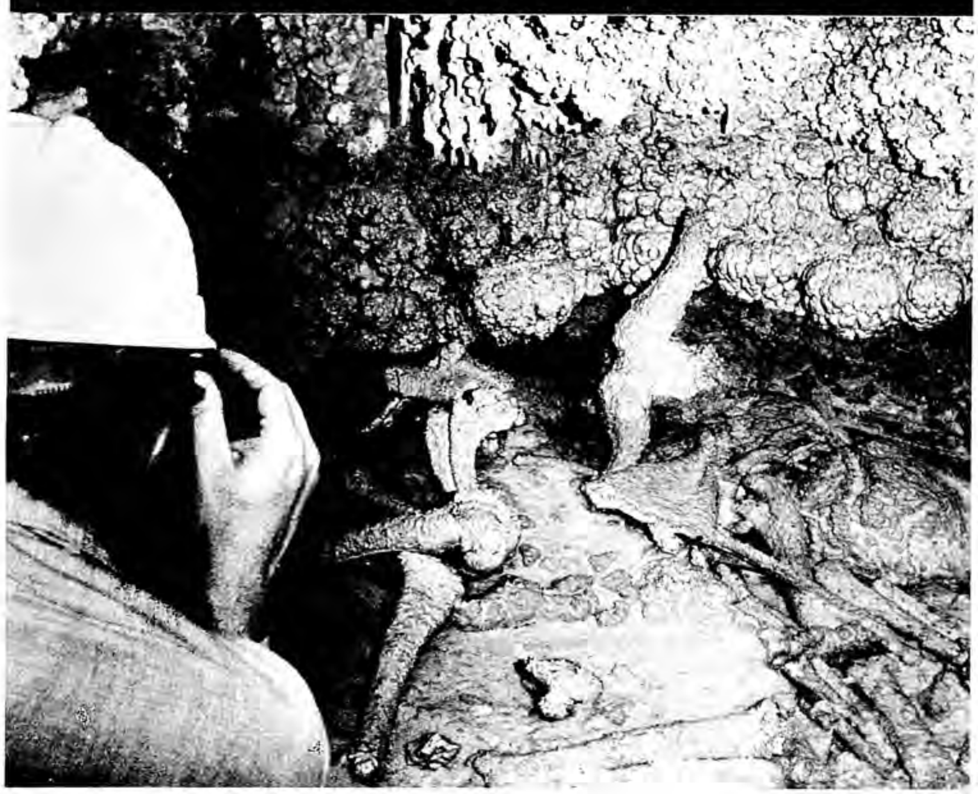
CAVE RESEARCH FOUNDATION

CAVE RESEARCH FOUNDATION 1976

Annual Report



Cave Research Foundation

1976 Annual Report

Cave Research Foundation
445 W. S. College Street
Yellow Springs, Ohio 45387

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

Cover: A decorated cave pool in Musk Ox Cave, Carlsbad Caverns National Park, holds the bones of an extinct Bush Ox. Discovered in February, 1976 by a CRF survey team, the bones are under study at the Smithsonian Institution. Photo by Cal Welbourn.

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CAVE RESEARCH FOUNDATION DIRECTORS

January 1977

Roger W. Brucker
President

W. Calvin Welbourn
Secretary and Guadalupe Escarpment Area Operations Manager

Dennis E. Drum
Treasurer

Stephen G. Wells
Chief Scientist

Charles F. Hildebolt
Central Kentucky Area Operations Manager

R. Pete Lindsley
New Project Operations Manager

Rondal R. Bridgemon
Conservation Affairs

Patricia P. Crowther
Cartographer

Stanley D. Sides
Historian

Acknowledgements

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

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

The saltpetre cave nitrate research described herein received partial support from The National Geographic Society.

Dr. Russell Harmon's research was conducted at McMaster University, Hamilton, Ontario, Canada under the supervision of Dr. D. C. Ford and H. P. Schwarcz. Financial support from the National Research Council of Canada and the Department of Energy, Mines, and Resources, Canadian Geological Survey to Drs. Ford and Schwarcz is acknowledged. Support from the National Speleological Society was also provided.

The Natural Trap Cave research was supported in part by The National Science Foundation.

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Highlights of 1976

The past year was marked by an unprecedented amount of publication of scientific and interpretive work by the Cave Research Foundation. The Publication List given later in this report tabulates five books, four theses, forty-two scientific articles, twenty-six papers at professional meetings, and more than thirty interpretive talks during 1976. In addition, two landmark publications having both interpretive and technical value were completed by the western part of CRF: *Wupatki Earth Crack Study* and the *New Cave Map Card*.

Cave Minerals, by CRF member Carol Hill, was published by the National Speleological Society in the summer of 1976. Carol Hill's book has been hailed as the basic reference on the subject. A number of minerals occurring in the Guadalupe Escarpment area and in the Mammoth Cave area are described, but the scope of the book is the North American continent.

The Longest Cave, by Roger W. Brucker and Richard A. Watson, published by Alfred A. Knopf, tells the story of how generations of cave explorers discovered more and more cave, and eventually found in 1972 a link between caves under Mammoth Cave Ridge and Flint Ridge. It is the principal book on the history of exploration in the Flint Mammoth Cave System.

The 1955 edition of *The Caves Beyond*, by Joe Lawrence, Jr. and Roger W. Brucker, has been reprinted with a new introduction and an index by Zephyrus Press. This book focuses on the 1954 C-3 NSS expedition to Floyd Collins' Crystal Cave, Flint Ridge, an expedition which had great influence on the creation and nature of the Cave Research Foundation three years later.

Der Karst in Zentralen Kentucky bei Mammoth Cave and *Die Höhlen in Mammoth Cave-Gebiet/Kentucky*, by Franz-Dieter Miotke, present the results of the author's intensive and extensive field investigations in 1971-72. These two books, profusely illustrated with photographs, diagrams, and maps, are the most comprehensive and authoritative descriptions of the Central Kentucky Karst and Mammoth Cave.

Titles for ten CRF contributions to the *National Cave Management Symposium Proceedings* (1975) are given in the Publication List later in the report. Several CRF investigators presented papers at the 1976 National Cave Management Symposium. It is evident that serious interest in better cave management is intensifying among the Federal and State agencies, and CRF's next contribution to this important subject might well be encouraging the implementation of ideas developed at the 1975 and 1976 meetings.

Perhaps the most significant and exciting CRF exploration event of the year occurred in Musk Ox Cave, Carlsbad Caverns National Park. As part of CRF's systematic study of the Park's backcountry caves, survey/exploration teams visited what was formerly believed to be a small one-room cave. Instead, more than 2000 feet of well-decorated virgin cave was discovered and, more importantly, an extraordinarily rich paleontological site was located. In a calcite-encrusted pool, a rare bush ox skeleton (perhaps the only nearly complete example known), a dire wolf skull, and bones of other now-extinct species were found. The remains were later removed from the cave for further study by a team including Joint Venturer Lloyd Logan and researchers from the Carnegie Institute and the Smithsonian Institution.

A variety of 1976 interpretive projects are highlighted in this report. The CRF Earth Cracks report on cave features of Wupatki National Monument includes an impressive 59-page publication and a descriptive slide show, together with detailed maps. A map card of New Cave, Carlsbad Caverns National Park, was published by CRF. The card contains a cave map on one side and a descriptive text with illustrations on the other side. The Park is using the map card as an interpretive tool by making it available to visitors.

Several briefing and training sessions for staff and visitors of Mammoth Cave and Carlsbad Caverns National Parks were conducted by CRF people during 1976.

There were eight applications for CRF Fellowship support in 1976. No Fellowship was given, but the following grants were awarded:

> "A Genetic Analysis of Epigean and Hypogean Populations of *Gammarus* and *Crangonyx* (Amphipoda: Gammaridae)," David L. Bechler, Department of Biology, St. Louis University.

> "Small Mammalian Fauna as Environmental Indicators: A Case Study in Northwestern Wyoming," Stephen A. Chomko, Department of Anthropology, University of Missouri-Columbia.

CRF discussions with The Nature Conservancy and the National Park Service, relating to cave conservation and planning, are discussed in the President's Report.

A merger was consummated between CRF and The Lilburn Cave Project, Kings Canyon National Park. Details of this promising event are given in The President's Report and in a special section later in this report.

At the November, 1976 Board meeting, the Directors authorized R. Pete Lindsley to establish a new CRF project at Buffalo River National Scenic Riverways, in response to needs of the National Park Service.

President's Report

Perhaps the most significant and long ranging events of 1976 were the strengthening of contacts within The Nature Conservancy and efforts to modify the Final Master Plan and Final Environmental Statement for Mammoth Cave National Park.

The Board of Directors of CRF asked me to become acquainted with individuals of The Nature Conservancy (TNC) for the purpose of seeking protection for karst features near Mammoth Cave National Park. The introductory project was to seek the protection of Mill Hole Farm. After presentations and inspections, the Kentucky Chapter TNC approved the project. Unfortunately, enthusiasm cooled when the price was found to be $318,000. However, the owner of Mill Hole Farm plans to live there for the near future, so indefinite protection is assured. The outcome was disappointing, but CRF did become acquainted with the purposes, methods, and individuals of TNC.

As a result of these contacts, Patrick Noonan, President of TNC, has asked CRF for a short description of those karst features in Central Kentucky which should be protected. The President of TNC and the President of CRF will seek the money required for acquisitions.

When the Final Master Plan and Final Environmental Statement for Mammoth Cave were published in May, 1976, CRF examined the documents carefully. One impression was that the laudable purposes and objectives of the plan had been weakened by proposals to: 1. build an overflow parking lot over Proctor Cave on Joppa Ridge; 2. replace the sewage disposal plant on its present site; 3. erect a new domestic water treatment plant atop the rarest rare mineral area of the Flint Ridge portion of the Flint Mammoth Cave System; and 4. construct a new elevator to permit extension of the unguided trips into areas of the cave having significant archeological remains. CRF was alarmed by these immediate threats to the cave resources of Mammoth Cave National Park.

CRF now is studying formally the Master Plan and Environmental Statement, and aims to have a report ready early in 1977. This report will be sent to the Regional Office in advance of a meeting. We are confident that the Park Service planners want to do the right things and will be sensitive to recommendations.

With the completion of the Wupatki Earth Cracks Report, the Foundation achieved a milestone. A single project—involving hundreds of hours of investigation, negotiation, writing, drafting, photographing, and editing—was initiated and brought to completion within one year. CRF projects sometimes seem to progress on geologic time scales, so Rondal Bridgemon's research team deserves commendation for thoroughness and speed.

At the November, 1976 CRF Annual Meeting the CRF Board of Directors and Stan Ulfeldt, Project Director, Lilburn Cave Project, Kings Canyon National Park, California, agreed to join forces. Lilburn Cave is the longest cave west of the continental divide, and since 1969 has been the object of intense research effort, under the direction of Mr. Ulfeldt. Lilburn participants believed that CRF could provide research and administrative support for their efforts. The CRF Board believed that the capable and dedicated people connected with the project would bring new ideas and opportunities to CRF. The amalgamation of the two efforts is expected to be mutually beneficial. Since the beginning years of the Foundation, the Directors have strongly felt that CRF should not "take over" ongoing research projects. We believe it is not possible to operate a new project without committed people, nor is it possible to "rescue" an ailing project. The Lilburn Cave Project has a committed group of about two dozen investigators, and the organization is vigorous and healthy. The mutual enthusiasm for the union produced a hearty cheer when CRF members heard the news. We welcome the association with Lilburn Cave Project Joint Venturers.

Some projects are stalled and, therefore, are problems. Publication of the Ogle Cave Symposium and the CRF Barra Honda Expedition Report are examples. We also hope to complete a Carlsbad Caverns Map Card similar to the New Cave Map Card in 1977.

One problem facing CRF is money. As an all-volunteer organization, CRF has been able to carry on a significant program whether it had cash or not. Most activities have required more direct labor than cash; when projects such as printing a CRF Personnel Manual required large outlays of cash, concerned individuals donated or loaned the money. Our field operations are organized to be self-supporting from fees collected from participants.

CRF received a total of about $14,000 from contracts for *The Longest Cave*. Of this amount about $2,500 was used for expenses in producing the manuscript, photos, and artwork for the book. Another $2,000 was earmarked for the Endowment Fund. The balance was used for a variety of projects. There probably will not be any additional, sizeable sums from this source, although we expect the book to continue to earn modest royalties for the foreseeable future. If there are any more large-sum windfalls, I recommend that they be used to increase the Endowment Fund. But a more realistic objective would be to build the fund to yield about $2,000 a year for research fellowships and grants. A $35,000 total would accomplish this objective. The Endowment Fund has about $3,000 now.

If you would like to do something wonderful during CRF's 20th year, contribute to the Endowment Fund. It will carry on your purpose forever.

Roger W. Brucker

Roger W. Brucker
President

Notes from the Retiring Science Director

After serving for several years as one of the Foundation's Directors, and for the past year as the chief science administrator, I have retired from an active management role in the Foundation. To all who have made this experience so rewarding, I extend my heartfelt thanks.

The changing roles of the Foundation in science, interpretation and conservation affairs, as well as shifting personal interests, sometimes create highly opportune times for important personnel changes. At the past Directors' meeting, Steve Wells simultaneously became a Director and Chief Scientist. With his present position as Assistant Professor of Geology, University of New Mexico, the Foundation once again has a Chief Scientist who is a scholar with professional karst interests. These circumstances bode well for the future of CRF's science program.

The 1976 publication record speaks clearly – the Foundation's science program is vigorous, healthy, and highly productive. The challenges I see for the new science administration are threefold: 1) seeing that partially completed projects are carried through to completion; 2; ensuring that new research blood continually joins the program; and 3) identifying important new research areas and establishing programs in these areas. CRF has not been highly successful recently in the second and third objectives, to which its long-range health is fundamentally tied. I have confidence that with the continued dedication of the Joint Venturers, these objectives will be achieved and science directions will be even more exciting in the future.

P. Gary Eller

P. Gary Eller
Director for Research

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SCIENTIFIC PROGRAMS

Figure 1. Marshall Avenue, Lee Cave, Kentucky. This passage was discovered by a Cave Research Foundation team in March, 1970. Photo by Roger Brucker.

Cartography

Central Kentucky Area

Patricia P. Crowther, John P. Wilcox and Roger W. Brucker

Most of the field work during 1976 took place in Mammoth Cave in passages that had not been surveyed before. Underground survey during the 12-month period ending November 1, 1976 totalled 11.46 miles. The surveyed length of the Flint Mammoth Cave System is now 184.64 miles.

Map Drafting Efforts

Cartographic efforts resulted in the production of a sequence of maps used in *The Longest Cave*. These maps are presented here because they provide an unprecedented understanding of the historic progression of discovery when viewed sequentially. They show successive stages in the enlargement of the Flint Ridge caves, which became the Flint Ridge Cave System in 1961 with the connection of Crystal/Unknown Cave with Colossal/Salts Cave. With the connection of the Flint Ridge Cave System and Mammoth Cave in 1972, the Flint Mammoth Cave System became by far the longest cave in the world.

Progress continues to be made in drafting two manuscript maps—New Discovery, and the east end of Mammoth Cave. A manuscript map is a careful compilation of many individual surveys in an area with loop errors corrected. It forms the basis for publication of the final cave map.

A field map of the Carlos Way area in Mammoth Cave is nearly completed. Field maps are a basic tool for managing exploration because they show the general relationship of the individual surveys with each other. Expedition and party leaders often infer from passage patterns which unexplored leads have the highest probability of yielding more passageways.

Exploration and Survey in Flint Ridge

New survey in the Flint Ridge portion of the system added 1.9 miles to the length, for a total of 94.11 miles (included in the 184.64 mile total length of the system). Exploration centered on Floyd's Lost Passage, Ralph's River Trail, Salts/Colossal Link, and Argo Junction.

Significant survey extensions at the eastern end of Floyd's Lost Passage yielded some promise of finding additional pieces of trunk passage. Ralph's River Trail and Colossal/Salts Link each provided more than a thousand feet of survey and should yield more.

Figure 2. Richard Zopf uses a Brunton compass to measure bearing between survey stations in the Flint-Mammoth Cave System. Photo by Roger Brucker

Exploration and Survey in Mammoth Cave

Systematic exploration has continued to result in new survey in a dozen different areas of the cave. Mammoth Cave surveys have increased by 7.77 miles, for a new total length of 90.5 miles (included in the 184.64 miles overall for the cave system).

Major exploration achievements include: the ascent of Cathedral Domes opening 1.7 miles of passage, a breakthrough in Miller Avenue leading to nearly a mile of cave including two isolated trunk segments of Kentucky Avenue, rediscovery of an extensive canyon beneath Silliman's Avenue, and a complex of passages from a shaft area near Robertson Avenue. Bransford Avenue and Cocklebur Avenue yielded a mile of new survey. A survey in New Discovery totalled 575 feet. More than 2,200 feet have been surveyed from leads off Kentucky Avenue. Parish's Pit and Bishop's Pit near Violet City have interesting surveys started.

Smaller Caves

Surveys in Proctor Cave totalled 3,500 feet. Most of this new survey heads northwest up Joppa Ridge from the north end of Frost Avenue. The surveyed length of Proctor Cave is now 5.70 miles.

Tom's Cave in the valley south of the Bedquilt area of the cave system yielded 768 feet of survey.

Mapping Facilities and Procedures

During the year a new mapping facility was set up in Beavercreek, Ohio. It consists of several drafting tables, equipment, and abundant wall space for permanent display of maps. Weekly cartographic sessions have included half a dozen joint venturers. Priority work is catching up on a backlog of individual surveys, wall-detailing, and completion of the Carlos Way field map.

Plans are being implemented to move the automatic drafting to a new computer, and to rewrite the survey reduction programs in Fortran. The Flint Mammoth Cave System data base is a reel of magnetic tape that contains more than 25,000 bearings and distances plus associated wall distances. A computer-driven plotter drafts overall maps at any scale from the data base. All of the more than 1200 survey books are being placed in microfiche form for easy reference at several locations where maps are prepared. It is estimated that approximately five hours of cartography time is spent per hour surveying.

Guadalupe Escarpment Area

James M. Hardy

In 1976, survey in Carlsbad Caverns National Park concentrated in Musk Ox Cave where a major paleontological discovery was made. In Carlsbad Caverns an effort was made to survey floor detail in the Bat Cave section. Two small caves on Bureau of Land Management lands were also surveyed. Work continued in Fort Stanton Cave, Wind Cave, Dry Cave and Three Fingers Cave. Survey totals for 1976 are shown in Table 1.

In addition, a survey tie was made into the Carlsbad Caverns control net and into the Slaughter Canyon control net from the National Geodetic control net.

Several maps were finished this year. These include Arch Cave, Dome Cave, Dry Cave, Ogle Cave, Porcupine Cave, Spider Cave, and Water Tank Cave. The Dry Cave and Ogle Cave maps are to be included in upcoming publications on these caves. The New Cave map was redrafted and published with an interpretive text.

Work is continuing on the Musk Ox Map and preparation of a 1'' = 200' (1:2400) scale map of Carlsbad Caverns. Both of these maps and several backcountry caves will be completed in 1977.

Reconnaissance was started on the gypsum plain to the east of the Guadalupe Escarpment where work is expected to expand during 1977. Work is also planned in Carlsbad Caverns where leads will be checked and an effort will be made to work on Lower Cave.

TABLE 1. 1976 Totals for the Guadalupe Escarpment Area

Cave	Cave Survey	Surface Survey
Carlsbad Caverns, CCNP	5857**	
Musk Ox Cave, CCNP	2358	367
Fort Stanton Cave, BLM	541	3923
Dry Cave, BLM	1106*	
Wind Cave, BLM	300	
Jurnigan I, BLM	316	
Jurnigan II, BLM	230	
Three Fingers Cave, LNF	1350	
TOTALS	12058	4290

* 46 feet were resurvey.

