops of the pages.

Hence, beside the usual problems of post-depositional stirring and mixing by humans or non-human animals, the cave archaeologist faces other significant problems in unravelling site formation processes.
Another distinctive aspect of cave and rockshelter research is the "timelessness" of real caves with respect to weathering. Interior passage shapes and conditions – on a human – are unvarying. We know that the upper-level passages of the cave interior were the same, physically, for them then 4000 years ago as it is for us now. This is not true for cave entrances and rockshelters, which are usually subject to erosion and mass wasting as well as host to the activities of various plant and animal species: large, small and microscopic.

The papers in this session are all about real caves, not rockshelters. One can group these caves into functional categories:

1) Those used for the disposal of human bodies (mortuary pits and burial caves).

2) Those used as quarries and/or workshops. The substances mined include chert and cave minerals [gypsum, epsomite, mirabilite, and fancy crystalline

forms of gypsum (satinspar and selenite)]. Some or all of these resources were traded regionally and perhaps more widely.

3) Those used for ceremonial or ritual purposes. Chief among these is Mud Glyph Cave in Tennessee, but some of the burial caves in Alabama and Georgia should also be included.

One of the most interesting results emerging from this recent research in karst features is that the functional patterns appear to be differentially distributed in time. That is, there seems to be a business-like and perhaps even commercial use of caves as sources of various raw materials (although some of these materials may have been wanted for ceremonial use: gypsum for white paint, crystals for a variety of ritual purposes), and as convenient disposal places for the dead. Later, with the chronological hinge being roughly the Middle Woodland period, the world underground becomes a very different place and one not to be lightly entered. Some caves are places of ritual interment, others are places of contact with the supernatural. There is some chronological overlap, however, and more evidence may reveal these patterns to be geographical or cultural variants rather than parts of a simple linear chronological trend.

But I think the extremes of the patterns are fairly firmly established: for Archaic and initial-Early Woodland people over much of Kentucky and Tennessee, caves were places to explore and use. Later, caves are apparently regarded in at least some places as points of contact with a possibly fearsome or awesome underworld. Thus the late prehistoric evidence from these caves provides a tantalizing prelude for the elaborate cosmology and mythology of the historic southeastern peoples – the Cherokee, Choctaw, and related groups – about a world below the earth's surface inhabited by terrifying and extremely dangerous creatures such as the Uktena. Glimpses of some of these creatures are preserved in Indian Cave and Mud Glyph Cave (both in Tennessee).

Finally, I want to acknowledge how pleased I am that several other archaeologists (for years I felt rather isolated) are now regularly going underground, braving that subterranean world where the sun never shines and the rain never falls in search of previously unsuspected realism of Eastern Woodlands prehistory.

[1] Watson, Patty Jo Watson, 1986, Cave archaeology in Eastern North America: Discussant's remarks presented to Society for American Archaeology 51st Annual Meeting, New Orleans, LA, April 27.

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CRF FELLOWSHIP AND GRANT SUPPORT

Each year, the Foundation may award up to $5,000 as a Fellowship or as one or more grants for research in karst-related fields. The truly exceptional proposal may receive a Karst Research Fellowship (limit $3,500); meritorious proposals may receive on or more karst research grants, in amounts less than $2,000, awarded to qualified students in graduate programs in the natural or social sciences. Applications are screened by a committee of scientists. The judges seek promising or innovative topics, supported by evidence that the student has command of the literature and methodology. A detailed announcement is mailed in early Autumn, and the deadline for the receipt of the proposal, supporting documents and letters of reference is January 31. Awards are announced by April 15. Send inquiries to:

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

In 1986, seven proposals were received and the following Grants were awarded:

1. A CRF Karst Research Grant ($1800) awarded to Miss Valerie A. Haskins, Department of Anthropology, Washington University, St. Louis, MO 63130, for her proposal entitled "The Prehistory of Prewitts Knob, Kentucky".

2. A CRF Karst Research Grant ($1500) awarded to Mr. Christopher G. Groves, Department of Geography and Geology, Western Kentucky University, Bowling Green, Kentucky 42101, for his proposal entitled "Structural and lithologic controls on karst groundwater flow and cavern development, Lost River ground water basin, Warren County, Kentucky".