** 4550 feet were floor detail survey.

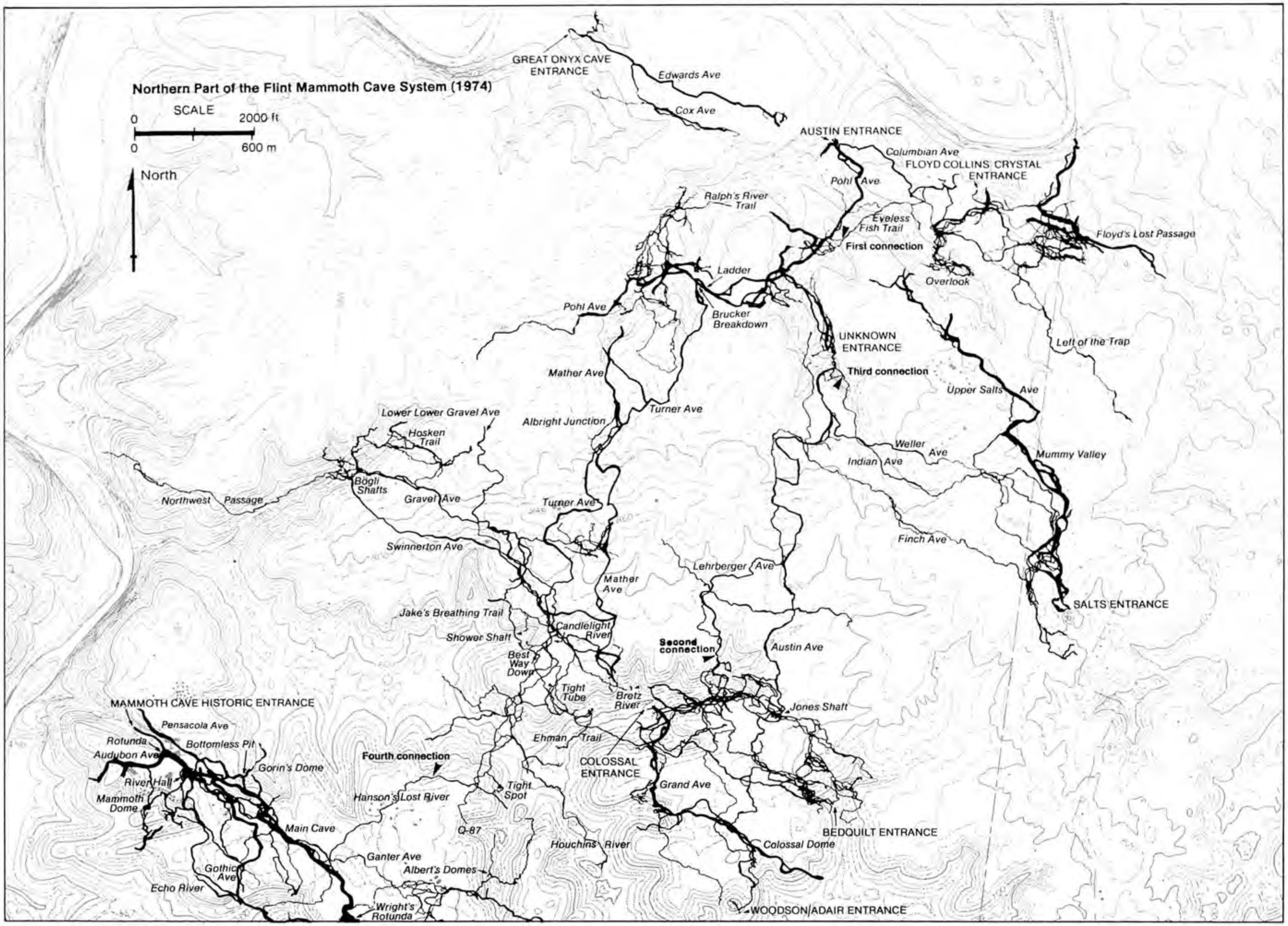
Northern Part of the Flint Mammoth Cave System (1974)
SCALE
0
2000 ft
0
600 m
North
GREAT ONYX CAVE ENTRANCE
Edwards Ave
Cox Ave
AUSTIN ENTRANCE
Columbian Ave
FLOYD COLLINS CRYSTAL ENTRANCE
Pohl Ave
Ralph's River Trail
Eyeless Fish Trail
First connection
Floyd's Lost Passage
Ladder
Overlook
Pohl Ave
Brucker Breakdown
UNKNOWN ENTRANCE
Left of the Trap
Third connection
Mather Ave
Upper Salts Ave
Turner Ave
Lower Lower Gravel Ave
Albright Junction
Hosken Trail
Weller Ave
Indian Ave
Mummy Valley
Bogli Shafts
Northwest Passage
Gravel Ave
Turner Ave
Finch Ave
Swinnerton Ave
Lehrberger Ave
Mather Ave
SALTS ENTRANCE
Jake's Breathing Trail
Candlelight River
Shower Shaft
Second connection
Austin Ave
Best Way Down
Tight Tube
Bretz River
MAMMOTH CAVE HISTORIC ENTRANCE
Jones Shaft
Pensacola Ave
Rotunda
Bottomless Pit
Ehman Trail
Audubon Ave
Fourth connection
COLOSSAL ENTRANCE
Gorin's Dome
River Hall
Grand Ave
Tight Spot
Mammoth Dome
Hanson's Lost River
Main Cave
Q-87
BEDQUILT ENTRANCE
Houchins River
Colossal Dome
Ganter Ave
Gothic Ave
Albert's Domes
Echo River
Wright's Rotunda
WOODSON/ADAIR ENTRANCE

Figure 3

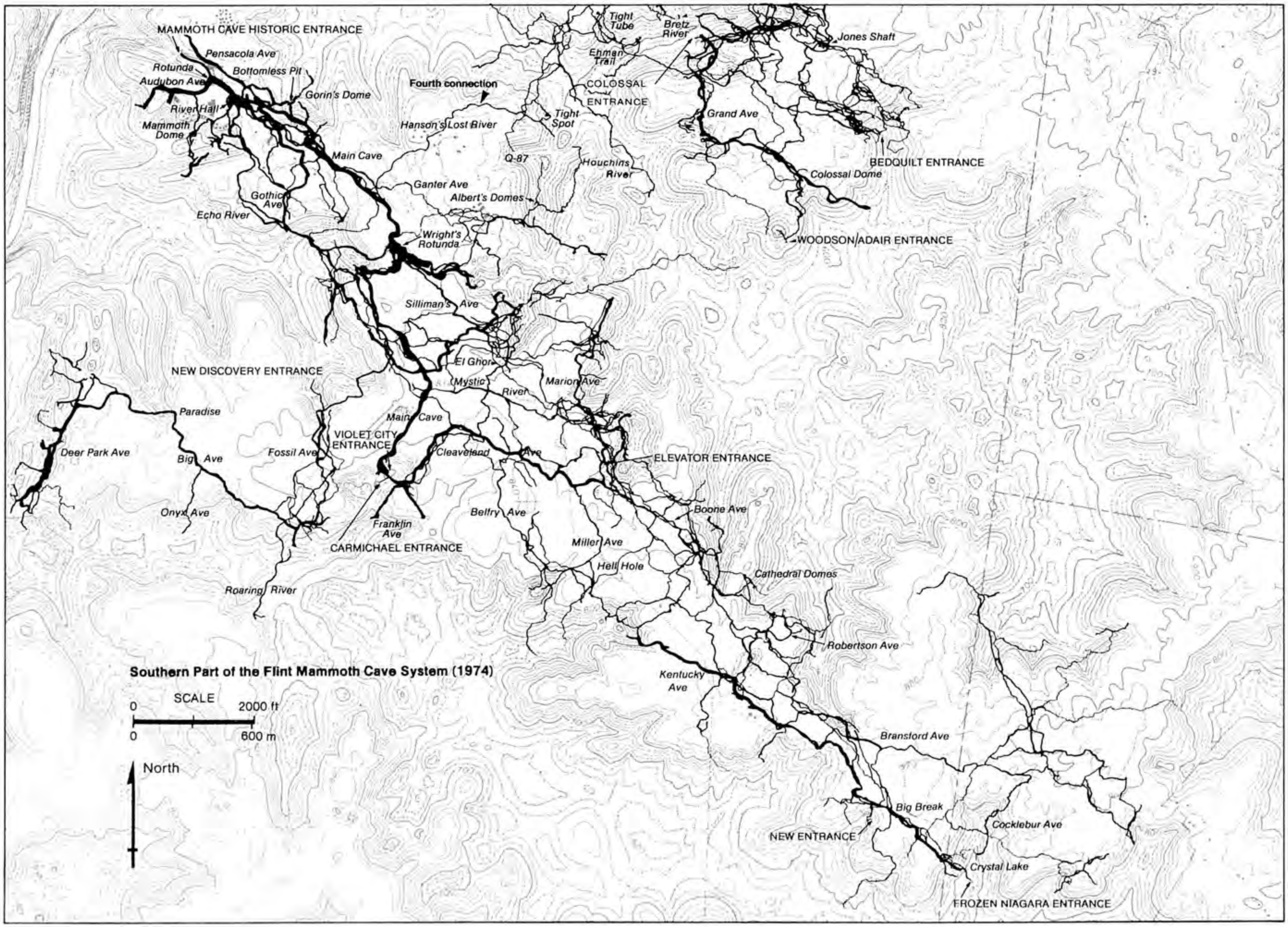
MAMMOTH CAVE HISTORIC ENTRANCE
Pensacola Ave
Rotunda
Bottomless Pit
Audubon Ave
Gorin's Dome
River Hall
Mammoth Dome
Fourth connection
Hanson's Lost River
Tight Tube
Bretz River
Ehman Trail
COLOSSAL ENTRANCE
Tight Spot
Jones Shaft
Grand Ave
Q-87
Houchins River
BEDQUILT ENTRANCE
Colossal Dome
Main Cave
Ganter Ave
Albert's Domes
Gothic Ave
Echo River
Wright's Rotunda
WOODSON/ADAIR ENTRANCE
Silliman's Ave
El Ghor
NEW DISCOVERY ENTRANCE
Mystic River
Marion Ave
Paradise
Main Cave
VIOLET CITY ENTRANCE
Deer Park Ave
Big Ave
Fossil Ave
Cleaveland Ave
ELEVATOR ENTRANCE
Onyx Ave
Franklin Ave
Belfry Ave
Boone Ave
CARMICHAEL ENTRANCE
Miller Ave
Hell Hole
Cathedral Domes
Roaring River
Robertson Ave
Southern Part of the Flint Mammoth Cave System (1974)
Kentucky Ave
SCALE
0
2000 ft
0
600 m
Bransford Ave
North
Big Break
NEW ENTRANCE
Cocklebur Ave
Crystal Lake
FROZEN NIAGARA ENTRANCE

Figure 4

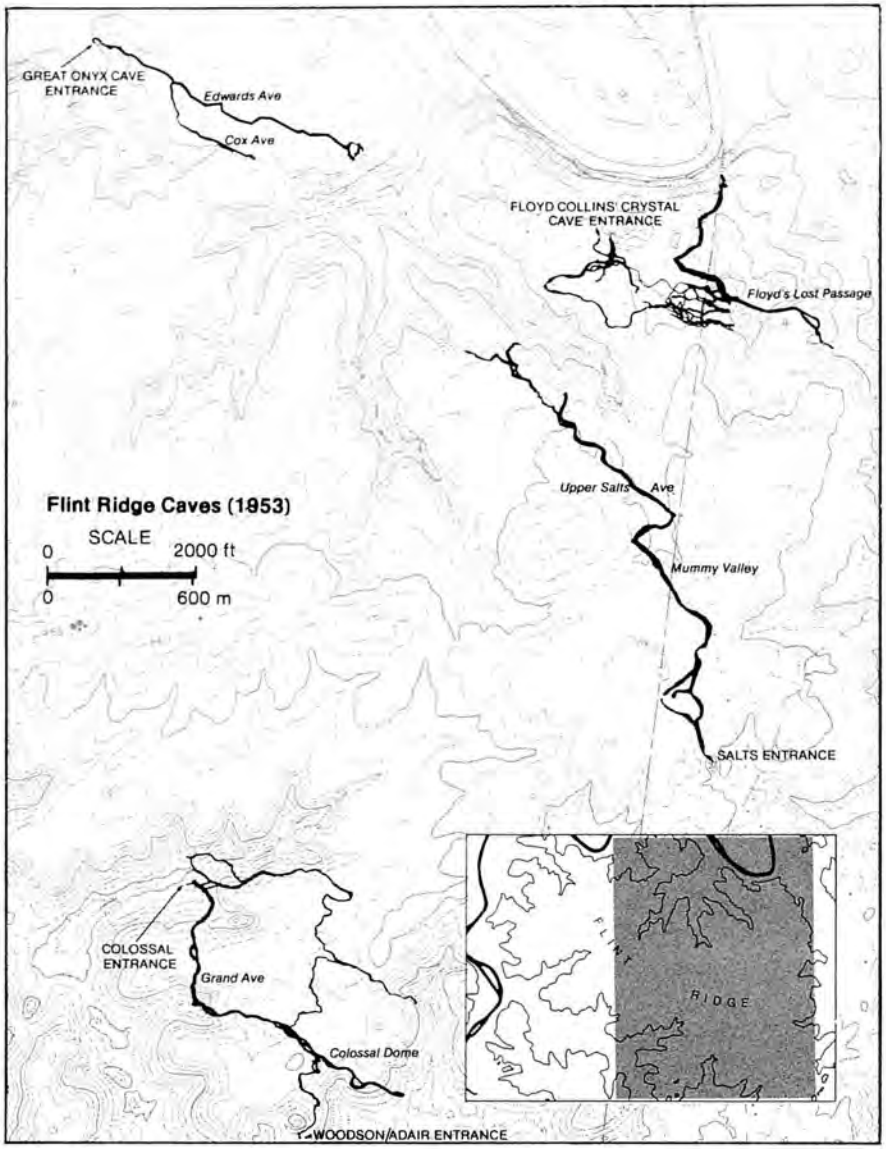

Figure 5. The maps shown on this page and the succeeding four pages show the integration of the Flint Mammoth Cave System as the result of systematic exploration and survey during the period 1953-1972. Colossal, Floyd Collins Crystal, Great Onyx and Salts caves had been known for years as separate caves.

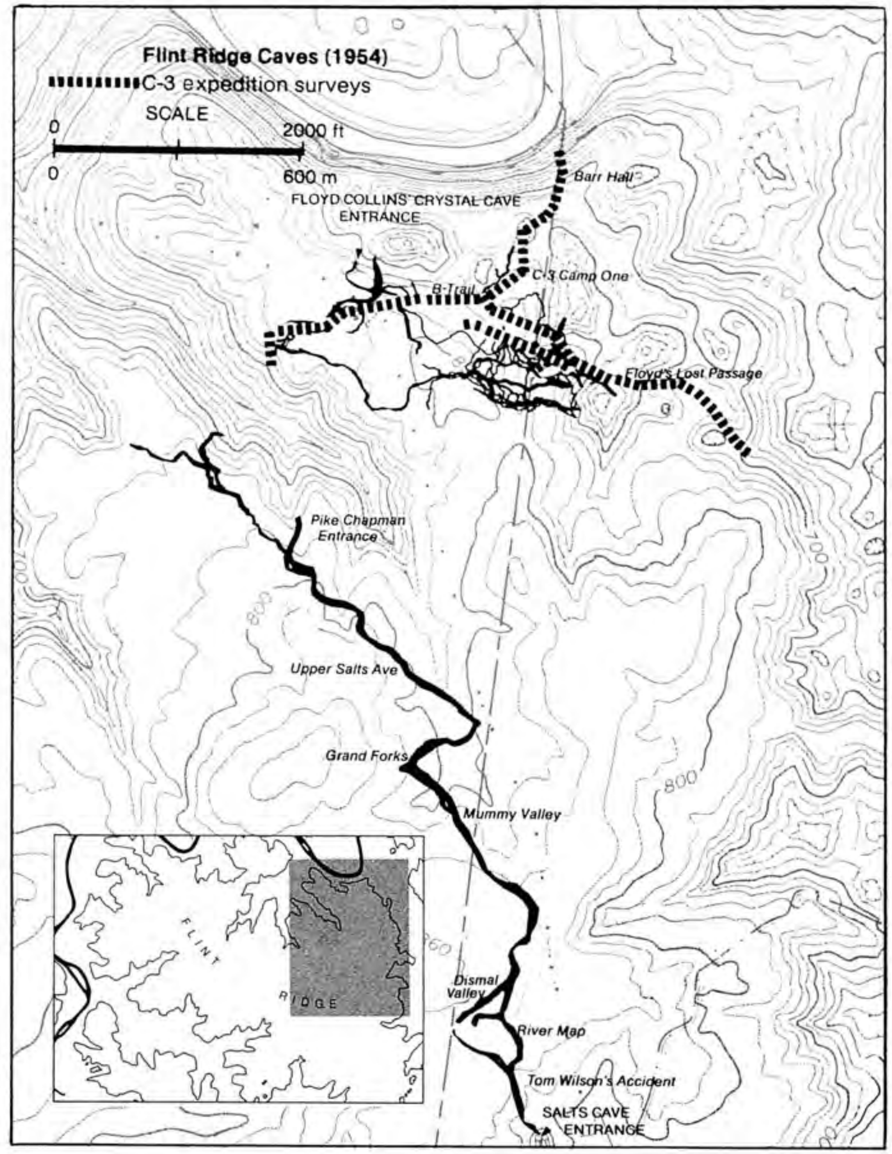

Figure 6. The 1954 National Speleological Society C-3 Expedition focused on the lower levels of Crystal Cave.

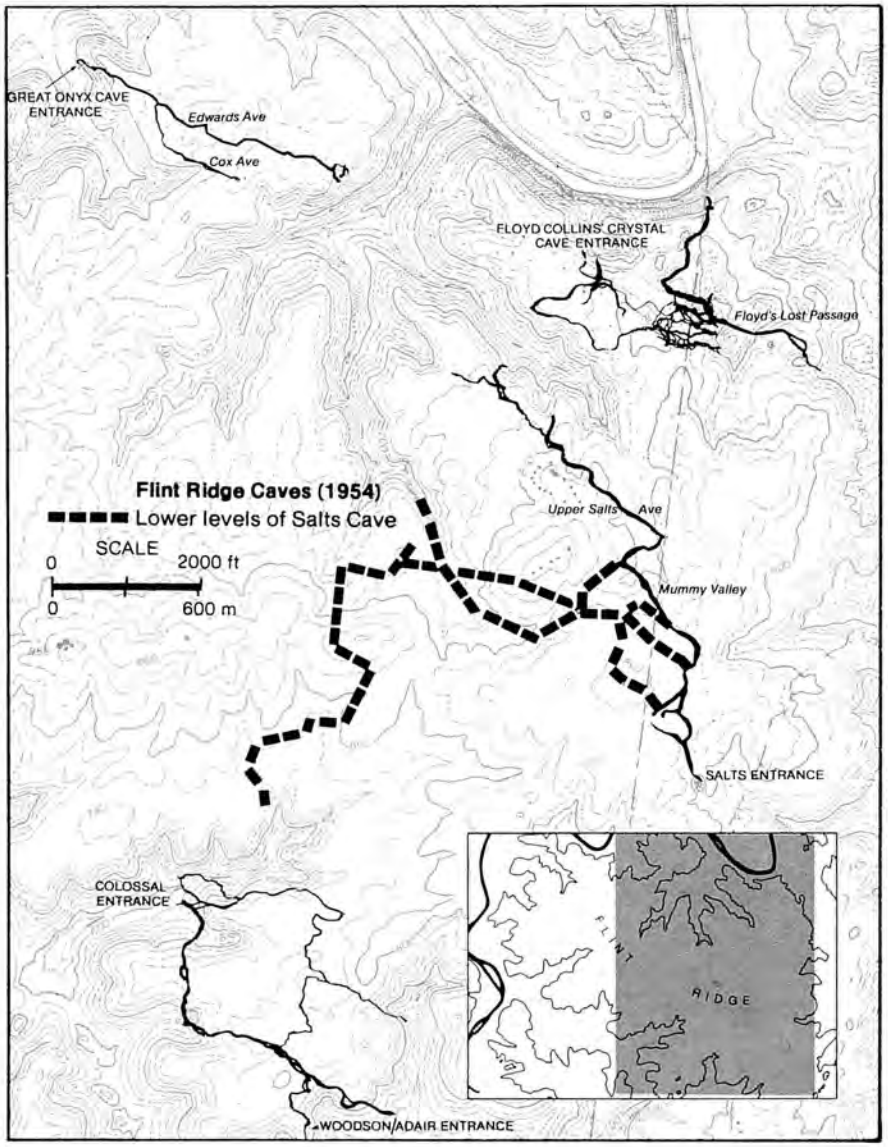

Figure 7. In 1954 extensive lower levels were discovered and mapped in Salts Cave.

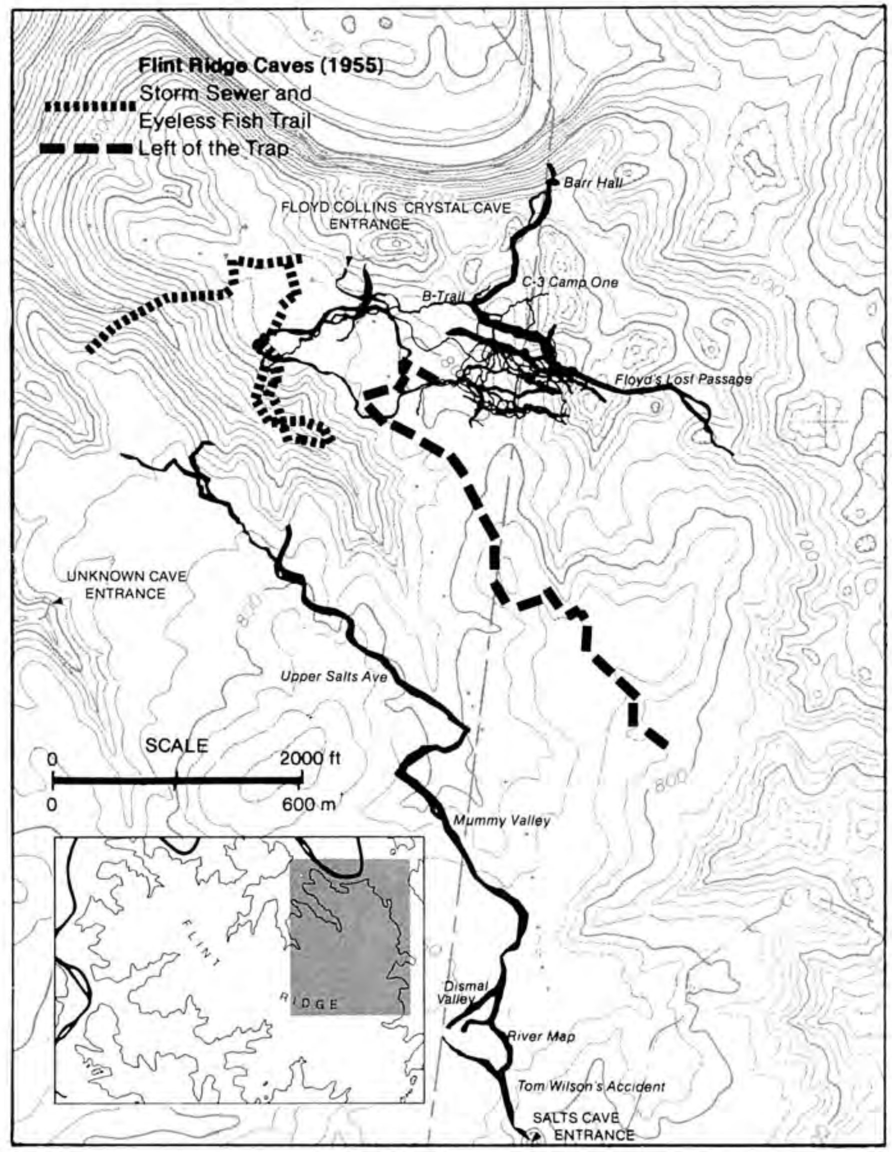

Figure 8. In 1955 extensive lower levels were discovered and mapped in Crystal Cave.

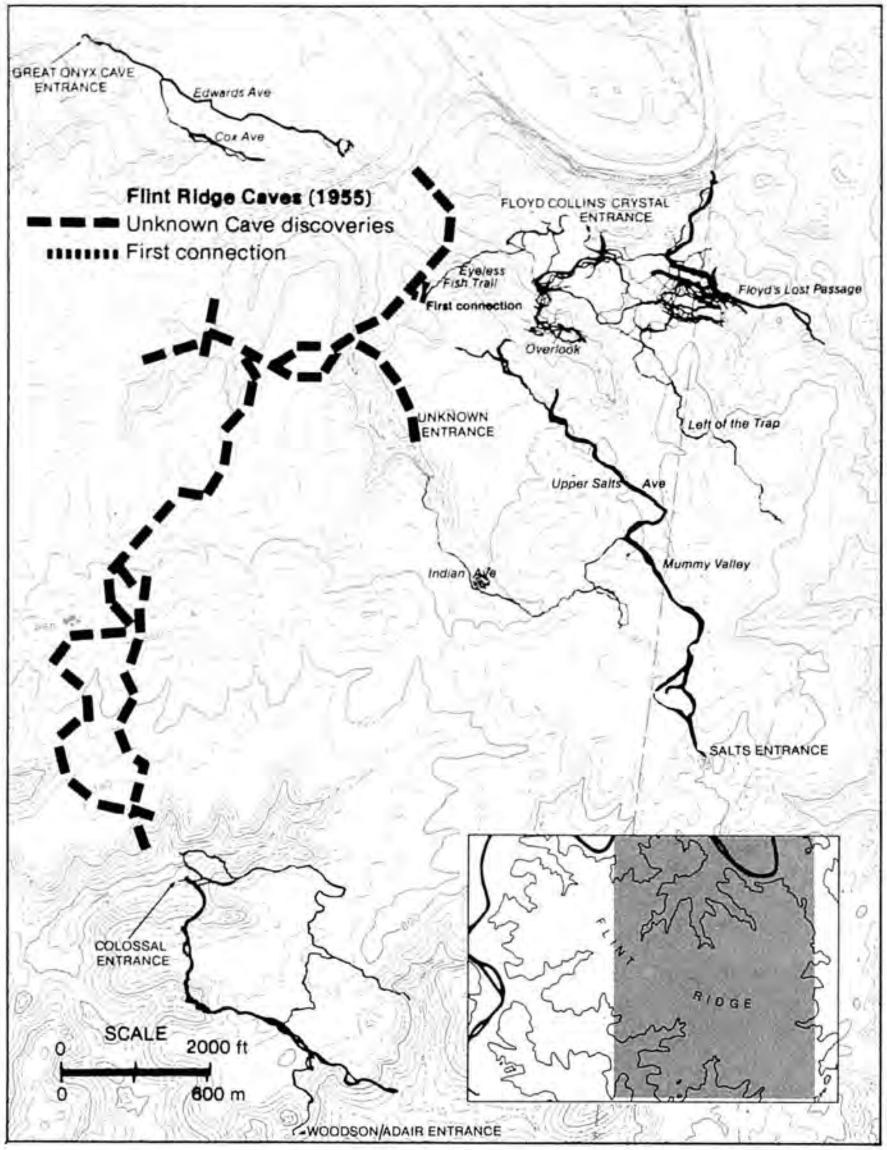

Figure 9. Exploration in Unknown Cave, previously believed to be a small isolated cave, led to a connection with Crystal Cave in 1955.

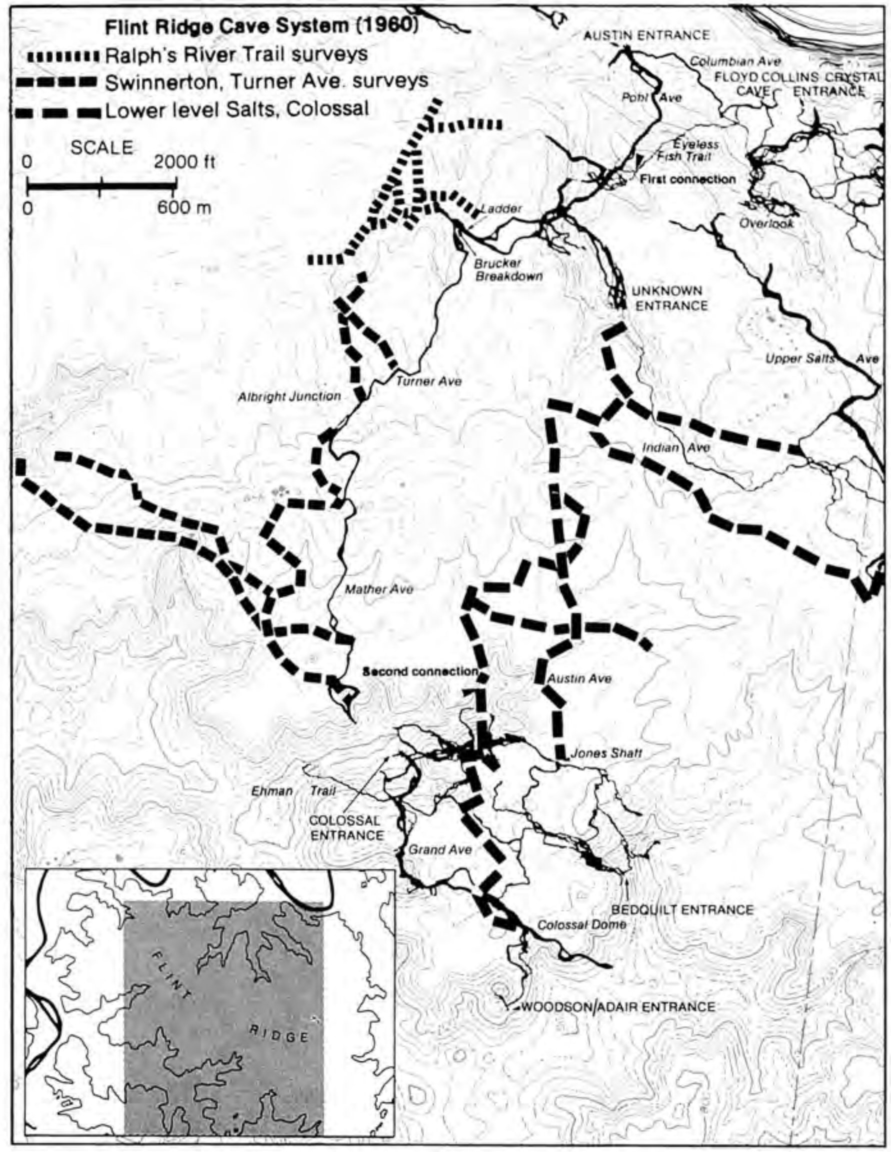

Figure 10. By 1960 a connection had been found between Colossal and Salts Caves.

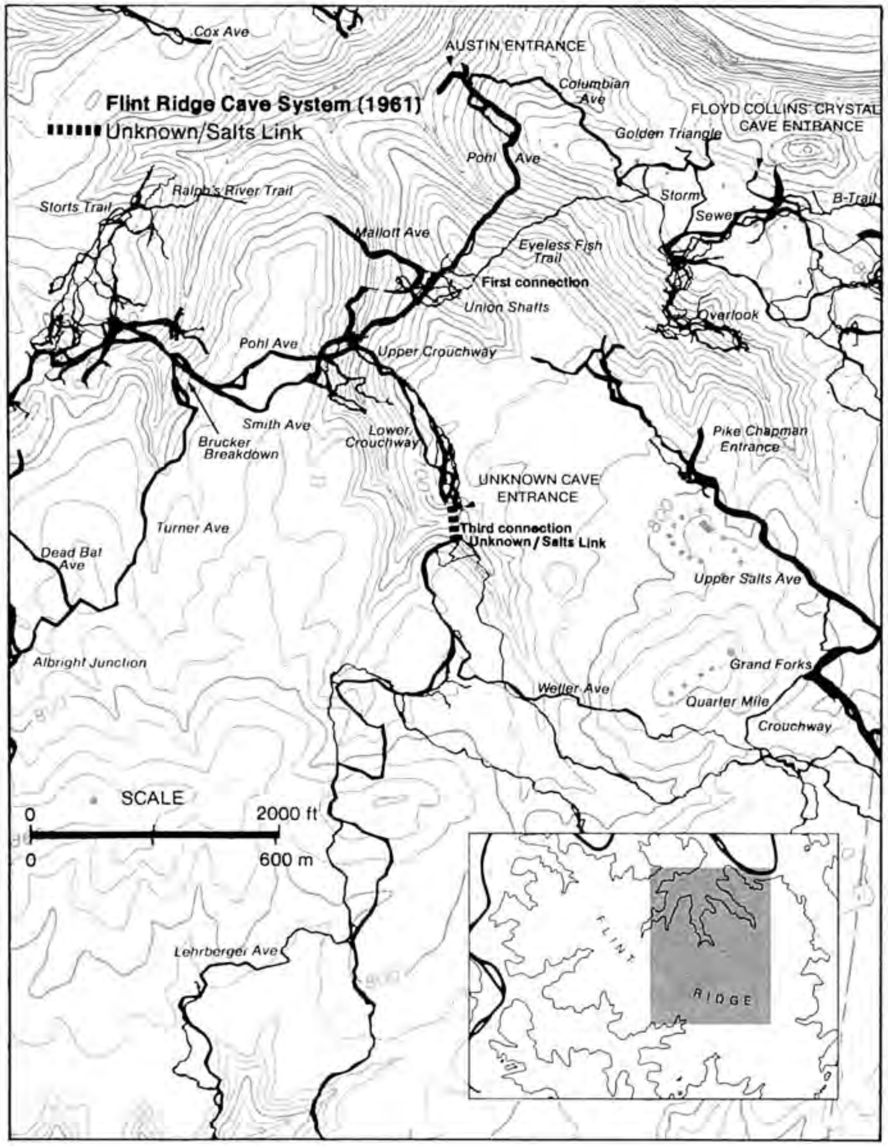

Figure 11. The third major connection in the integration of the Flint-Mammoth System occurred in 1961 when a passage was found connecting Colossal-Salts and Crystal-Unknown caves.

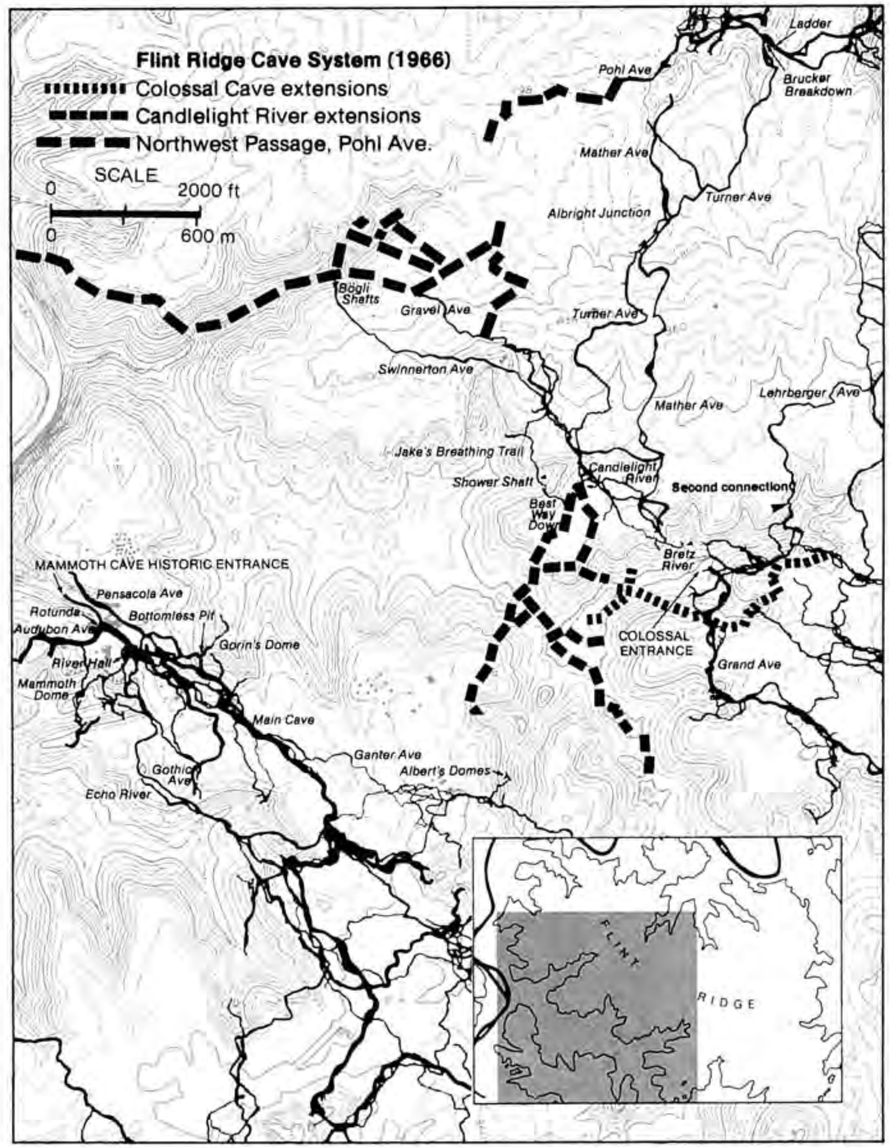

Figure 12. By 1966, major extensions were found leading toward Mammoth Cave from the Flint Ridge Cave system.

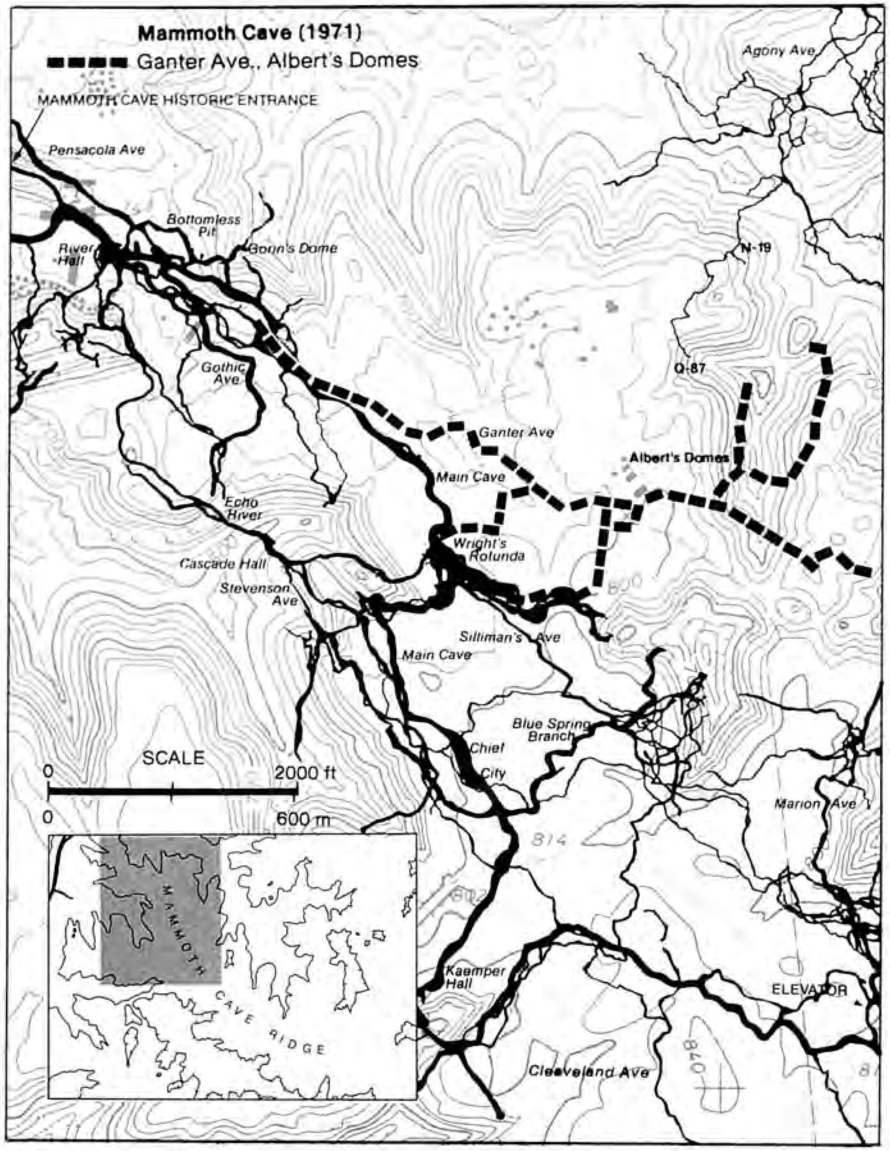

Figure 13. Beginning in 1971, unsuccessful efforts to connect the Flint Ridge Cave System and the Mammoth Cave from Mammoth Cave were made.

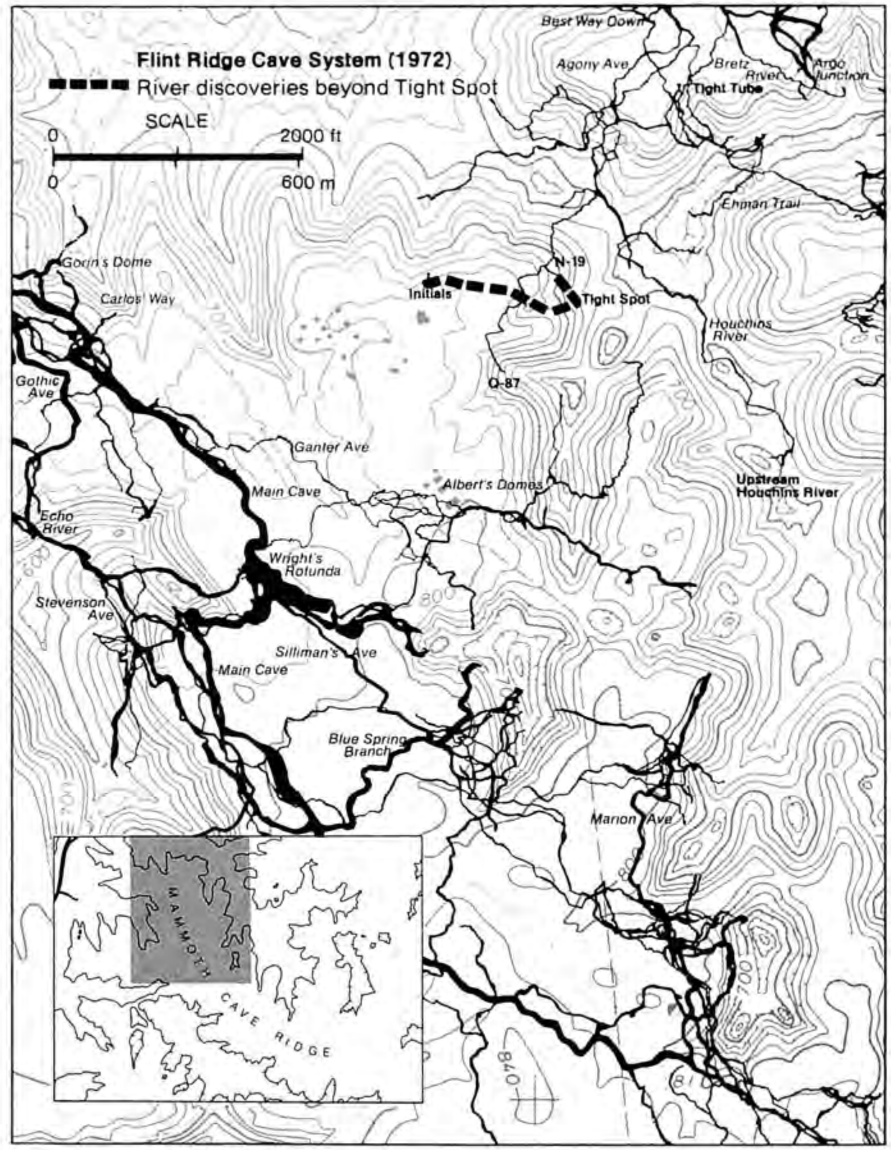

Figure 14. In September, 1972 the long sought connection was made via the Candlelight River-Bretz River Complex from the Flint Ridge side.

Hydrology

Hydraulic Geometry of the Flint Mammoth Cave System

W. B. White and G. H. Deike

Calculations on the hydraulic geometry of the Flint Mammoth Cave System are underway using Rane Curl's new analysis of scallop size-flow velocity relationships. Scallops serve as indicators of paleo-flow. Curl's analysis relates the Sauter mean

$$\overline{L_{32}} = \frac{\sum_i \ell_i^3}{\sum_i \ell_i^2}$$

of the scallop size distribution, the temperature of the water (assumed to be 10°C, a guess since the water disappeared from the upper level passages sometime during the Pleistocene), and the hydraulic radius of the passage to the mean flow velocity. Curl's best estimate of 21,000 for the scallop Reynolds number was assumed. The calculations were performed on an HP-65 calculator using a program written by Curl. It appears that scallop lengths can be transformed into mean flow velocities for the channel if the channel maintains a regular cross-section for a reasonable distance and if it is uniformly scalloped. Velocity can be converted into discharge by multiplying by the cross-sectional area of the channel. It is less clear what discharge the scallops have recorded. Do scallops provide an estimate of the mean discharge, the most probable discharge, or some flood discharge?