3. A CRF Karst Research Grant ($1500) awarded to Mr. James W. Webster, Department of Geography and Geology, Western Kentucky University, Bowling Green, Kentucky 42101, for his proposal entitled "The movement of contaminants through a diffuse flow portion of a karstified carbonate aquifer".

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

INTERPRETATION AND EDUCATION PROGRAM

Figure 14: Display and Sales Floor at the 9th International Congress of Speleology held in Barcelona, Spain during August, 1986. *Photo by Pete Lindsley.*

EDUCATION PROGRAM

ACCUMULATION AND DISPERSAL OF AIRBORNE PARTICULATES AT CARLSBAD CAVERN

Bernard Szukalski and Cyndi Mosch Seanor

Certain areas of Carlsbad Cavern have accumulated significant amounts of dust, lint and other particulate debris. The large numbers of visitors which tour Carlsbad throughout the year are thought to contribute significantly to the accumulation and dispersal of various particulates. Little is known in regards to the range of dispersal, accumulation rates, mechanisms, types, sources and effects on the cave environment. In order to evaluate some of these parameters, a preliminary experiment was designed and 40 collection stations were established at 20 locations throughout Carlsbad Cavern in March 1986.

The first phase of collection will be complete within one year of the initial collector placements and results evaluated. It is hoped that this will provide insight into the types of particulates, rates of accumulation, and range of dispersal in the various areas of the cave studied. Based on these initial findings, methods will be refined and others developed to evaluate additional parameters.

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Publications and Presentations

Published Articles and Papers

Archaeology, Anthropology, and Paleontology

Haskins, Valerie A., (in press). Prehistory of Prewitts Knob, Kentucky: preliminary analyses and interpretations. In *PaleoIndian and Archaic Period Research in Kentucky*, David Pollack et al, eds., The Kentucky Heritage Council.

Watson, Patty Jo, 1986, Prehistoric Cavers of the Eastern Woodlands: Chapter VIII in Charles Faulkner, ed., *The Prehistoric Native American Art of Mud Glyph Cave*, University of Tennessee Press, pp. 109-116.

——, 1986, Cave Archaeology in the Eastern Woodlands: *Masterkey*, 59:19-25.

——, 1986, Cave Archaeology in the Eastern Woodlands of North America: *Communicacions: 9th Congresso Internacional de Espeleologia*, Barcelona, Spain, Vol. 2, pp. 199-201.

Geosciences

Davis, Donald G., 1986, That much-discovered cave - who actually found Cave of the Winds?: *Colorado Heritage 1986*, Issue 3, pp. 34-47.

Hill, C. A., 1986, Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico: a sulfuric acid speleogenesis related to the oil and gas fields of the Permian Basin: Conference on Science in the National Parks, Colorado State University, Ft. Collins, CO, July 13-18. Programs and Abstracts, p. 243.

_____, 1986, Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico: a sulfuric acid speleogenesis related to the oil and gas fields of the Permian Basin: 9th Congreso Internacional de Espeleologia, Barcelona, Spain, August 1-7: Proceedings, Vol. 1, p. 267.

_____ and P. Forti, 1986, The classification of cave minerals: 9th Congreso Internacional de Espeleologia, Barcelona, Spain, August 1-7: Proceedings, Vol 2, p. 60.

Palmer, Arthur N., 1987, Prediction of contaminant paths in karst aquifers: Dublin, Ohio, National Water Well Assoc., Proc. of Conference on Environmental Problems in Karst Terranes and their Solutions.

Books

Crothers, George M., 1986. *Final Report on the Survey and Assessment of the Prehistoric and Historic Archaeological Remains in Big Bone Cave, Van Buren County, Tennessee*: Submitted to Tennessee Department of Conservation, Contract ID 2087. Dept. of Anthropology, Univ. of Tennessee, Knoxville, TN, iv + 66 pages.