A surface basin is drained by a network of streams converging on master trunks in such a way that a distinct catchment area can be assigned to any chosen point on the stream course. There is a distinct relationship between the area of the catchment and the mean discharge past the chosen point on the stream. Catchment

TABLE 2. Discharge Characteristics For Some Flint-Mammoth Trunks.

Passage	Cross-Section (m^2)	Mean Velocity (cm/sec)	Discharge (m^3/sec)	Catchment (km^2)
Austin Ave	2.8	1.67	0.05	2.5
Lehrberger Ave	12.7	2.79	0.36	18.4
Great Onyx	17.7	3.90	0.69	35.0
Grand Ave	20.7	2.55	0.53	27.0
Great Salts	28.8	3.85	1.11	57.0

Mean runoff for Central Kentucky Karst = 19.5 liter/sec/km^2 (Hess and White, 1974)

areas for the cave trunks are difficult to delineate because the cave provides an inadequate sample of the drainage net. However, the calculation can be carried out in reverse, using the paleo-discharge measured from scallops and the mean runoff of the area to calculate the catchment area that drained through the trunk when the trunk was active. Table 2 shows the cross-sections, discharges, and estimated catchments for five trunks in the Flint Mammoth System.

These were chosen because they exhibit good scalloping and, thus, may be expected to give reasonable values for the paleo-discharge. Catchment areas were calculated by assuming that the present mean runoff in the Central Kentucky Karst obtained from the water balance study of Hess and White would be a reasonable estimate for the regional runoff at the times the trunks were formed. The areas of catchment that provided water for the trunks are at least reasonable estimates with the possible exception of Great Salts Avenue. Great Salts is a large canyon and the cross-sectional area of effective flow is not easy to estimate. There is evidence that Great Salts was a regional trunk carrying water from the ancestral Sinkhole Plain to Green River. It's probable catchment would seem more likely to be in the range of 200 to 300 km^2.

Conceptual Models for Carbonate Aquifers

W. B. White

The classification scheme for carbonate aquifers first published in 1969 has been revised to take into account factors of structure and relief not incorporated into the first classification. The basis of analysis of carbonate aquifers by hydrogeologic setting has also been recast in terms of flow dynamics and, in particular, of aquifer response to transient events.

The important distinction between a conduit aquifer and a diffuse flow aquifer is in their response to sudden recharge events such as spring snow melts and summer storms. The response of the conduit is very flashy, as illustrated schematically in Fig. 15. For an ideally sharp storm pulse, there is a lag followed by a very steep rise in the hydrograph. There is a high peak discharge followed by rapid recession which, in the simplest case, can be described by an exponential curve. The diffuse flow system, on the other hand, is much less flashy and decays much more slowly. The response of the conduit aquifer is more like that of a surface stream and operates on a similar time scale.

It appears that with increasing karstification, the underground drainage system, directly linked to the internal runoff, becomes more like surface drainage in spite of the fact that much of the main conduit system in certain classes of aquifers is below the water table or below regional base level. The shallow conduit

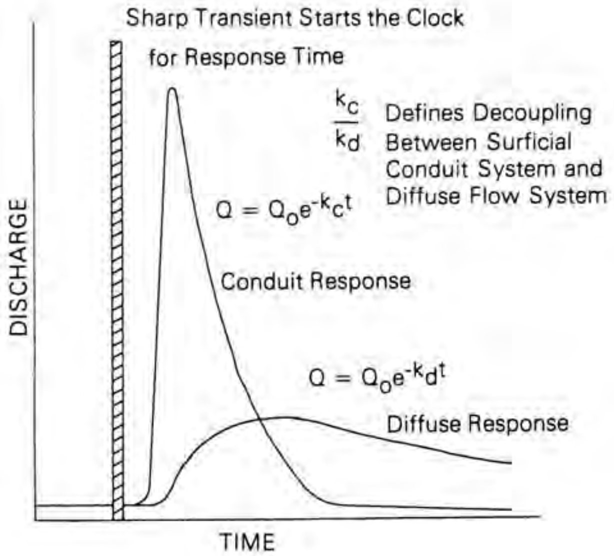

Figure 15

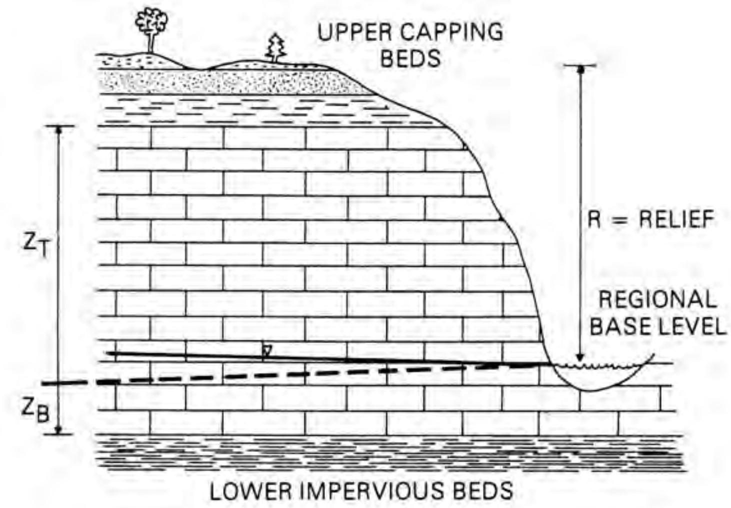

Figure 16

system becomes progressively decoupled from the deeper diffuse flow system. It would seem that the ratio of the decay constants might be a measure of the degree of decoupling between the two flow systems since it is, in effect, a ratio of their characteristic time scales.

As the effective decoupling becomes larger, the shallow conduit system becomes linked more and more tightly to the surface drainage system while the diffuse flow system may retain its regional character. The exchange of water between the conduit and diffuse system becomes as poorly coupled as in the exchange between surface and ground water in a porous medium aquifer.

The main distinguishing characteristics of carbonate aquifers appear to be:

1. Structural complexity of the hydrogeologic setting.
2. Areal extent of the aquifer.
3. Thickness and lithology of carbonate sequences.
4. Degree of development of conduit permeability.

The previous classification was based on the thickness factors and on the degree of conduit development. This can be expressed more qualitatively by defining some thickness terms as shown in Fig. 16, which shows a schematic cross-section of a carbonate mass with an indication of regional base level. The bedrock is shown as flat, although it would not need to be. The regional base level is used as an origin. The vertical distance from regional base level to the highest point in the uplands of the catchment is the relief, R. The distance from regional base level to the top of the limestone unit is Z_T and the distance from regional base level to the base of the limestone unit is Z_B. $Z_T - Z_B$ (since Z_B is measured with respect to base level) is obviously the thickness of the carbonate aquifer. This allows the previous classification of free flow systems to be written in terms of these thickness and relief parameters.

	$Z_B < 0$	$Z_B > 0$
$R > Z_T$	Capped	Perched/Capped
$R < Z_T$	Open	Perched/Open

A sort of mapping of carbonate aquifer types in terms of the scale factors of relief, thickness of carbonate units, and the area extent is shown schematically in Fig. 17. Degree of conduit

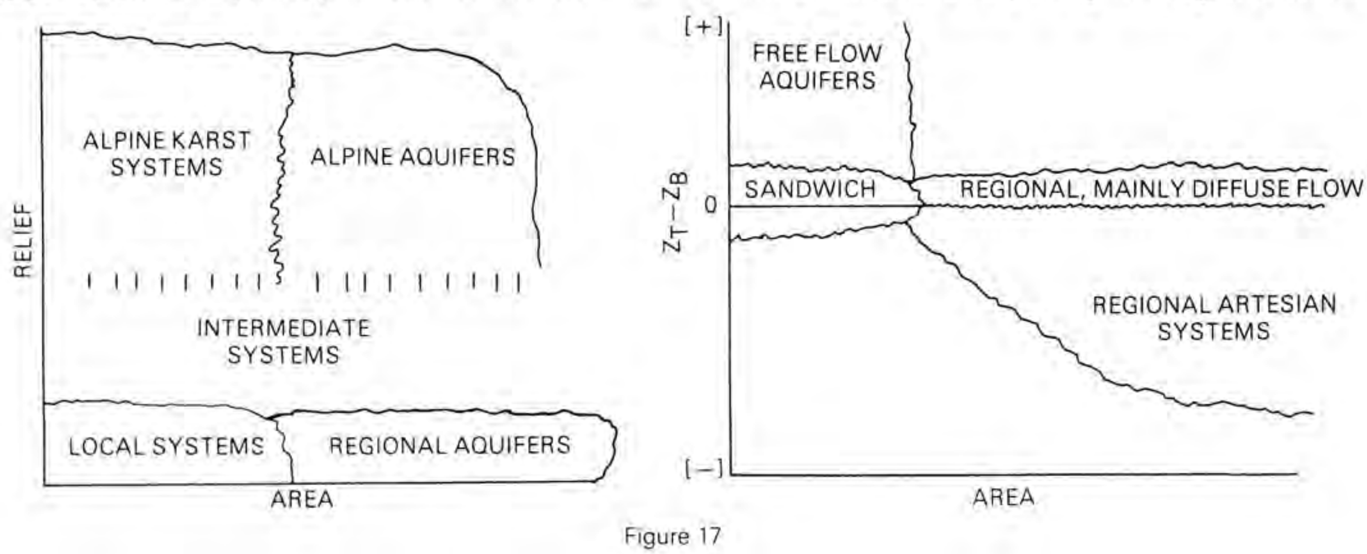

Figure 17

development is not plotted as a variable but appears indirectly. The boundaries between the several kinds of aquifers are not very distinct when the aquifer is exclusively a diffuse flow system; they become progressively more distinct as the conduit permeability becomes dominant.

The classification published in 1969 is seen as a sub-set of the total possible varieties of carbonate aquifers. The concepts expressed here can perhaps best be quantified by either water balance and careful flow measurements in individual examples, or by an examination of recharge-discharge relationships by statistical analysis.

Monograph of the Hydrology of the Central Kentucky Karst

W. B. White and G. H. Deike

The monograph on the Hydrology of the Central Kentucky Karst continues to make progress. Chapters on the influence of hydrogeologic setting and the geomorphic history by A. N. Palmer, on hydrogeology of the Green River drainage by J. W. Hess and W. B. White, on the Barren River drainage by S. G. Wells, and on cave development north of Green River by A. I. George have reached first or second draft stage.

Geology

Karst Landforms in the Wasatch and Uinta Mountains, Utah

W. B. White

A reconnaissance investigation was made of the karst in the Wasatch and Uinta Mountains as part of a study of karst development in the Rocky Mountains. The Wasatch range is a north-south trending fault block mountain. Its western edge is a prominent fault scarp that marks the boundary between the Rocky Mountain and Basin and Range Provinces. The Wasatch have been tectonically active to the present time; the peaks are cragy and relief is very rugged. The Uinta Mountains are an east-west trending anticlinal fold. The peaks are rounded and deeply sculptured by Pleistocene glaciation. In both ranges karst is developed on the thick sequence of limestones and dolomites, mainly of Mississippian age. Most of the carbonate sequence is dolomitic and the sluggish solution rates of the dolomites has inhibited landform development. The carbonate rocks outcrop in irregular patches in the Wasatch because of the intense block faulting. In the Uinta Range, the carbonate rocks crop out in a band along the flanks of the anticlinal fold.

The landforms of both ranges consist of sculptured bedrock pavement, pinnacles, closed depression features, blind valleys, and caves. Pavement karst of the sort often associated with glaciated terrain is common but occurs in small patches. The secondary karren sculpturing is mild, usually limited to solution grooving and a few runnels. Pinnacles range in relief from small features a meter or so in height to towers ten to twenty meters high. Large pinnacles occur in both the Uinta and Wasatch ranges. Doline karst is rare. Closed depression features of irregular shape occur in the Soapstone Basin in the western Uintas. Internal drainage is greatly different in the two ranges. Sinking streams and blind or dry valleys are rare in the Wasatch where catchment areas are small. The central portion of the Uinta Range forms a catchment for large streams that must cross the band of carbonate rocks on their way to Green River. A number of such streams such as Little Brush Creek and Big Brush Creek sink at the carbonate rock contact and have cut deep blind valleys which terminate in large cave entrances. Other streams such as those that drain into Dry Fork Canyon merely disappear in their beds.

Caves in the Wasatch tend to develop along active faults. The resulting cave pattern is an angulate pattern of high, narrow passages sometimes, as in the case of Neff Canyon Cave, developed to considerable depth. Tilted beds of layered sand and silt in Timpanogos Cave provide some evidence of tectonic movement after the cave formed. Uinta Mountain caves are connected with the underground drainage system. Big Brush Creek Cave has formed a type example for a floodwater maze according to A. N. Palmer's classification. The slow rate of solution of the dolomite prohibits development of large cave passages. The runoff from the central Uintas occurs as a single annual peak flow in May and June when the snow melts from the high parts of the range. The caves are not capable of carrying the peak flows and so flood until the hydraulic gradient becomes large enough to drive the water through the small passages. There is evidence of nearly 300 meters of hydrostatic head on the lowest levels of Big Brush Creek Cave during periods of peak runoff.

The underground drainage system in the Uintas is unique. The dip of the anticline along the flanks of the range is greater than the slope of the canyon floors on the surface. Thus, drainage into the caves is carried down the anticlinal fold and there is no place where the carbonate rocks crop out again to permit return of the drainage to the surface. Dye traces carried out in connection with water resource evaluation by the Soil Conservation Service and the Bureau of Reclamation show that the large streams flowing into Little Brush Creek and Big Brush Creek resurge at a single spring more than 600 meters below the cave entrances. The spring is in the Weber Sandstone and apparently the water rises under artesian pressure from the carbonate aquifer below, along fracture traces. An analysis of available gage records shows that transit time from the caves to the spring is on the order of a day or less, comparable to that of large conduit aquifers such as those in south central Kentucky. On the north side of the Uinta Range, there is evidence that Lost Creek drains rapidly to Sheep Creek Spring along a fracture zone in the Mississippian carbonates over a distance of 25 km.

Surface Reconnaissance in Mammoth Cave National Park

William Wilson

Systematic surface reconnaissance in Mammoth Cave National Park and adjacent areas during the last two years by William Wilson, Thomas Gracanin, and many others has begun to reveal the character and distribution of small surface karst features. About 800 acres, mostly along ridge slopes in the area south of the Green River, have been thoroughly searched and described. Karst feature locations are plotted on 1.5 minute quadrangles having a scale of 1":1000' and numbered to correspond to written notes and sketches. Distinct groups of karst features are associated with three specific combinations of hillslope and bedrock.

Background

Hillslopes may be divided into five profile components which are the summit, shoulder, backslope, footslope, and toeslope. The summit includes the broad, relatively level ridge tops. Ordinarily the toeslope is a decreasing gradient that extends from the base of the footslope and ends at a drainageway. However, in the karst landscape of MCNP, broad valleys have no integrated surface drainage, making the toeslope difficult or impossible to recognize. Therefore, it is convenient to recognize the karst valley floors as a geomorphic hillslope component. Three additional geomorphic components, related to entrenched surface streams, are the headslope, sideslope, and noseslope (Fig. 18).

The bedrock units are the Big Clifty Sandstone, Girkin Limestone, and Ste. Genevieve Limestone. The contact between the Big Clifty and the Girkin is a particularly important horizon. Lithologic differences between the Girkin and Ste. Genevieve may exert little control over karst features, but each unit tends to associate with a different hillslope component, especially in the south of the park, making it desirable to distinguish between them.

The three most important combinations of hillslope and bedrock are the 1) shoulder and Big Clifty, usually including the sandstone-limestone contact, 2) backslope and Girkin, and 3) valley floor and Ste. Genevieve, although near the Green River the valley floor may be on the basal Girkin. The broad ridge summits have almost no karst features, and the footslope tends to be a narrow transition zone. The karst features associated with each of the three hillslope-bedrock zones are described below.

The Shoulder-Big Clifty Zone

The shoulder is usually a convexly-rounded slope which abruptly descends from the more level ridge summits. The shoulder breaks over the Big Clifty Sandstone and descends to, or near to, the top of the Girkin Limestone. Along the shoulder are numerous small sinkholes ranging in size from 3 to 20 feet across and from 1 to 10 feet deep. These sinkholes are developed through the Big Clifty Sandstone. Every several hundred feet are small holes between sandstone boulders or in soil, through which some air moves, often with impressive force. About every 500 to 2000 feet is a sandstone-talus cave which consists of an overhung sandstone wall sheltering a low entrance with a sloping talus floor that descends 6 to 20 feet to a boulder-covered or limestone bedrock floor. The caves are 3 to 15 feet high and tend to be a single room increasing in width with depth, sometimes attaining widths of more than 20 feet (Fig. 19). Some talus caves have short, usually impassably small canyons developed in the limestone immediately beneath the sandstone. The canyons usually have prominent vertical fluting developed by descending vadose water. Talus caves are found on nose and sideslopes, but are most common and wettest near headslopes. At low and moderate flow, runoff from the ridge summits sinks at the top of the Girkin Limestone or somewhere along the backslope, and may be seen entering crevices and talus caves. These are apparently the injection points feeding vertical shaft complexes that are known to exist under valley heads. Talus caves appear to form by collapse of the Big Clifty Sandstone after it is undermined by solutional removal of the Girkin Limestone. Undermining of the Big Clifty and subsequent slumping and mass wasting, widens the karst valleys.

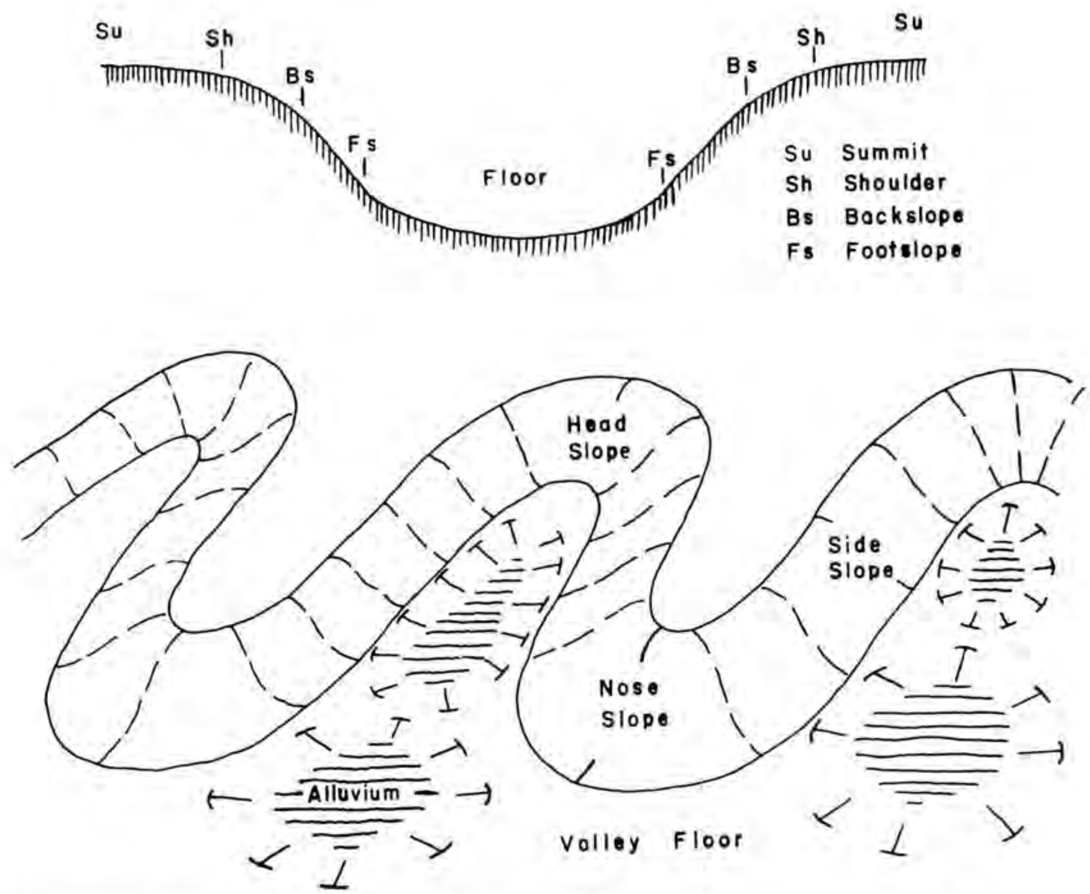

Figure 18. The geomorphic components of a slope along a hill profile and of a slope bounding a karst valley.

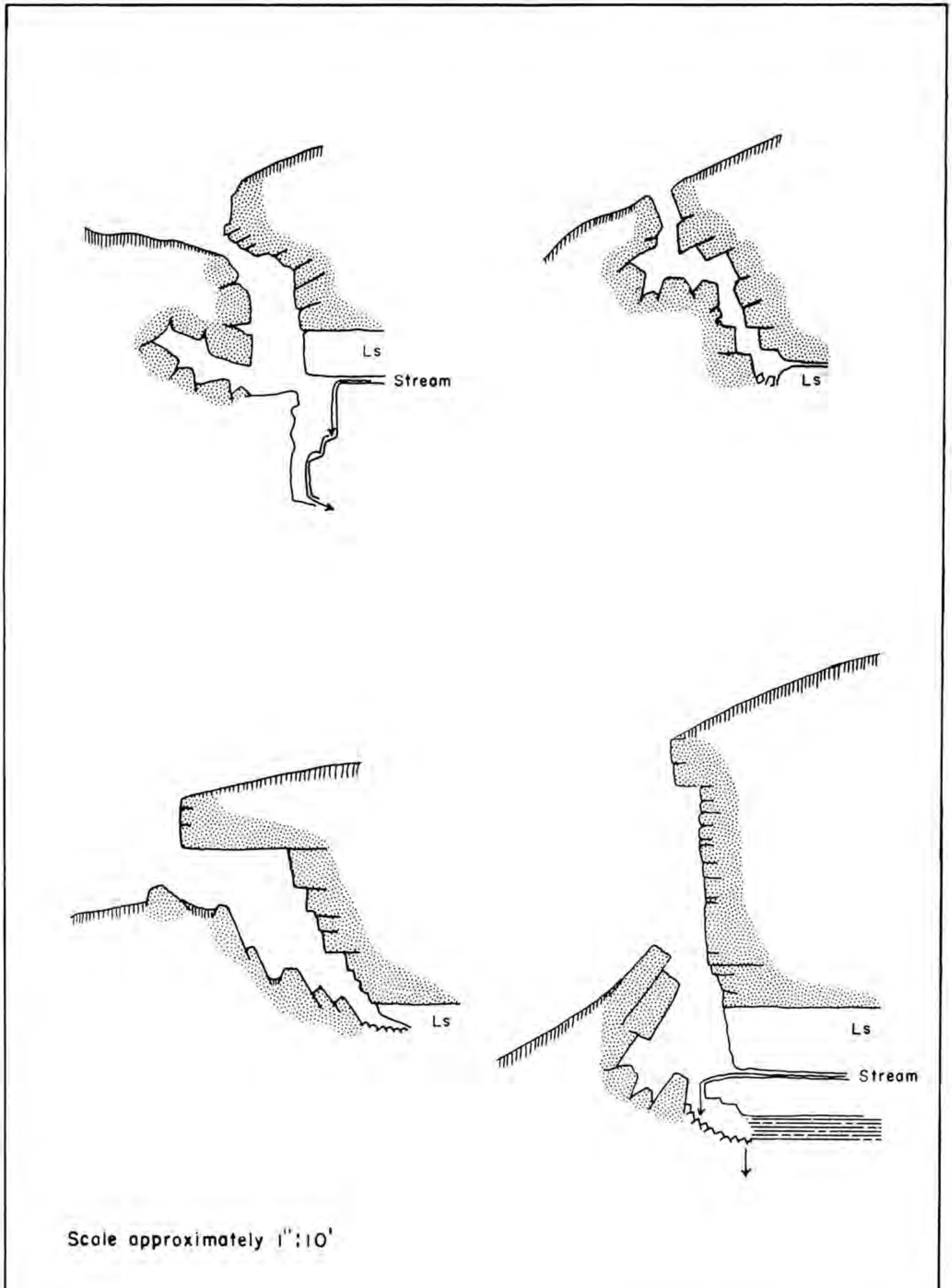

Figure 19. Profiles of typical sandstone talus caves.

The Backslope-Girkin Zone

The backslope descends steeply, at an approximate slope of 15°, from the shoulder to the footslope where the slope becomes much gentler, concave, and grades into the karst valley floor. The backslope is usually almost linear and is developed mostly on the Girkin Limestone. In contrast to the frequency of karst features on the shoulder, the limestone backslope is characterized by a lack of karst features. Sinkholes are very infrequent, small and shallow. Limestone outcrops are rare, although tiers of ledges, each up to several feet high, are sometimes found on noseslopes in association with cedar cover. Karren is usually weakly developed. The most obvious karst features are cave entrances and pits which occur about once every mile. The pits are usually only 10 to 50 feet deep. Both caves and pits appear to have been intersected by surface erosion and can occupy any position along the backslope and footslope. Sandstone boulders, derived from slumping and mass wasting of the Big Clifty, tend to concentrate in steep ephemeral stream channels that cross the backslope, making the channels easy to recognize even though they may not be associated with a large valley entrenched in the ridge side. The uniformity of the backslope and paucity of karst features suggests that the limestone wears down rapidly after the sandstone cap is removed.

The Valley Floor-Ste. Genevieve Zone

The valley floors are developed mostly on the Ste. Genevieve Limestone. Although ephemeral stream channels from the ridges may run onto the valley floor, they carry water only during high flow, and always sink in the first depression that they enter. Integrated surface drainage does not exist. The broad, shallow depressions on the valley floors are alluviated to depths of 5 to 20 feet. Very often an inner, collapse sinkhole, 10 to 30 feet across, and 5 to 15 feet deep is present on the alluviated floor. Sometimes limestone is exposed in the bottom of the sink and very rarely a cave or pit may be present. The caves and pits in valley floor sinkholes have not yet been completely explored, but some caves are at least 200 feet long, and one pit is about 60 feet deep. A stream channel incised in the alluvium and running into the inner sink is sometimes present. The alluvium is homogeneous, dark brown to yellowish-brown, silty loam, as might be derived from the ridge summits and sideslopes. The soil on the divides between valley floor depressions is reddish-brown and clayey. The alluvium may be the product of erosion caused by farming during the period 1820 to 1930. The inner, collapse sinkholes may represent rejuvenation of the valley floors since reforestation began about 40 years ago.

Summary

The descriptions above are necessarily generalizations distilled from the wide variety of physical forms found in the karst landscape of Mammoth Cave National Park. As presented, the groupings serve to reveal some mechanisms and events of karst landscape development in the Mammoth Cave Plateau.

Quantitative Morphology of Landforms in Carbonate Rock Basins

E. L. White and W. B. White

Karst areas of considerable diversity occur in the Appalachian Highlands. Sixty-two such basins were selected from Pennsylvania into northern Alabama and distributed between the flat-lying Mississippian limestone karsts of the Cumberland Plateau and Highland Rim and the folded Ordovician limestone and dolomite karsts of the Valley and Ridge Province. The total basin area was 4200 mi^2 of which 41% was underlain by carbonate rocks.

Both conventional and newly-invented karst parameters were measured from topographic and geologic maps of the 62 basins. Conventional measures included a relief factor, drainage factors, and size and shape factors. Karst measures included carbonate rock fractions, measures of doline development, and measures of internal drainage. A total of 15 parameters were measured which factor analysis in the R-mode reduced to 5 independent factors.

Relationships and internal properties of the measures were investigated by regression methods. Some relationships found are

$$\mathrm{SCE} = 5.8\ \mathrm{LEXT}^{0.72}$$

where SCE is the channel slope of surface streams and LEXT is the length of the main stream channel extended to the watershed divide, and

$$\mathrm{LEXT} = 1.4\ \mathrm{AREA}^{0.6}$$

where AREA is the area of the drainage basin. The surface area that drains internally into dolines is related to the number of dolines by

$$\mathrm{AD} = 0.09\ \mathrm{N}^{0.05}$$

This relationship was interpreted to mean that only minor doline development is necessary to derange the overland flow normally feeding the lowest order tributaries of surface streams. As the karst development intensifies, the number and depth of dolines increase but the area of internal runoff increases only slowly. Comparisons of the number of dolines of a given depth (determined crudely by counting the number of closed depression contours on topographic maps) with the doline depth, reveals a nearly exponential fall-off in the number of dolines with increasing depth. Dolomite basins contain fewer dolines of any given size per unit area than limestone basins, but the surprising result obtained was that the distribution of doline sizes was the same for all rock types and structural settings.

The Origin of Cave Nitrates

Carol A. Hill

The nitrate project is a multidisciplinary research project that deals with many aspects of nitrates in caves, including microbiology, historical archeology, history, geography, chemistry, geology and mineralogy. A primary research objective of this project is to determine the origin of nitrates in cave soils. A comprehensive study of nitrates in bedrock is also being done by the author as part of a Masters thesis in Geology, University of New Mexico. This report will only discuss preliminary and partial findings.

A possible origin of cave nitrates is bat guano. Other possibilities are: (1) that the nitrates are brought into the cave by slowly seeping ground water, or (2) that the nitrates are derived from the limestone itself.

The purpose of the geology experiments is to determine whether either mechanism (1) or (2) could be responsible for the origin of nitrates in caves. To test the limestone for nitrates, 3/8" diameter holes 9" in length were drilled into the limestone in 1" segments. The core samples were later analyzed for nitrates using the phenoldisulfonic acid method (Figure 20). Table 3 lists all the caves in which drill holes were made, the purpose of drilling at these sites, and pertinent remarks regarding each site. Important conclusions concerning the origin of nitrates are summarized below:

1) The amount of nitrate in limestone bedrock seems to be a function of the amount of weathering (rainfall and runoff) to which the limestone has been exposed. In unexposed crevices and recesses, the nitrate values seem to be higher than in exposed areas, probably due to leaching of the very soluble nitrates from exposed limestones. Caves are large recesses that are protected from surface weathering, and therefore they are ideal locations for the accumulation of nitrates. Previously reported nitrate data for limestone (Chalk and Keeney, 1971) are practically useless since precise conditions of exposure to weathering are unknown.
2) Limestone type does not seem to affect the nitrate content of the limestone in any systematic way, e.g. fossiliferous or argillaceous limestone did not seem to vary appreciably from micritic types of limestone in their nitrate content. However, the true nitrate values of the limestone have probably been concealed by later nitrates brought in by seeping groundwater solutions.
3) High limestone bedrock nitrate values within the cave do not mean that a particular limestone member or unit is inherently high in nitrate due to primary depositional conditions. The Joppa limestone of Dixon Cave has nitrate values up to 500 ppm (curve (3) of Fig. 20), yet the same Joppa unit drilled in two locations outside the cave has nitrate values below 1 ppm [see Fig 20, curves (10) and (11]. Therefore, it is concluded that the source of nitrates in Dixon Cave is not necessarily from limestone units high in inherent nitrate content.
4) High nitrate content in limestones does not seem to be related to active bat colonies or bat guano in caves. The very low values (under 1 ppm) of nitrate in the unexposed limestones of New Cave and Carlsbad Caverns, Carlsbad Caverns National Park, show that the limestone does not pick up nitrate from ammonia in the air or from guano deposits in the cave. This has important implications for the origin of nitrates in saltpetre soils in Dixon Cave because it shows that the high nitrates of the Joppa, Karnak and Paoli limestones are probably not the result of bat-originated nitrates moving *into* the limestone from the cave. Instead, the direction of nitrate movement may be from the limestone into the cave.
5) High nitrate values in caves might be related to high amounts of vegetation and organic soils on the surface over the caves. In caves of very sparse vegetation (e.g. New Cave and Carlsbad Caverns) nitrates are very low. In areas of semi-sparse vegetation and fairly low organic-type soils, the nitrate values are higher (e.g. Ellis Cave, curve 7) of Figure 20 and Ft. Stanton Cave, curve (6) of Figure 20). The one exception is Malmquist Fissure. Here the vegetation is very sparse, yet there is a fairly high amount of nitrate present in the cave, both in the limestone and as nitrate ($NaNO_3$) mineral crusts. However, in this case the nitrates could be derived

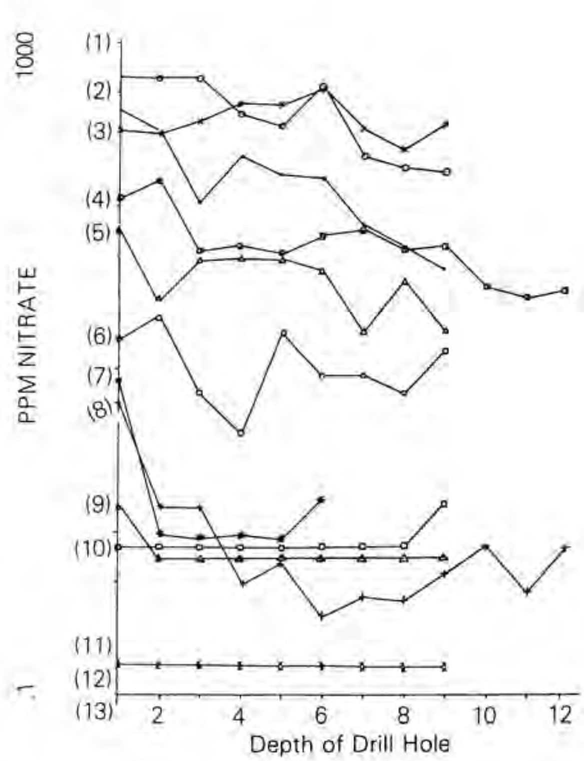

Figure 20
Nitrate Analyses of Limestone Bedrock

(1) Karnak Limestone, Dixon Cave, DS#4
(2) Paoli Limestone, Dixon Cave, DS#6 (not exposed to weather)
(3) Joppa Limestone, Dixon Cave, DS#5
(4) Fredona Limestone, Dixon Cave, DS#3
(5) Kaibab Limestone, Malmquist Fissure, DS#14
(6) San Andres Limestone, Ft. Stanton Cave, DS#13
(7) Madera Limestone, Ellis Cave, DS#12
(8) Paoli Limestone, Dixon Cave, DS#2 (exposed to weather)
(9) Tansill Formation, Carlsbad Caverns, DS#11
(10) Capitan Limestone, New Cave, DS#10
(11) Beaver Bend Limestone, Dixon Cave, DS#7
(12) Joppa Limestone, Surface location, by Dixon Cave, DS#8
(13) Joppa Limestone, Surface location, by Mammoth Cave DS#9

TABLE 3. Drill Sites

Cave	Location	Limestone	Purpose of Drill Sites	Remarks
Dixon Cave	Mammoth Cave Nat'l Park, KY	Fredona, Karnak, Joppa (F), Paoli, Beaver Bend	5 drill sites from top to bottom of entrance sink. Check for vertical change in nitrate content.	Limestone in sinkhole exposed to weathering. Limestone in cave not exposed to weathering. Small modern bat colony in back of cave.
Surface Location down slope from Dixon Cave entrance.	Mammoth Cave Nat'l Park, KY	Joppa (F)	Joppa (F) was drilled outside of cave to see if Joppa Ls is inherently high	Limestone exposed to weathering.
Surface Location down slope from Mammoth Cave	Mammoth Cave Nat'l Park, KY	Joppa (F)	Drilled to see if Joppa (F) changed in nitrate content with lateral location.	Limestone exposed to weathering.
New Cave	Carlsbad Caverns National Park, NM	Capitan Ls (Massive Mbr.)	Drilled to compare nitrates in limestones of cave containing lots of bat guano.	Site not exposed to surface weathering. Lots of old bat guano in cave. Cave was once mined for its bat guano. No modern bat colonies.
Carlsbad Caverns	Carlsbad Caverns National Park, NM	Tansill Ls.	Drilled to compare nitrates in limestones of caves harboring active bat colonies.	Very large, active bat colony. Bat and bird excreta in entrance of cave. Not exposed to surface weathering.
Ellis Cave	Sandia Mountains, NM	Madera Ls.	Cave at high elevation coniferous forest.	Partially exposed to weathering.
Fort Stanton Cave	Capitan, NM	San Andres Ls.	Large passage cave like Dixon with similar entrance but with different climate.	Not exposed to weather. Small modern bat colony. Much human visitation.
Malmquist Fissure	Wupatki Nat'l Monument, AZ	Kaibab Ls.	Cave with known nitrate minerals.	Bat excrement and $NaNO_3$ mineral crusts present.

from volcanic ash that overlies the Kaibab limestone at Malmquist Fissure. The highly organic soils of the southeast may be the reason why saltpetre caves have always been reported from the southeast and not from the northeast or western regions of the United States.

6) Within each drill site the maximum amount of nitrate usually is found in the first one or two inches of the drill hole, or at the limestone surface layer. This may be due to the presence of a *Nitrobacterium* on the rock surface (Hill, Eller, Fliermans and Hauer, 1974). However, the correlation between the microbiological nitrate cycle and the geologic nitrate cycle is not yet known and requires a future detailed study.

7) Nitrates in the saltpetre dirt of Dixon Cave may be derived from seeping ground water (of course guano could also be a contributing source of some nitrates). A gradient is maintained between wet surface conditions and the dry cave so that water very slowly seeps through the limestone pores and into the cave. In the process, dissolved nitrates are transported and deposited both within the limestone and the cave soils. This continual process could thus account for the regeneration of nitrate in leached saltpetre soils.

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Geochronology of Speleothems from the Flint Mammoth Cave System

Russell S. Harmon

Nine $^{230}Th/^{234}U$ ages have been obtained for five speleothems from the Flint Mammoth Cave System of central Kentucky. The analytical data are given in Table 4.

TABLE 4.

Sample #	Description	$^{230}Th/^{234}U$	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	Age (10^3 Years B.P.)
72035:1	flowstone (base)	1.10 ± .04	1.13±.03	5050	>350
72035:2	flowstone (top)	0.897±.03	1.21±.02	24	213±25
72036:5	flowstone (base)	1.05 ± .01	0.99±.01	21	>350
72036:4	flowstone (top)	1.14 ± .08	0.97±.10	75	>350
72037:1	stalagmite (top)	1.05 ± .08	0.99±.05	20	> 350
72041:5	stalagmite (base)	0.886±.01	1.11±.02	44	204±8
72041:9	stalagmite (mid)	0.787±.01	1.12±.02	>1000	159±6
72041:13	stalagmite (top)	0.697±.03	1.17±.03	37	124±5
74009:1	flowstone (top)	0.904±.02	1.05±.03	254	247±26

A flowstone deposit from the wall of the terminal end of Davis Hall (72036) and a stalagmite deposited on a fill in Grand Avenue cut by a canyon passage associated with Colossal Dome (72037) are both greater than 350,000 years old. A flowstone deposit capping a silt deposit in Edwards Avenue of Great Onyx Cave (72035) was deposited from some time before 350,000 years B. P. to 213,000 years B. P. while a second flowstone deposit from Great Onyx which overlies a limestone breccia in a side passage (74009) was found to be 247,000 years old. The final specimen dated was an 18 cm. portion of a stalagmite from Davis Hall (72041), found to have grown at a relatively constant rate over the period 220,000 years B. P. to about 100,000 years B. P. Fluid inclusion D/H and the speleothem calcite $^{16}O/^{18}O$ isotopic variations for this specimen indicate that the cave temperatures during the periods 200,000 to 170,000 and 125,000 to 100,000 years B. P. were similar to that at present, whereas those during the period 165,000 to 130,000 were 6 to 10°C less than that at present.

The age data from the Flint Mammoth Cave System are unique in the consistent antiquity of the speleothem material preserved. Only in one other area of the ten North American karst regions studied to date, the Nahanni region, N.W.T., is speleothem material older than 200,000 years B. P. the common occurrence rather than the exception. The fact that such old speleothem material is common in the Flint Mammoth Cave System support geomorphological evidence that the active sections of the cave are quite old, perhaps pre-Pleistocene in age.

Stability Relationships for Cave Nitrate Minerals

P. Gary Eller

In Mammoth Cave, many thousands of pounds of saltpetre were produced from cave sediments in the early 1800's, and recent investigations have shown that nitrate levels can be as high as several percent in parts of the cave. It is interesting, then, that modern mineralogical investigations have failed to show the existence of crystalline nitrate minerals in Mammoth Cave and other Southeastern U. S. caves (Hill, 1976). In contrast, earlier articles in this report by Carol A. Hill describe recently discovered nitrate minerals in caves of the American Southwest, where saltpetre production never was carried out on any sizeable scale. These observations are explicable from consideration of stability relationships for nitrate minerals. The significance of the numbers presented in Table 5 is that the respective mineral will spontaneously deliquesce when atmospheric humidity exceeds the given value. These values are for pure phases at 25°C, and the exact numbers will change with deviations from these conditions. However, the trends are clear. In humid caves (as in the Southeast) it is highly unlikely that any of these nitrates except saltpetre (KNO_3) will be found. Since potassium is a relatively uncommon ion in the environment of these caves, even the occurrence of saltpetre is unlikely. However, in Southwest caves, where cave humidities are often lower than 75%, nitrate minerals (especially $NaNO_3$) should be observable. These conclusions are in accord with recent observations.

The relating of relative humidity to cave mineral stability, of course, is hardly a novel concept, but a tabulation of values for nitrate minerals apparently has not been published previously.

TABLE 5. Relative Humidity over Common Nitrates in Equilibrium with their Saturated Solutions at 25° C.*

Nitrate Mineral	Relative Humidity (%)
Soda Nitre ($NaNO_3$)	75
Saltpetre (KNO_3)	95
Nitamite (NH_4NO_3)	63
Nitrocalcite ($Ca(NO_3)_2 \bullet 4H_2O$)	54
Nitromagnesite ($Mg(NO_3)_2 \bullet 6H_2O$)	54

* All these nitrates have been reported as occurring in caves. Values could not be found for the other known cave nitrate mineral, darapskite, $Na_3(NO_3)(SO_4) \bullet H_2O$ (Hill, 1976). Values are taken from a variety of published sources.

References

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Mineralogy of Cave Nitrates

Carol A. Hill

Another important objective of the comprehensive saltpetre research project, mentioned in the Geology section of this report, is the location and description of nitrate minerals in caverns having differing temperatures and humidities. The study of nitrate minerals is an almost untouched branch of cave mineralogy.

Nitrate minerals are extremely soluble salts and are very susceptible to changing humidity conditions. Early saltpetre miners reported the mineral nitrocalcite ($Ca(NO_3)_2 \bullet 4H_2O$) from the soils of Mammoth Cave but these early reports have never been verified. Recent investigations by the saltpetre research team have shown no evidence for crystalline nitrate minerals in the soils of Dixon Cave or Mammoth Cave. Most x-rayed crystalline materials in these soils have proven to be gypsum. The nonexistence of crystalline nitrocalcite in these Mammoth Cave National Park caves, despite the widespread occurrence of nitrate ions, is due to the high relative humidity. In these high relative humidities, nitrocalcite and other nitrate minerals deliquesce and disperse into the soils. Chemical analyses show up to 4% dissolved nitrate in the saltpetre soils of Dixon Cave.

However, crystalline nitrate minerals have recently been found in low humidity Southwestern caves. Darapskite ($Na_3(NO_3)(SO_4) \bullet H_2O$) has been found as a cave flower in Big Bend National Park. The darapskite occurs in parallel layers that alternate with halite (NaCl). Soda niter ($NaNO_3$) has also recently been found as white crystalline wall crusts in the earth crack caves of Wupatki National Monument. The low relative humidity of these caves allows the nitrates to deposit and remain as crystalline minerals. More complete descriptions of the darapskite cave flower from Big Bend (Hill and Ewing) and the soda niter crusts of Wupatki National Monument (Eller and Hill) are in progress.