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

Jagnow, David H. 1986, *Cavern Development in the Guadalupe Mountains, New Mexico*: reprint of 1979 book, 55 pp.

_____ and Harvey R. DuChene, 1986, *Geology Field Trip Guidebook*: Nat'l Speleol. Soc. Convention 1986, Tularosa, NM, 102 pp.

PRESENTATIONS

Archaeology, Anthropology, and Paleontology

Haskins, Valerie A., 1986. The prehistory of Prewitts Knob, Kentucky: preliminary analyses and interpretations. Presented at Kentucky Heritage Council Annual Meeting, Louisville, KY, March 8 - 9.

________, 1986. The prehistory of Prewitts Knob, Kentucky: preliminary analyses and interpretation. Presented at Society for American Archaeology 51st Annual Meeting, in the symposium "Cave Archaeology in the Eastern U.S.", New Orleans, Louisiana, April 23 - 26.

Watson, Patty Jo, 1986, Archaeobotany and geoarchaeology at a late archaic shell heap in western Kentucky: presented tothe Third USA - USSR Archaeological Symposium, Smithsonian Institution, Washington, D. C., May 8.

Geosciences

Groves, Christopher G., 1986, Stratigraphic and structural controls on karst groundwater flow in the vicinity of the Lost River, Uvala, Warren County, Kentucky: paper presented at the 16th Research Conference of the Western Kentucky University Club of Sigma Xi, Bowling Green, Kentucky, March.

_____, 1986, Robinson Cave: talk presented to the University of Virginia Student Grotto of the National Speleological Society, Charlottesville, Virginia, September.

_____, 1986, Some Kentucky karst features: talk presented to the University of Virginia Student Grotto of the National Speleological Society, Charlottesville, Virginia, November.

_____ and N. C. Crawford, 1986, High tech ridgewalking: the location and exploration of Robinson Cave, Warren County, Kentucky: paper presented at the Annual Meeting of the National Speleological Society, Tularosa, New Mexico, June.

Hill, C. A., 1986, Carlsbad cavern and other caves in the Guadalupe Mountains, New Mexico: a sulfuric acid speleogenesis related to the oil and gas fields of the Delaware Basin: National Speleological Convention, Tularosa, NM, June 26.

_____, 1986, Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains: Seminar, University of New Mexico Geology Dept., Albuquerque, NM, December 11.

_____, 1986, Preview of *Cave Minerals of the World*: talk presented to Rocky Mountain Grotto, Denver, CO, January 26.

_____, 1986, Cave minerals: talk presented to University of New Mexico PE Caving Class, spring session, Albuquerque, NM, April 8.

_____, 1986, Silent Splendor, Cave of the Winds: talk presented to Sandia Grotto, Albuquerque, NM, May 19.

_____, 1986, Silent Splendor: shown on PBS television, Rocky Mountain Region, April 16.

_____, 1986, Silent Splendor: shown on PBS television, Southwest Region, September 4.

_____, 1986, Cave minerals: talk presented to University of New Mexico PE Caving Class, fall session, Albuquerque, NM, November 10.

_____, 1986, Lechuguilla Cave, talk presented to Sandia Grotto, Albuquerque, NM, November 24.

Jagnow, David H., 1986, The geology of Crockett's Cave, a New Mexico Gypsum Cave (abs): Nat'l Speleol Soc. Convention, Tularosa, NM, June.

_____, 1986, Western Oklahoma gypsum caves (abs): Nat'l Speleol. Soc. Convention, Tularosa, NM, June.

Palmer, Margaret V., June, 1986, Silica crusts on cave walls: Natl. Speleol. Soc., annual convention, Tularosa, NM.

Palmer, Arthur N., October, 1986, Prediction of contaminant paths in karst aquifers: National Water Well Assoc., Conference on Environmental Problems in Karst Terranes and their Solutions, Bowling Green, KY.

Rhinehart, Richard J., 1986, Exploring the mysterious underground: caves of Colorado: Lecture presented to Denver Museum of Natural History, August.

Special Commendations

Hill, C. A. 1986, mentioned in *Who's Who in the West* (Marquis), 21st edition.