Very little work has ever been done on the amount of trace nitrates in sulfate and carbonate speleothems. A slightly recessed gypsum crustal seam in Dixon Cave was tested for nitrate and was found to have a very high value of over 2300 ppm. This gypsum was collected at the entrance of Dixon Cave near site DS#5 in the Joppa (F) limestone. This high nitrate value may be another indication that the source of nitrates in Dixon Cave is seeping ground water.

Two samples of gypsum crust were also collected in Mammoth Cave. The first sample, collected near the TB huts, had a black coating on its outer surface. Black coatings on gypsum crust are very common in the main passage of Mammoth Cave and these coatings have alternatively been described as being manganese, humic acid and carbon soot. X-ray analysis of this sample, however, revealed it to be carbon. This same gypsum crust sample had a nitrate concentration of 39 ppm.

Mineralogy of Wind Cave, Eddy County, NM

Carol A. Hill

Wind Cave is located near Carlsbad, New Mexico on Bureau of Land Management land and has been the site of recent exploration by Joint Venturers of the CRF. Geology of this cave has been described briefly by A. and M. Palmer in the 1975 CRF Annual Report. The predominant speleothems in Wind Cave are popcorn coralloids. Popcorn occurs on cave ceilings, floors and walls and varies from typical round nodules to "flower" or "button" popcorn to monocrystalline popcorn. The monocrystalline variety of popcorn occurs as small (1 cm or less) rhombohedrons of calcite. The monocrystalline rhombohedrons exist on the walls and ceilings of the caves interspersed between larger nodular popcorn. Like the monocrystalline rhombs of Musk Ox Cave, the rhombs probably form the nucleus for much of the later nodular popcorn growth. The "flower" or "button" shaped popcorn is a morphological variation of nodular popcorn and is common in many caves of the Guadalupe Mountains. This special variety is believed to form in several stages: 1) initial formation as typical round nodular popcorn (see Fig. 21a);

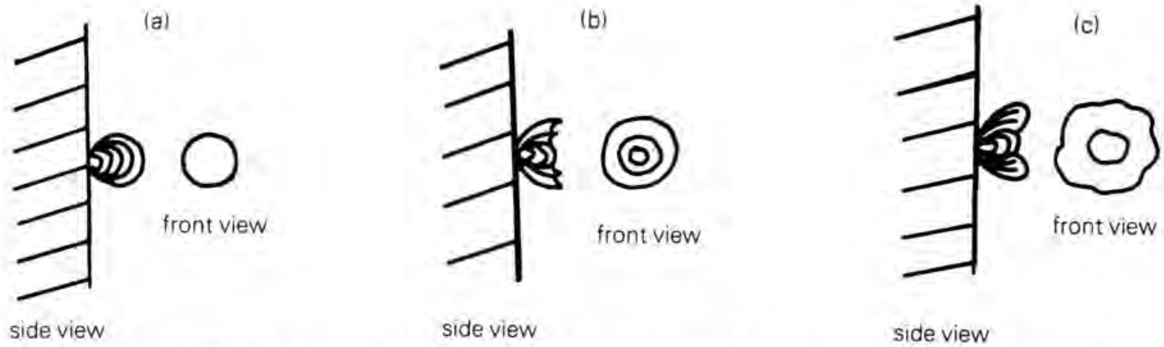

Figure 21. Possible growth stages of "flower" or "button" popcorn. (a) typical nodular popcorn growth; (b) weathering and separation of popcorn layers; (c) regrowth and resultant "flower" or "button" shape.

2) weathering of popcorn with resultant separation of the individual popcorn layers (Fig. 21b) regrowth from new solutions that have deposited over the separated layers (Fig. 21c). The result of these growth stages is a "flower" or "button" shaped popcorn coralloid.

Other less frequently occurring speleothems in Wind Cave are: stalactites, stalagmites, draperies, calcite rafts, boxwork, flowstone and antler-type helictites. The TD survey, at the bottom of the 5th level, is the best decorated area of the cave. Large growths of popcorn line the entire passage. Pyrolusite (MnO_2) was noted as a dendritic deposit along one flowstone-popcorn ledge in this passage. Huntite flowstone ($Mg_3Ca(CO_3)_4$) is a rare speleothem type which has been reported formerly from only one cave, Carlsbad Caverns (Hill, 1972). Overlying the huntite flowstone are small (15 cm) blobs of moonmilk which were analyzed as dolomite, $CaMg(CO_3)_2$. Dolomite is only rarely found in caves because its solubility product is much lower than the solubility product of calcite. Dolomite has been reported by Hill (1973) in association with the above mentioned huntite flowstone in Carlsbad Caverns and also by Moore (1961) associated with huntite moonmilk in Titus Canyon Cave.

Gypsum crust covers calcite popcorn and wall linings in the upper levels of Wind Cave. The gypsum crust occurs as tabular gypsum and individual tabs are 2-5 mm in length. Also, subhedral gypsum needles (approximately 2 cm long) were found growing within (and not on top of) muddy cave floor soils.

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Mineralogy of Musk Ox Cave, Carlsbad Caverns National Park

Carol A. Hill

Musk Ox Cave, Carlsbad Caverns National Park, has received considerable interest since the discovery of a bush ox skeleton in a rimstone pool area of the cave by a CRF exploration team. The bush ox bones were coated with a thin layer of calcite flowstone, but evidently were not calcified to a great extent.

Musk Ox Cave is essentially a narrow fissure passage developed along a few intersecting joints. The passages are choked with massive carbonate dripstone and flowstone deposits. Travel through the cave is actually impeded by these massive speleothems and one must climb, rappel, and squeeze through passages blocked by the secondary calcium carbonate.

The mineralogy of Musk Ox Cave is relatively simple and no mineral types other than calcium carbonate have yet been found. However, Musk Ox Cave has many types of calcite speleothems: stalactites, stalagmites, draperies, flowstone, rimstone shelves, rimstone dams, shields, bell canopies, and helictites. In the upper levels of the cave the speleothems are "dead," dusty and dry. Many large stalactites and columns have broken and fallen to the floor. Also, a good number of speleothems, such as draperies and flowstone, have experienced resolution and etching. However, the lower levels of Musk Ox contain many "living" speleothems.

Monocrystalline popcorn is composed of small (1 cm) rhombohedrons of calcite which form between larger nodular popcorn on the walls of the upper levels of the cave.

The only unusual speleothems of Musk Ox Cave are filamental helictites and monocrystalline popcorn. Filamental helictites resemble small seaweed bushes with thin radiating branches. Cross-sections of the nodular popcorn reveal that the popcorn began its growth as monocrystalline rhombohedrons; later growth surrounded these rhombs and the popcorn became increasingly rounder with each additional growth layer until nodular popcorn was produced.

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Ecology

Terrestrial Ecology: The Relation Between Species Biology and Community Complexity

Thomas L. Poulson

This year I have concentrated on laboratory studies, comparing species rates of survival, growth, and reproduction to see whether such aspects of species biology are related to the complexity of the communities where the species occur in nature. Generally we find that a few time efficient, fast reproducing species (r+ species of last year's report) dominate on foods with high payoff and high risk, whereas there are no dominants on low payoff and low risk foods where many resource efficient, slow reproducing species (r- species) occur. Thus, a complex community has a high species diversity (H) and low dominance = high evenness (J). These patterns are summarized below (Fig. 22-23).

The chart on p. 37 of the 1975 CRF Annual Report, summarized by the diagram shown here, showed that payoff and risk are closely related. The leaf and manure experiments on that diagram are analogues of litter and rat feces, respectively, but they were done in areas of no microclimatic or flooding risk and, thus, serve to separate the compounding effects of payoff and risk. These experiments (see p. 38 of the 1975 CRF Annual Report) and Kane's geographic comparisons (elsewhere in this report and p. 41 of the 1975 CRF Annual Report) utilize baiting with liver-cheese (very high payoff analogue of carrion), horse manure (high payoff analogue of cave rat feces), and leaves (low payoff analogue of leaf litter). The results clearly show that high payoff foods result in simple communities with few species (low H) which dominate (low J). This is not to say that risk cannot further reduce species diversity and evenness; the diagram above right shows the modulating effects of risk and of heterotrophic succession. During succession, the food payoff decreases and community complexity increases.

Table 6 outlines different aspects of food payoff (= caloric availability) from the point of view of the organism searching for, consuming, and digesting the food. The foods listed are the bases for different communities in central Kentucky caves. Data on leached organic litter, generally found in vertical shaft stream areas, are not available as yet.

We hypothesize that caloric availability is the basis for species specialization to food type which is seen in the field as distinct component communities (= subcommunities of the 1975 CRF Annual Report). The kinds of evidence for this are as follows:

I. Evidence for Component Communities Based on Kind of Heterotrophic Input.
   A. Guild Structure
   B. Unique Species
   C. Dominance-Diversity Relationships
   D. A-C Maintained in:
      1. compound communities (= entrance areas with multiple food types)
      2. manipulations in areas where food input does not occur.

II. Basis for Component Community.
   A. Constraints of Risk and Caloric Availability Determine:
      1. guild structure
      2. kinds of species in the guild
   B. Species Biology
      1. life history patterns
      2. foraging patterns
      3. bioenergetics

Figure 22

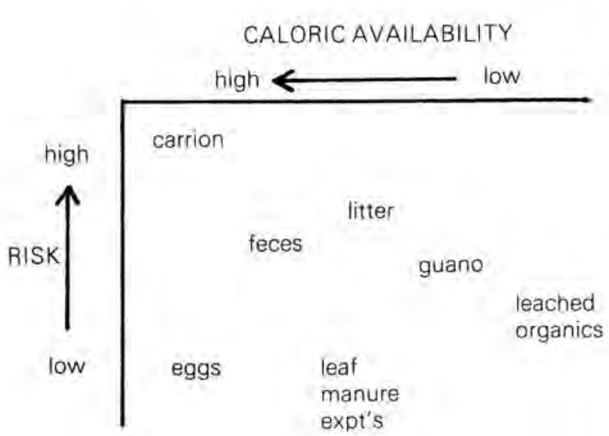


Figure 23

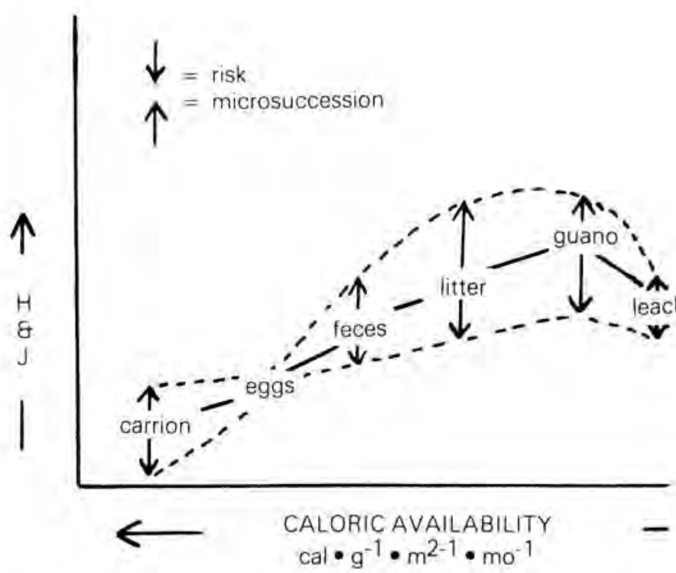


TABLE 6. Aspects of caloric availability of allochthonous foods in caves. Ranked high to low.

Characteristic	Cricket Eggs	Rat Feces	Twig-leaf Litter	Cricket Guano	Clay-silt
Resource Concentration					
mg/unit	5	450	500-2500	0.1	N. A.
g/m^2	0.6	50000	1500	2200	5500
patch size m^2	50-5000	0.1-2.0	3-10	1-20	100-10000
Resource Renewal					
g/m^2/month					
neab	0.07	450	50	10	5
Pulse (max/min)	30	2	6	2	10
Resource Quality					
kcal/g wet wt.	3.50	1.28	0.35	0.51	0.15
% water	50	69	85	85	10
% fat	29	1.2	0.8	0.4	0
% low digestibility*	2	10	13	15	90
Resource Heterogeneity#	+	+ + + +	+ + +	+ +	+
Overall Availability	+	+ + + + + +	+ + +	+ +	±

* includes cellulose, lignin, humates, silt, ash, etc.

\# related to the degree of heterotrophic succession.

The dominance and diversity relationships are very different if one lumps all of the component communities as in the overall curve of the following graph instead of separating component communities as done in the next graph. The separate lines for different guilds (= groups of species using a common resource base in a similar way) are all of similar shape but the steepness of the lines and distance between species is greatest for the rat feces reflecting the high degree of dominance in that component community.

The laboratory studies this year are based on the hypothesis that food payoff and risk are selective pressures which constrain the life history, foraging, and energetics of species specializing on the food resource. Simply stated, high payoff and risk selects for time efficient, fast reproducing species which get to the food quickly, reproduce, and emigrate to a new patch of food as the old patch disappears or microclimate and/or flooding make it too risky to stay. Conversely, low payoff and low risk foods are not easy to digest and so life cycles are long. This is not a problem with low risk but it does require efficient use of the resource; hence resource efficient, slow reproducing species are favored. The greater number of species on low payoff foods is thought to be related to both specialization and inability to monopolize low payoff foods by getting there first and using them up. Time efficient species are present on low payoff foods but they do not do well; conversely, resource efficient species are not present on high payoff foods. These observations and hypotheses are the basis for comparing survival, growth, and reproduction of pairs of time and resource efficient species on high and low payoff foods in the laboratory.

The most interesting aspect of the lab experiments is that time efficient species do well on high payoff food and poorly on low, with the converse for resource efficient species even when there are no competitive interations allowed. Since these results are consonant with field baiting experiments, we must conclude that if competition was ever important, it was in the evolutionary past. An example for the macro-detritovore guild follows: *Plusiocampa cookei* is a dipluran found mainly in silt or sand areas where it apparently relies either directly or indirectly, via fungi, on dry cave beetle feces which have low payoff. Another resource efficient species studied is the millipede *Scoterpes copei* which is found mainly on leached litter or leached cricket guano. These have been contrasted with a time efficient species, the leiodid

TABLE 7

Numerical response (immigration + reproduction) to baits of different payoff values

low ------------ high payoff

Species	control (clay-silt)	leaf unrenewed	leaf renewed	manure unrenewed	manure renewed
Ptomaphagus					
1 month	13	171	121	2296	726
6 months	0	5	43	5	94
18 months	0	1	--*	8	--
Plusiocampa					
1 month	3	1	0	0	0
6 months	8	23	13	24	9
18 months	3	0	--	0	--
Scoterpes					
1 month	0	0	0	3	0
6 months	0	15	2	25	5
18 months	4	15	--	25	--

Baits were not renewed after 6 months so the only baits at 18 months are unrenewed.

scavenger beetle *Ptomaphagus hirtus*, which has its center of distribution on fresh cricket guano but also occurs on higher payoff foods like rat feces and carrion.

The laboratory results suggest that the main response of the resource effluent species in the field was immigration since no reproduction has been observed in the lab and there were very few of the smallest size changes in the field: it is clear from both lab and field data that the time efficient species response is mainly reproduction.

Comparative studies of a pair of time efficient (*Phanetta*) and resource efficient (*Anthrobia*) spiders are continuing with studies of egg production as a function of food supply. Suffice to say that the results are analogous to those for the macrodetritovores. *Phanetta* has an egg case output ranging from 0 with three collembola per spider per week to 2.0 at 30 Collembola per week over a two month period. *Anthrobia* has the same low egg case output of 0.3-0.4 at both high and low food levels. Related data are being collected on minimum maintenance requirements and survivorship.

TABLE 8

	Experimental Conditions	Ptomaphagus % survival	Ptomaphagus mature larvae/	Plusiocampa % survival	Plusiocampa % initial body lgth	Scoterpres % survival	Scoterpres % initial body lgth
	1 month	98	2.1	96	4.6	85	0.0
FRESH	2 months	93	5.2	92	7.6	67	1.1
MANURE	4 months	92	12.3	86	13.6	60	8.0
	1 month	60	0.1	100	18.5	80	8.3
OLD	2 months	50	0.2	92	20.5	77	11.0
MANURE	4 months	0	0.5	65	21.5	65	13.1

A Genetic Analysis of Epigean and Hypogean Populations of *Gammarus* and *Crangonxy* (Amphipoda:Gammaridae)

David L. Bechler

In a recently completed M.S. thesis, Hetrick (1975), Old Dominion University was able to stain for seven enzymes in *Gammarus minus*. I have been able to reproduce his results for five of the seven enzymes with partial success for a sixth one. In addition, I have successfully stained for three additional enzymes heretofore not isolated from amphipods. In an unpublished volume of *Physiology of Fishes*, Academic Press (in press), it was noted that work involving comparisons of heterozygosity should be based on a minimum of twenty loci if the work is to be considered truly representative. I have, therefore, set a goal of twenty enzymes as a minimum. This will give me more than twenty loci, since some enzymes will be coded for by more than one loci.

During the latter part of August, 1976, I visited with Dr. John Holsinger. He provided me with valuable information concerning the ecology and taxonomy of the Gammaridae with which I will be working. In addition, I learned from him several hundred localities for the species I'll be studying.

At Dr. Holsinger's suggestion I have added *Crangonyx packardii* to the list of species with which I'll be working. He pointed out that one species I believed to be strictly hypogean has been found in some epigean localities. Therefore, the addition of the strictly hypogean *C. packardii* will replace one species.

Using the localities furnished by Dr. Holsinger I have plotted the known range of all eight species in my study. I have chosen five collecting sites situated to divide up a distribution into marginal and central areas.

In order to better define the niche, I decided to take data describing a niche from within and beyond the periphery of an amphipod's distribution. This may allow the possible identification of any limiting factors not readily apparent from data acquired only from within a species distribution.

Bacteriological Examination of Moon Milk and Iron Pools in Left Hand Tunnel of Carlsbad Caverns

Douglas Caldwell

Samples of moon milk and loose iron deposits from several pools were collected in Left Hand Tunnel for examination of microbial flora. Direct observation by phase microscopy indicated the absence of active microbial flora in the moon milk but revealed the presence of filamentous iron depositing bacteria in the loose iron deposits. These samples are being prepared for examination by transmission electron microscopy.

Small Mammalian Fauna as Environmental Indicators: A Case Study in Northwestern Wyoming

Stephen A. Chomko

Hole in the Wall Shelter, an inactive solution cavern in Mississippian age Madison limestone, is located in Big Horn County, northwestern Wyoming. The shelter is in the juniper breaks life zone (approximately 600 feet above Porcupine Creek) with a remnant conifer slopes floral community immediately to the east. A chimney in the roof of the outer chamber had been used as a roost for a large raptorial bird resulting in the deposition of a cone-shaped deposit of guano approximately 90 cm high with a basal diameter of 100 cm (Fig. 24). The guano provides a unique opportunity to test the degree of correlation of environmental records based on floral and faunal data.

Figure 24.

Finally, the guano documents the dietary habits, predator-prey relations, and exploitive patterns of a raptor through time. The feathers in the guano should permit identification of the species responsible for the deposit. The exploitive pattern of the bird has important implications for the environmental reconstruction; should the raptor have a preferred prey, that species will be consistently represented in the guano irrespective of environmental conditions in the vicinity of the roost. However, it is hypothesized that species more abundant in the vicinity of the roost will be more heavily represented in the guano than species available at a greater distance from the site (in other ecological zones).

Personnel involved in the project are: B. Miles Gilbert, University of Missouri- Columbia, will identify the insect fragments; James E. King, Illinois State Museum, Springfield, will do the pollen analysis; J. D. Stewart, University of Kansas, Lawrence will identify the plant remains; and the author will identify the faunal remains.

One column of guano has been analyzed for the plant, insect and bone content. Preliminary results (based on a small sample size) indicate no appreciable environmental change has taken place during or since deposition of the guano. Plant remains include prickly pear cactus (*Opuntia polyacantha*), mountain juniper (*Juniperus scopulorum*), fir (*Pseudotsuga menziesii*), mountain mahoganey (*Cercocarpus intricatus*), *Prunus* sp., and unidentified herb seeds. Only two insects occur in significant quantity; grasshopper (cf. *Melanoplus texanum*) and a beetle somewhat larger than a *Cerambicid* and as yet unidentified. Additional insect fragments probably not representative of food remains include dermestid larvae and fly pupae. The fauna includes fish, amphibians, birds and small mammals with more specific identifications offered as: sage grouse (*Centrocercus urophasianus*), woodpecker (*Melanerpes* cf. *formicivorus*), rabbit (*Sylvilagus* sp.), a mustelid (*Mustela* sp), and rodents which compare favorably with *Neotoma, Geomys, Zapus, Peromyscus*, and a possible *Microtus* (species identifications have not yet been completed). Although the fir and microtine rodent are generally associated with conifer slopes vegetation it is not possible, at this point, to determine if they represent a vegetational change or are related to the remnant community presently in the vicinity of the site.

In 1975, B. Miles Gilbert located the shelter as part of a survey to find faunal and floral sequences to complement the faunal record from Natural Trap Cave. A preliminary analysis of the guano indicated the presence of animal bones and plant macrofossils. In the summer of 1976 the deposit was sectioned into vertical columns (20 x 40 cm) which were subdivided into horizontal levels (15 cm thick) to form the units of analysis. A series of pollen samples were collected from the center of the cone and radiocarbon samples were taken from near the top and bottom of the deposit. One vertical column has been processed in the dry state by gently separating the material to recover animal bones, insect fragments, plant remains, and feathers.

There are three interrelated research objectives for the project. First, environmental conditions will be reconstructed using the pollen, faunal and floral material as data sets. Dates on the radiocarbon samples will provide the chronological control. Archeological material in the shelter indicates it was occupied in the late prehistoric period suggesting the guano (which probably represents a relatively short time span) is no older than 600 years.