_____, 1986, presented with Certificate of Excellence for Best Paper at 1986 NSS Convention by the National Caves Association, $50 award.

Cave Books

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

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

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

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

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

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

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

Bibliography of Cave Books Publications to Date

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

Crowther, P. P., et al, 1984, *The Grand Kentucky Junction*: Cave Books, St. Louis, MO, 96 pp.

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

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

Lindsley, Karen Bradley (ed.), 1984, *Cave Research Foundation Annual Report - 1981*: Cave Books, St. Louis, MO, (illus.), 55 pp.

_____ (ed.), 1985, *Cave Research Foundation Annual Report - 1984*: Cave Books, St. Louis, MO, (illus.), 60 pp.

_____ (ed.), 1986, *Cave Research Foundation Annual Report - 1985*: Cave Books, St. Louis, MO, (illus.), 48 pp.

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

Noswat, Erd, 1976, *Maws, A Parody*: Cave Books, St. Louis, MO, (illus.), 36 pp.

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

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

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

Steele, C. William, 1985, *Yochib: The River Cave*: Cave Books, St. Louis, MO, (illus.), 176 pp.

Watson, Richard A. (ed.), 1981, *Cave Research Foundation: Origins and the First Twelve Years*: 1957-1968: Cave Books, St. Louis, MO, (illus.), 495 pp.

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

_____ (ed.), 1984, *Cave Research Foundation: 1974-1978*: Cave Books, St. Louis, MO, (illus.), 366 pp.

THE CAVE RESEARCH FOUNDATION

Figure 15: Main entrance to the 9th International Congress of Speleology in Barcelona, Spain during August, 1986. *Photo by Pete Lindsley.*

CRF MANAGEMENT STRUCTURE 1986

Directors

Ronald C. Wilson, President

R. Pete Lindsley, Secretary	Roger E. McClure, Treasurer
Sarah G. Bishop	John C. Tinsley
Rich Wolfert	Richard B. Zopf

Officers and Management Personnel

General

Chief Scientist	Thomas L. Poulson
Personnel Records Officer	Kathleen M. Womack
Computer Records Officer	William F. Mann
Cave Books Editor	Richard A. Watson
Publisher	Roger E. McClure
Sales	Thomas A. Brucker
Production Manager	Karen Bradley Lindsley
Newsletter Editor	Janet Alfred
Annual Report Editor	Karen Bradley Lindsley

Central Kentucky Area Management Personnel

Operations Manager	Diana Miller
Personnel Officer	Philip DiBlasi
Chief Cartographer	Richard B. Zopf
Medical Officer	Stanley D. Sides
Safety Officer	Thomas Alfred
Supply Officer	Roger Miller
Vertical Supplies Officer	Rick Olson
Log Keeper	Diana Emerson George
Field Station Maintenance	Daryle Hensel

California Area Management Personnel

Operations Manager	John C. Tinsley
Personnel Officer	Luther Perry
Chief Cartographers	David DesMarais
	Peter Bosted
	Howard Hurtt
Safety Officer	Jack Hess
Science Officer	Mike Spiess
Field Station Maintenance	Stan Ulfeldt

Guadalupe Escarpment Area Management Personnel

Operations Manager	Rich Wolfert
Personnel Officer	Bill Wilson
Chief Cartographer	Alan Williams
Finance and Supply Coordinator	John Francisco
Field Station Maintenance	Ron Kerbo

Arkansas Project Management Personnel

Project Manager	Pete Lindsley
Operations Manager	Gary R. Schaecher
Chief Surveyor	David Hoffman
Project Cartographers	Gary R. Schaecher
	Jack Regal
	John P. Brooks
	Robert L. Taylor
Newsletter	Pete Lindsley

Operating Committees

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

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

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

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

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

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

Roger E. McClure, Chairman	Roger W. Brucker	Thomas A. Brucker
Karen Bradley Lindsley	Richard A. Watson	Claire B. Wood

Conservation Committee: Identifies conservation issues of concern to the Foundation and maintains liaison with conservation organization. Sarah G. Bishop, Chairman.

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