Second, each data set will be independently analyzed and will result in three separate records of environmental conditions while the plant macrofossils will represent a more localized pattern. The record from the faunal remains, particularly the small mammals, will then be compared to those of the floral materials to determine their degree of correlation and, in effect, the ability of mammalian faunal remains to reflect environmental parameters. Such a correlation will have important implications for sites in which pollen and plant remains are not preserved, necessitating the use of animal bone for statements on environmental reconstruction.

Arthropod Fauna of the Guano in the Bat Cave Section of Carlsbad Caverns

W. Calvin Welbourn

From November 1974 to February 1976 samples of guano were taken from six sites in Bat Cave at approximately one month intervals. Each sample was placed in a berlese funnel to separate the arthropods. Five of the sites were in guano from the Mexican Freetail Bat (*Tadarida braseiliensis*) and one was in Cave Swallow guano (*Petrochalidon fulva*).

Work this year centered on the separation and identification of previously collected specimens. The following additional arthropods have been identified:

Mites
- Family Rosensteiniidae
  - *Nycteriglyphus sp.*
- Family Cheyletidae
- Family Tydeidae

Pseudoscorpionida
- Family Chernetidae
  - *Dinocheirus astutus*

Collembola
- Family Onychiuridae
  - *Seira reinhardi*
  - *Seira bipunctata*
- Family Entomobryidae
  - *Drepanura sp.*

As work progresses on the identification of mites, work will start on the many insect larva which were found in some samples. Samples of guano will be collected periodically during the next year. Future work will concentrate on identification and correlation of arthropods with the amount of guano deposited. The guano from several other caves will also be examined.

Survey of the Cave Fauna of the Guadalupe Escarpment Region

W. Calvin Welbourn

Eighteen caves were examined in the Guadalupe region during 1976. Nine of these caves were not previously examined. The work this year brings the number of caves examined for cave fauna in this area to 55. Of these, 21 were in Carlsbad Caverns National Park, 5 in Guadalupe Mountains National Park, 15 in the Guadalupe District, Lincoln National Forest and 14 on other lands. Work this year centered on continued identification of existing specimens, especially coleoptera, diptera, and mites. More than 80 species have been identified from limestone caves in the Guadalupe Mountains. The cave fauna is dominated by troglophiles (62%) and trogloxenes (20%), troglobites (9%) and accidentals making up the remainder of the animals.

To the east of Guadalupe Mountains there is an extensive area of gypsum karst which has not been examined extensively. Two caves in the gypsum karst were examined this year, resulting in the discovery of a new amphipod.

Next year, work will concentrate on the gypsum karst and preparation of a final manuscript on the distribution, habitat, and possible origin of the cave fauna in the Guadalupe Mountains area.

Resource Partitioning by Carabid Cave Beetles in the Mammoth Cave Region

Thomas C. Kane and Terry Van Zant

This work has centered on the patterns of coexistence observed in the carabid species *Neaphaenops tellkampfii* and three species of the genus *Pseudanophthalmus* which co-occur in many caves of the central Kentucky Karst (see CRF Annual Reports, 1972-75, for previous work). Our most recent data indicate that there are adaptations in these species to local cave conditions. Specifically, *P. menetriesii* and *P. pubescens* show character divergence in body size when they occur in equal abundance in a cave of low rigor. This may afford them niche separation along the lines of food size selection. Presently this is being tested in the laboratory.

Kane is also conducting electrophoresis on these species to correlate the genetic and evolutionary patterns with the ecology. Preliminary surveys of six populations of *N. tellkampfii* indicate levels of genetic variability approaching those of surface invertebrates (i.e. H 0.15). This is much higher than data for other Central Kentucky troglobites (i.e. *Scoterpes copei* and *Ptomaphagus hirtus*), but is consistent with data reported for *Rhadine subterranea*, a troglobitic carabid of a Texas cave system. It is interesting to note that *R. subterranea* and *N. tellkampfii* are ecologically quite similar.

The Influence of Patterns of Guano Renewal on Bat Guano Arthropod Communities

Barbara Martin

Introduction

The characteristics of the food base of an heterotrophic community (predictability, variability, and rigor) are bound to have some effect on community characteristics such as: species number, dominance and trophic structure.

Methods

Data were collected in Tumbling Creek Cave, Taney County, Missouri from 10 cm cores of guano taken at four times throughout the year (summer, fall, winter, spring). The cores were extracted for arthropods (Berlese technique) and nematodes (Baermann technique). These cores were taken from four different piles of guano whose characteristics are given in Table 9.

TABLE 9. Guano Piles Characteristics

PILE	SIZE*				PATTERN OF RENEWAL			RESOURCE QUALITY
	Volume (m^3)	Surface Area (m^2)	Total Amount Per Annum (dry weight) grams: Jars[1]	Whole Pile[2]	Frequency[3] (April-Oct.)	Predictability In Time	Variability of Input	Rigor[4]
3	0.27	2.14	6.75 2.32	10^2	-high- a few droppings a night throughout the summer	high	low	medium
12	6.79	6.78	12.32 13.28	10^3	-high- a few fly-by droppings throughout summer major input – June secondary input – Oct.	high	medium	low
13	7.55	19.76		10^1	-low- (0 – twice/year) April – a few droppings Sept.-Oct. – a few droppings/night	low		mostly high
5	11.06	21.27	7.23 7.08	10^3	-low- (once-twice/year) April – a few droppings major input – Sept.-Oct.	medium	high	high & low

* Size was estimated by approximating sections of geometric figures. Surface area is underestimated and volume overestimated.

1 Two jars (diameter-8 cm) were placed on top of the piles where the major input occurred. No jars were put on Pile 13 because it was not supposed to get any input. Copper sulphate solution was used to prevent biological activity.

2 Two independent estimates of total input were attempted (1. from the jars; 2. from depth measurements). Problems resulting from variable input on different parts of the piles and projecting surface area of irregular figures resulted in great variation of values for total input. I have, therefore, only given the order of magnitude.

3 I have monitored these piles through two "bat seasons". Frequency gives the results for the first season. Piles 3 and 12 were similar both years. Piles 13 and 5 are two of three neighboring piles, any one of which will get one major input, Sept.-Oct., while the other two may be slightly used or not at all. A longer time period is necessary to evaluate predictability reliably.

4 Fresh guano is a low rigor food; old guano, a high rigor food.

Results and Discussion

Species Composition of the Community—Mites predominate in species number and biomass* (Table 10). In fresh guano fly larvae, especially *Bradysia* sp., probably surpassed the mites in abundance and biomass in the top centimeter but the Berlese technique discriminates against their extraction. Nematodes were the most abundant organisms at all times, varying from 200/g in old guano (Pile 13) to 8000/g in fresher guano (Pile 12). However, their biomass was negligible. Collembola (six species) were abundant where the guano was not as concentrated, for example in areas of fly-by droppings, or thin smears of older guano.

Although a number of taxa other than mites (mostly flies, beetles, and springtails) were important members of the guano community, they were not well represented in guano cores. Therefore, I have confined the rest of this report almost entirely to mites.

Succession

A definite autogenic successional sequence followed guano renewal at any site. Figure 25 presents a somewhat generalized view of three aspects: chemical*, bacterial-fungal*, and arthropod.

Soluble carbohydrates, lipids, and water-soluble extracts drop precipitously within the first couple of weeks. pH drops within the first few months from 7.0 to around 3 at which point biological activity is reduced to a minimum. At the bacterial-fungal level, fresh guano is dominated by bacteria, largely enteric in origin. Within a week, the sporangia of a *Mucor* fungus appear. This is the first in a series of phycomycetes which regularly occur in the succession. With the appearance of the *Mucor* fungus the guano community increases exponentially in number of individuals and subsequently tapers off as the guano becomes more acidic. At the bottom of Figure 25 I have assigned organisms a response time which represents either the first appearance of the species in the successional sequence or more usually the time at which the greatest number of individuals of that species were found.

There are three major points revealed in Table 11. Piles 3 and 12 maintain a constant number of species throughout the year. These two piles share similar renewal patterns in the following

Biomass is inferred from numbers and size for both mites and nematodes. Nematodes fell into two major size classes as to length: 0.17 mm and 0.5 mm. At most. 1% were as long as 1.0 mm. Cross-sectional diameter was on the order of microns.

* Unpublished data from Mickey Fletcher, Southwest Missouri State University.

TABLE 10. Identified Mites

Suborder	Family	Genus (where available)	Number of Species	*Size	Description Morphology	† *Guild*
Prostigmata	Rhagidiidae	*Rhagidia*	1	large	soft, white	P
	Ereynetidae	*Ereynetes*	1	medium	small velvet	P or S
	Trombidiidae		2 or 3	large	large velvet (adult)	P
				small	thin-legged chigger (larva)	S
	Stigmaeidae		2 or 3	medium	hairy oval, lumpy	P
	Trombiculidae		1	large	(adult)	P
				small	chigger (larva)	S
	Pyeomotidae		1	small	hairy	F & S
Mesostigmata	Ascidae		1 or 2	medium	longsnout, pale shiny	P
	Uropodidae	*Polyaspis*	1	medium	squat	F
	Macronyssidae	*Macronyssus*	1	medium	black squat	S
	Macrochelidae	*Macrocheles*	1 or 2	large	brown shiny	P
	Parasitidae	*Poecilochirus*	1	large	split-black shiny	P & S
	Laelapidae	*Hypoaspis*	1	large	shiny	P
Astigmata	Sagrogliphidae	*Calvolia*	1	small		
Cryptostigmata	Thyrisomidae-(Oppioidea)	*Banksinoma*	1	small	slender-knobby-legged oribatid	F
	Oppiidae	*Multioppia*	1	small	slender-knobby-legged oribatid	
	Palaeacaridae	*Palaeacarus*	1	medium	black-hair	F

**Size* (length not including mouthparts)
small — 0.33 mm
medium — 0.33-0.69 mm
large — 0.69-1.20 mm

†Guild
P = predator
S = parasite
F = fungivore

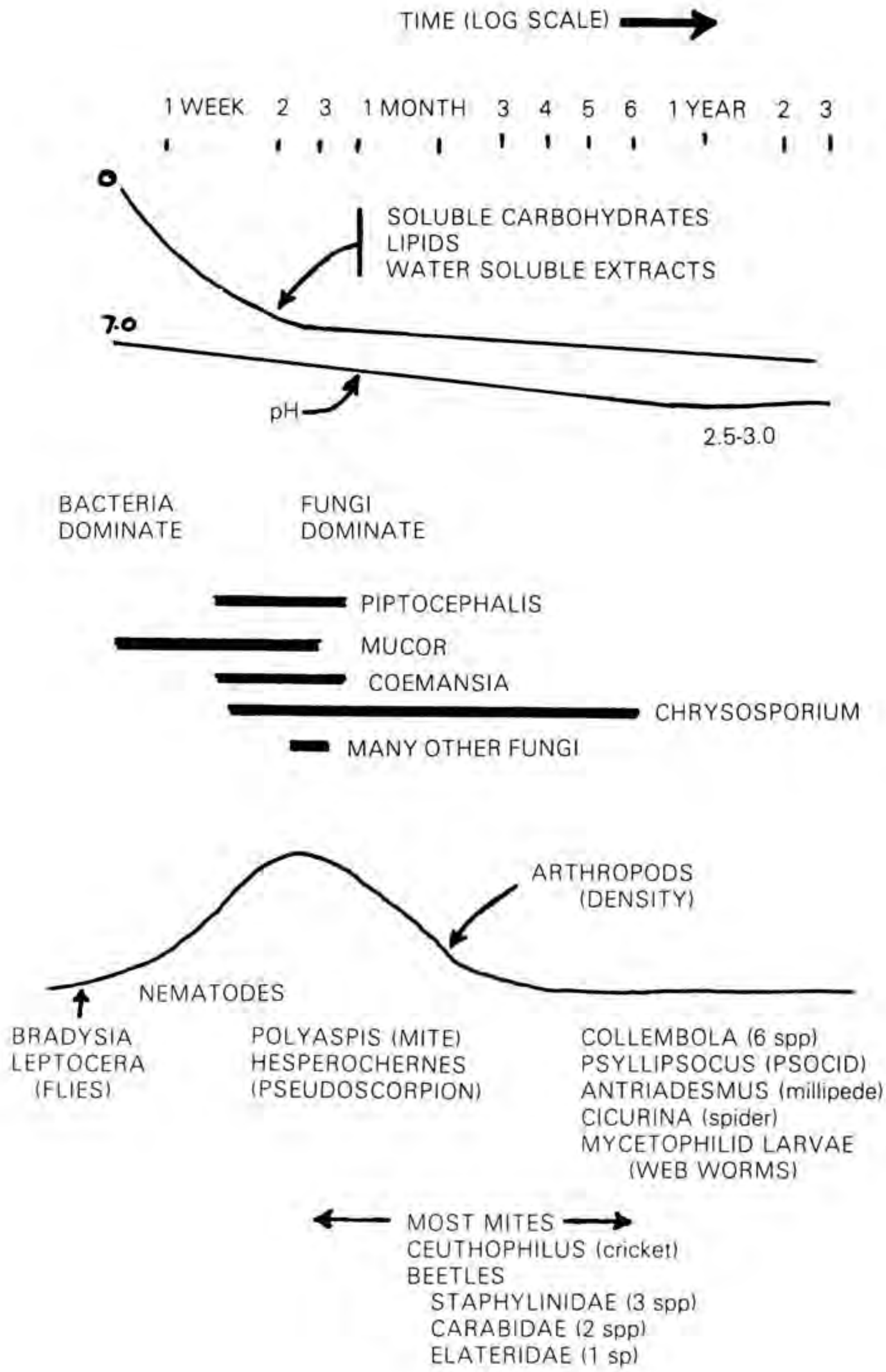


Figure 25. Generalized view of three aspects of an autogenic successional sequence following guano renewal

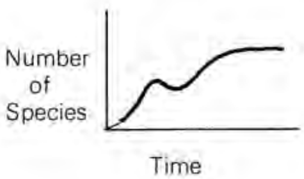
respects: high temporal predictability, high frequency, low variability, and low rigor. High frequency and low variability lead to a more stable physical environment and I think it is this factor which imparts constancy of species number. Another situation which I suspect also imparts constancy is that of high rigor (old guano) and predictably *no* guano input (hence low temporal variability), for example one or two year old guano. This was the case for the first sampling of Pile 13 which harbored an assemblage of "old guanobites" (e.g. several collembolan species, a web worm and an elaterid beetle) and which probably had done so for more than a year.

TABLE 11. Relative Species Numbers

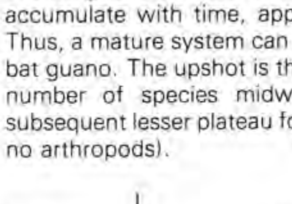
Guano Pile No.	July	Oct.	Jan.	Mar.
3	9	-	9	-
12	14	14	14	14
13	8	6	7	12
5	6	15	13	15

Size of the habitat (guano pile) also appeared to exert some limit on species number when one compares the maximum numbers occurring in any pile. Despite small numbers, the trend exhibited still tends to support the MacArthur-Wilson equilibrium model (1963) for the effect of island size on species number.

It is of interest to compare guano succession with other types of autogenic succession. In secondary autotrophic succession (e.g. an old field) the sequence of species numbers follows the pattern below.

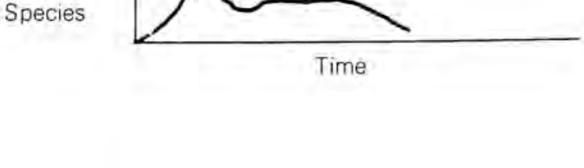


Maximum species number is associated with the system's maturity and stability (both as species persistence and resistance to invasion).



Heterotrophic succession (e.g. on dung, carrion, old logs) has the following pattern. Because the resource is used up, a mature system never materializes and maximum species number is attained at an early successional stage.

Bat guano is a heterotrophic resource but since piles accumulate with time, apparently it is never entirely used up. Thus, a mature system can and has, in a sense, evolved with old bat guano. The upshot is the following pattern with a maximum number of species midway through the succession but a subsequent lesser plateau for old guano (very old guano harbours no arthropods).



Relative Abundance

There are two aspects of relative abundance:

1) relative abundance between species at one time (community level);
2) relative abundance within a species through time (population level).

Simple communities of few species and/or communities in the early stages of succession are usually characterized by high dominance of one or two species. As one progresses toward more complex or mature systems there tends to be a more even distribution of numbers or biomass among the species.

The bat guano showed a variety of patterns but there is certainly a correlation between high dominance and fresh guano. These communities are both simple and early successional. The older guano showed a more even distribution of numbers (i.e. a lower slope to the species importance line). For example, follow Pile 13 from July through March (Figure 26).

July represented at least one year old guano. Renewal in October resulted in elimination of a few species (notably Collembola) and an increase in a *Polyaspis* mite. Through time, this evened out again. The dominant mite species at all sites and times were fungivores.

I have lumped all species together in Table 12. Density increases exponentially shortly after renewal. The *Polyaspis* mite (fungivore) mentioned above is responsible for the bulk of the increase (excepting Pile 3 which did not show a major increase in density). However, virtually all the other mite species increased at the same time. Pitfall data show that the dominant macropredator of fresh guano (a pseudoscorpion, *Hesperochernes occidentalis*) also increases in density.

TABLE 12. Relative Densities of all Organisms (number/gram).

Guano Pile No.	July	October	January	March
3	3.91	-	4.39	-
12	12.23	127.98	83.22	103.73
13	0.99	2.74	5.28	4.54
5	0.88	114.67	57.37	23.84

This increase in density was a result of both immigration and reproduction exemplified by the ubiquitous mite, *Polyaspis* sp. Immigration was implied by the recruitment to the adult class and reproduction by the appearance of larvae.

Vertical Distribution

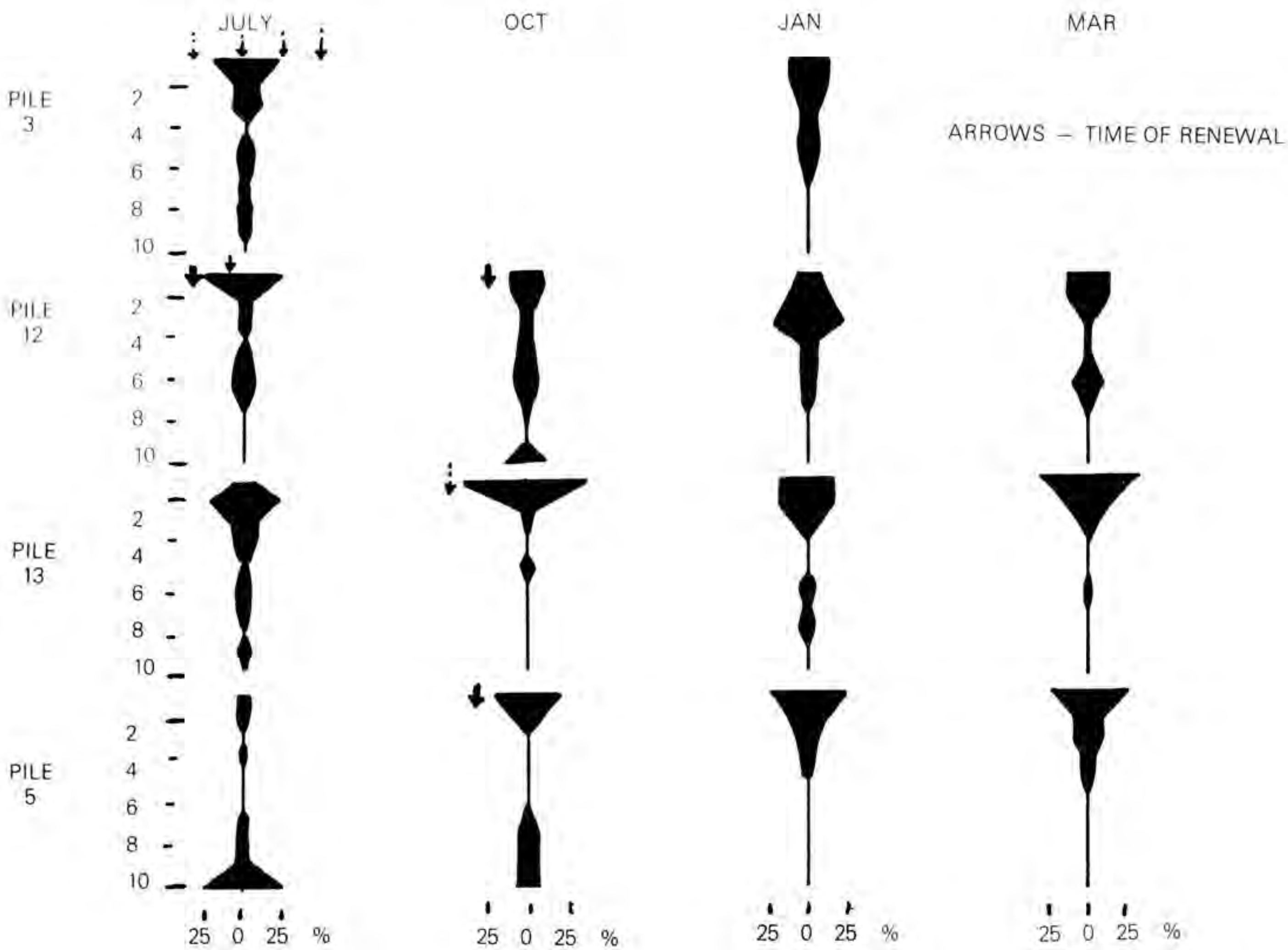
The relative densities of mites and nematodes at different depths was related to guano renewal (Figure 27).

One pattern which appeared consistently is a concentration of organisms in the top centimeter or two in conjunction with guano renewal. This was particularly evident in the July samples for Piles 3 and 12 and for Piles 13 and 5 after the pulse of new guano. There was also a secondary concentration at the six centimeter depth in Pile 12. This may be the result of some physical-chemical disjunction at this depth. Harris* found a similar phenomenon on a guano pile in Australia. It is my belief that this represents the surface of the last year's guano, compacted with time and matted together with fungus. Crusting was evident from digging through this and several of the piles.

* Harris, J. A., unpublished slides.

Figure 26. Pile 13: Dominance Structure

Figure 27. Relative Mite and Nematode Densities with Depth



Guild Structure

Fungivores were consistently the most abundant in terms of number of individuals, but not number of species (Figure 28). The fact that there was a greater abundance of fungivores was reasonable, considering they are lower than predators on the food chain. The percentage of fungivores appeared to be higher in fresh guano than old.

What of the actual species involved? Although the same number of species was maintained on the regularly renewed piles (3 & 12) and roughly the same ratio of fungivore to predator, the actual species involved was not constant. I don't feel that this represents any conventional succession but is merely a result of small-scale sampling error. Individuals, especially in the predator group, will move between patches on a guano pile. Nonetheless, each local patch will only support a given number of fungivores and predators. Hence, we have a system in the guano pile consisting of different and constantly changing local patches. Although this was also true of the infrequently renewed piles (13 & 5), I believe that some of the change in species was due to autogenic succession.

Figure 28. Relative Abundance of Fungivores and Predators

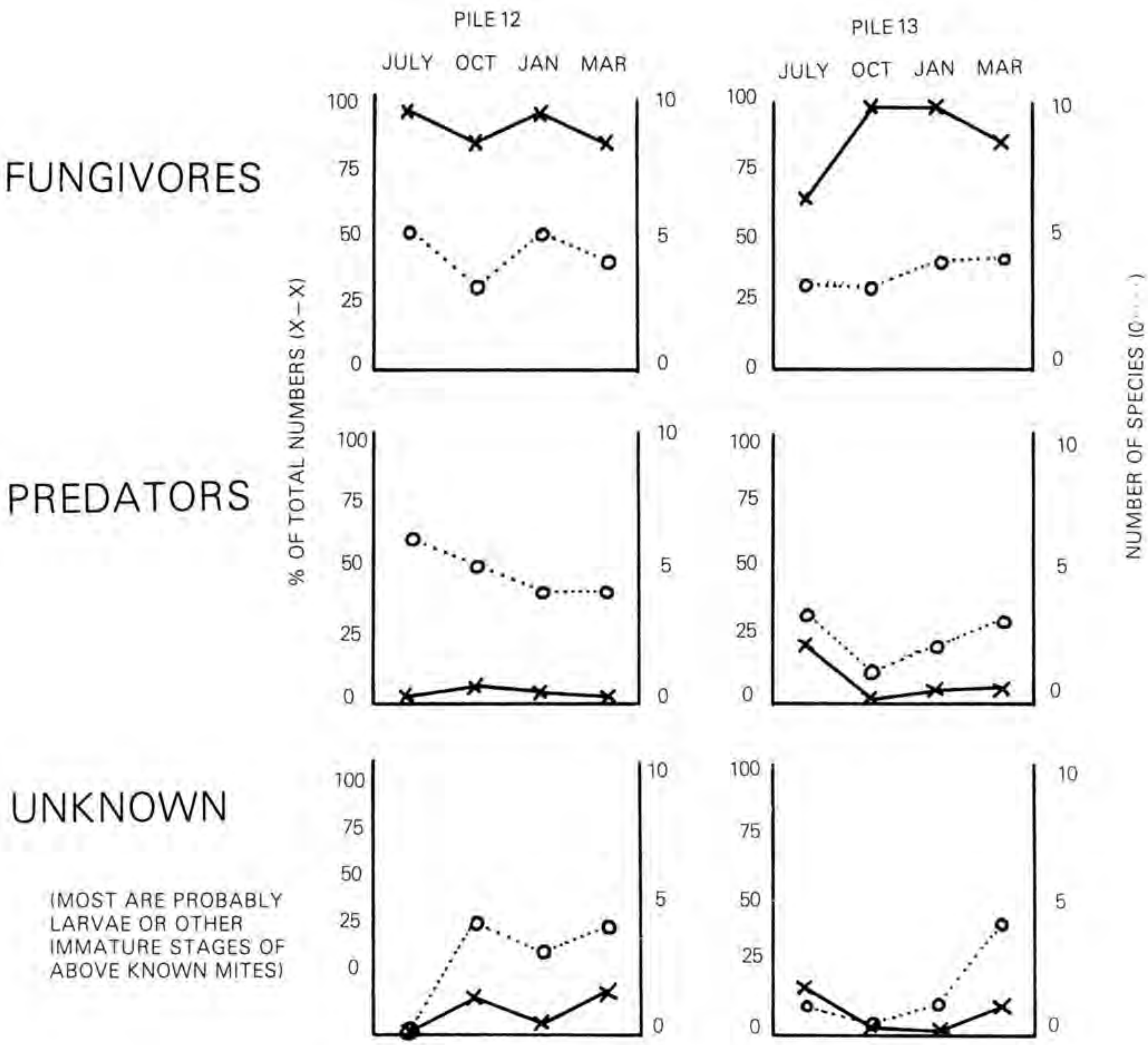
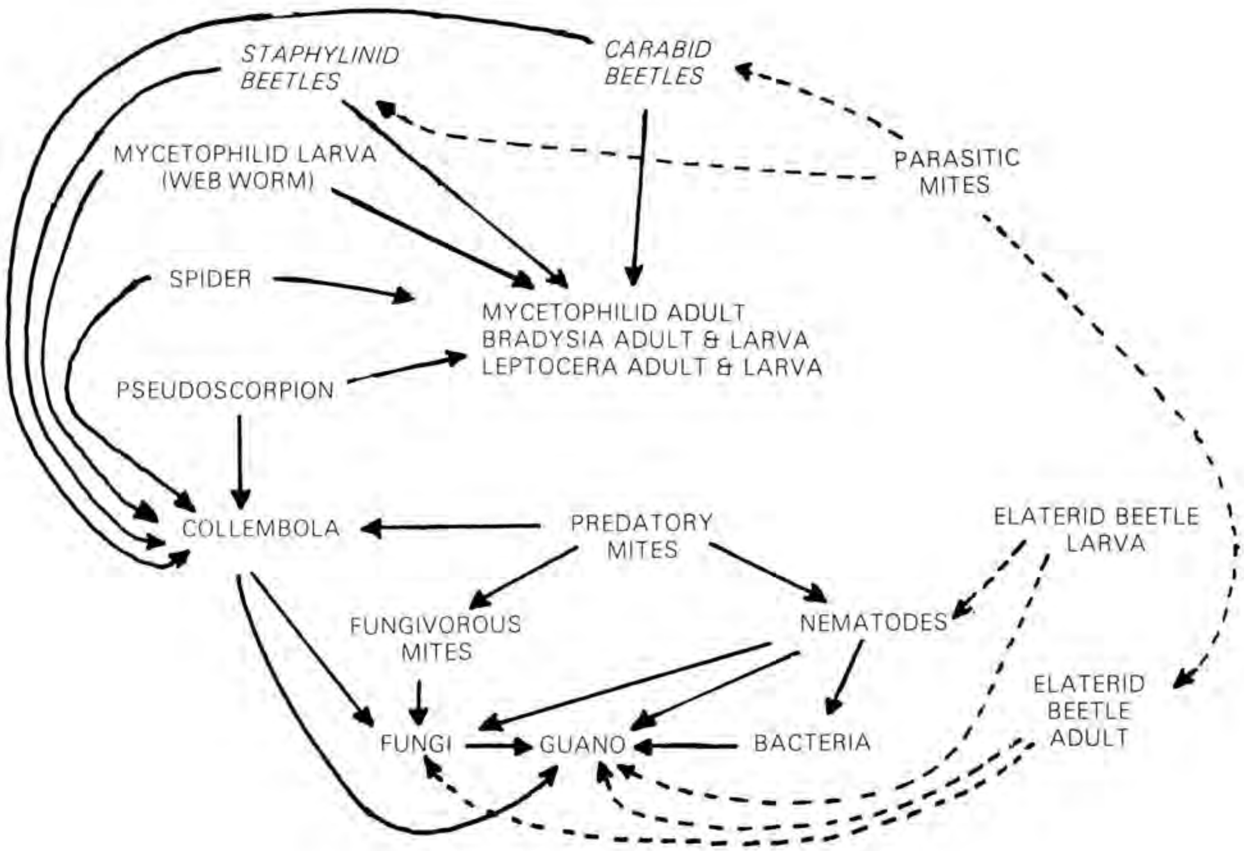


Figure 29. Hypothesized Feeding Web for the Bat Guano Community



Summary

1. Acarina (mites) is the dominant taxon in terms of species number in this bat guano arthropod community.
2. A definite autogenic succession follows guano renewal at any site.
3. Fresh guano is associated with the greatest number of species, high densities of organisms, concentrations of organisms in the top two centimeters of guano, and high dominance.
4. Constancy of species number is associated with the following renewal pattern: high temporal predictability, high frequency, low variability and low rigor. The most important variable resulting in stability of species number is probably lack of variability in the resource which can arise from several combinations of the other variables.
5. Fungivorous mites are consistently the most abundant in terms of numbers of individuals 85%-95%), although there are more species of predatory mites. The percentage of fungivores is higher in fresh guano than old.
6. A food web is presented (Figure 29).

References

MacArthur, R. H. and Wilson, E. O. (1963). "An Equilibrium Theory of Insular Zoogeography." Evolution, *17*, pp. 373-387.

Foraging Behavior of *Neaphaenops tellkampfii* (COLEOPTERA: CARABIDAE)

Barbara Martin

Introduction

Neaphaenops tellkampfii is an obligate cave dweller of the central Kentucky karst area. Kane (1974) found that its behavior was adapted to its main food source, the eggs and nymphs of the common cave cricket, *Hadenoecus subterraneus*. *Hadenoecus* has a preference for oviposition in sandy or silty substrates. *Neaphaenops* prefers to forage on sand in the spring months (when *Hadenoecus* oviposition is high), then switches its preference in summer and fall to mud and rock substrates where alternate prey are available. *Neaphaenops* also displays digging behavior which it prefers to do on sandy substrates. Mechanical disturbance of the substrate has been noted by several people (unpublished) to elicit digging behavior.

Foraging behavior is of paramount importance to the survival of a species and of individuals of that species. Food is limiting in cave situations and so inefficiency is particularly costly. Within the species *Neaphaenops tellkampfii* energy requirements are going to be different for the two sexes and for tenerals (newly eclosed adults) *vs.* adults. Above basic maintenance requirements, adult females need energy for egg production, and adult males may need energy for the wear and tear of running around finding mates. Tenerals need energy for maturation processes (hardening of the exoskeleton and gonad development). One might, therefore, expect differences in foraging behavior between (1) adult females and adult males, and (2) tenerals and adults.

What might this foraging behavior entail? Basically, it involves locating cricket oviposition sites, digging up the egg, eating the egg before another predator finds it (defense of the egg by aggression). Looking at this from a population perspective one might expect the beetles to have evolved one of two means of optimizing food acquisition: (1) aggregating of beetles at a good foraging site (requiring recognition of conspecifics by mechanical or chemical means, or else recognition of good foraging sites and conspecific tolerance) *or* (2) partitioning of the resource in a territorial way (recognition and avoidance of conspecifics).

With these alternatives in mind I decided to examine the foraging behavior of *Neaphaenops* in more detail.

Methods

1. Rate of hole-digging and ability to find cricket eggs were observed for five adult males, five adult females, and five tenerals of mixed sex using 16 oz. jars lined with 1.5 cm of cave sand.
2. The effects of: (1) mechanical disturbance to the substrate—(a) artificial cricket oviposition sites, (b) artificial beetle holes; and (2) conditioning of the substrate by conspecifics were examined using a plexiglass arena (54 cm x 54 cm x 9 cm) lined with 1.5 cm of cave sand. A removable plexiglass barrier divided the arena into an experimental and a control side. A thread grid could be overlain to give coordinates for beetle movements. The sand was autoclaved and smoothed prior to each experiment to remove possible effects of previous conditioning. For each run a beetle was acclimated for one hour to the control side. The barrier was subsequently removed and the position of the beetle noted every five seconds for the first 30 seconds of every minute for 10 minutes. This was repeated a half hour later.

   Five artificial cricket oviposition sites and five sets of beetle holes were created using forceps. The dispersion was random. Since beetle holes tend to be clumped in nature, I made five holes per clump.

   In all cases of the use of the chi-square test, the control run of the experimental animal was used for the expected values.

Results and Discussion

The Effect of Artificial Cricket Oviposition Sites on Foraging Behavior

Table 13 indicates that male 1 spent significantly more time in the area of the artificial cricket oviposition sites, although he could not be induced to dig. This has obvious adaptive advantage. If a beetle spends more time in the vicinity of cricket oviposition sites, it is more likely to find an egg.

TABLE 13. The Effect of Artificial Cricket Oviposition Sites on Foraging Behavior.

Time 0			Time 30 minutes		
Number of times observed on:	Control Run	Experimental Run	Number of times observed on:	Control Run	Experimental Run
Control Side	42	31	Control Side	41	27
Experimental Side	29	40	Experimental Side	30	44
	$\chi^2 = 3.41$			$\chi^2 = 5.53$	
	Significant at $\alpha = 0.1$			Significant at $\alpha = 0.05$	

Hole-Digging

In caves, hole-digging (in the right place) is directly correlated to successful egg-finding. Table 14 Shows that the rate of hole-digging differs for sex and age. The rate increases from tenerals to adult males to adult females.

TABLE 14. Rate of Hole Digging as a Function of Beetle Sex and Age

(average number of holes/unfed beetle/day/jar)

	Adult Females	Adult Males	Tenerals
	3.68	3.68	0.60
	4.74	1.49	0.29
	2.00	1.12	1.20
	2.93	2.37	2.57
	2.23	0.56	0.40
Mean	3.12	1.83	1.01

Ability to Find an Egg

Five pairs of male + female adults and three pairs of teneral + adult were set up in jars with one cricket egg partially buried in the center. The one which consumed the egg was noted by observing which had the distended abdomen when the egg disappeared.

Table 15 indicates that among adults, males do better than females and tenerals do better than either. Recall, however, that in nature the eggs are buried and must be dug up. This test then was examining chemical recognition of the egg and ability to keep it from conspecifics.

TABLE 15. "Who Got the Egg First"

	Between the Sexes			Between Teneral & Adult	
	♂	♀		Teneral	Adult
1	•		1	•	
2			2	•	
3		•	3	•	
4	•				
5	•				

• indicates which one of the pair got the egg

These two experiments indicate that there are differences in foraging. From personal observations and inconclusive data (not presented here) the following patterns emerged. Tenerals find eggs virtually immediately. They appear to move rapidly and search more thoroughly *when* active. Adult females seem to cover an area rapidly and then reduce activity if nothing has been found (even if an egg is present). Adult males, on the other hand, seem slower to find eggs but more methodical in their search. This may appear to contradict the above table but it does not if one considers the time it took to find the egg.

The Effect of Artificial Beetle Holes on Foraging Behavior

One might expect beetles to avoid conspecific diggings (assuming the food to have been taken) or one might expect beetles to concentrate their efforts where others have been successful. Either way, there might be some discernible effect. Table 16 shows that artificial beetle diggings had no effect on the activity of male 1.

TABLE 16. The Effect of Artificial Beetle Holes on Foraging Behavior.

Time 0			Time 30 minutes		
Number of times observed on:	Control Run	Experimental Run	Number of times observed on:	Control Run	Experimental Run
Control Side	42	34	Control Side	41	38
Experimental Side	29	37	Experimental Side	30	33
	$\chi^2 = 1.81$ insignificant			$\chi^2 = 0.26$ insignificant	

TABLE 17. The Effect of Conditioning by Other Beetles.

Time 0			Time 30 minutes		
Number of times observed on:	Control Run	Experimental Run	Number of times observed on:	Control Run	Experimental Run
Control side	42	34	Control Side	41	30
Experimental side	29	37	Experimental side	30	41
	$\chi^2 = 1.81$ insignificant			$\chi^2 = 3.41$ insignificant	

The Effect of Conditioning of the Substrate on Foraging Behavior

Table 17 indicates that male 1 spent significantly more time on the side conditioned by five other males after half an hour. This is odd if one assumes, as I did, that any chemical conditioning would be short-lived (i.e. involving volatile chemicals). It could be that the important factor is mechanical disturbance of the substrate, although the artificial beetle holes did not indicate that. Other behavior-dipping the abdomen and "plopping on the ground" (bringing the ventral surface in contact with the substrate) performed only on "new" substrate indicates to me some sort of chemical communication (both testing and marking). This particular experimental result intrigues me, especially as the effect of conditioning decayed with the number of subsequent runs after the autoclaving of the sand. One other male showed a preference for the conditioned side (not significant) and 2 subsequent females showed no preference. These are all, obviously, preliminary investigations and would be worth following up.

Conclusions

Neaphaneops tellkampfii displays a foraging behavior which differs between sexes and between tenerals and adults. There is an indication that some recognition between conspecifics via conditioning of the substrate tends to keep individuals in the vicinity of others and presumably at a good foraging site.

References

Kane, T. C. (1974). Studies of Simple Cave Communities: Predation Strategies of Two Co-occurring Carabid Beetles. Ph. D. Thesis, University of Notre Dame, Notre Dame, Indiana, 125 p.

Figure 30. Cave Cricket (*Ceuthophilus* sp) in the Guadalupe Mountains, New Mexico. Photo by Pete Lindsley

Archeology and Anthropology

Central Kentucky Karst Archeology Project

Patty Jo Watson

Field work on archeological aspects of the Central Kentucky Karst was carried out during 5 visits to Flint Ridge in 1976 (April 22-24, June 10-12, July 9-17, October 15-19, November 25-27). Results of the field sessions are summarized as follows:

I. At the request of Superintendent Joseph Kulesza and Chief Interpreter Steven Smith, members of the CRF Archeological Project helped Park Service personnel move the aboriginal body found in Mammoth Cave in 1935 ("Lost John") off display. The case containing the body was carried from a spot near Giants Coffin to a dry place behind a locked gate at the end of Cyclops Avenue. Project personnel also aided in preparation of the new interpretive displays at Giants Coffin.

Permission was received by Louise Robbins to remove sufficient tissue from inside the aboriginal body to enable radiocarbon dating. A total of 51 grams of lower intestinal tissue was submitted to Dr. Robert Stuckenrath at the Smithsonian Radiocarbon Laboratory in November 1976. This should be sufficient for at least one and possibly two dates.

II. Surface survey in the Park resulted in location of one more possible site (a rock shelter) in addition to those already noted (see pp. 61-62 of the 1975 CRF Annual Report), while survey outside the Park at the Elmore/Mill Hole site failed to reveal the source area for the abundant chert tools and flakes found in one of Elmore's fields. The Elmore site was mapped, and the surface collections made there are being described and analyzed by Ken Carstens (in his dissertation, Department of Anthropology, Washington University, St. Louis) and by Jeff Brown (in his Senior Honors Thesis, Department of Anthropology, Washington University).

At the request of Bill Austin and Mrs. E. R. Pohl, an archeological survey crew visited a rock shelter on the Mammoth Onyx property and assessed the prehistoric materials there, which seemed to include remains from at least two cultural periods (Late Archaic/Early Woodland and Late Woodland).

III. Diana Patch concluded her study of the mussels found in our archeological sites inside and outside the Park (she concentrated on the molluscan remains from one of the Green River shell middens about 40 miles west of the Park—the Carlston Annis mound). The results of her work included an assessment of the current mussel fauna in the Green River, both inside and outside Mammoth Cave National Park. The current roster of species is very much diminished from the prehistoric situation because of recent disturbance of the river regime by dams and because of heavy recent pollution. Diana's study formed the basis for her Senior Honors Thesis (Department of Anthropology, Washington University).

IV. Ken Carstens (aided by Janet Levy and Pat Watson) spent four days in April, 1976, working at the Natural History Museum in New York City on unpublished material (mostly chipped stone) collected in the Mammoth Cave National Park area by N. C. Nelson 50 to 60 years ago. These data will be included in his dissertation.

V. Louise Robbins and Pat Watson presented a summary of the prehistory of Mammoth Cave National Park to the seasonal employees on June 11, 1976, as part of the Park's orientation program. We also gave a public talk on Park archeology at the Visitor Center on July 13.

VI. Pat Watson and Ron Wilson (via John Guilday at Carnegie Museum in Pittsburgh) were contacted by NSS cavers Bill Deane and Lou Simpson who, with a number of other cavers, had been mapping a cave in Tennessee and had found possible prehistoric footprints in the mud floor of one passage, animal bone in another. The animal bone was jaguar (not found this far north since the early post-Pleistocene period), so Ron visited the cave over Labor Day to examine the rest of the skeleton. He also looked at the footprint passage and collected some charcoal there. Louise Robbins, Pat Watson, and Ron Wilson—guided by Lou Simpson— directed recording trips to the Tennessee cave during the fall of 1976. Ron reports that the remains of two jaguars (one male, one female) were in two different and rather widely separated passages, plus a series of pawprints on the sandy floor of a third part of the cave. Watson and Robbins' crew measured 83 separate prints of human feet created by 8 or 9 different individuals, and made numerous photographs. They also succeeded in making casts of two of the human and one of the jaguar footprints. Probable prehistoric torch charcoal collected in the vicinity of the human footprints was submitted in November to the Smithsonian Radiocarbon Laboratory for dating.

Figure 31. Excavation in Progress at Blue Spring Hollow Shelter (6RS-12), Mammoth Cave National Park, Summer, 1975, looking west. Three firepits are distinguished by fire-cracked rock piles. Photograph by James Kurtz.

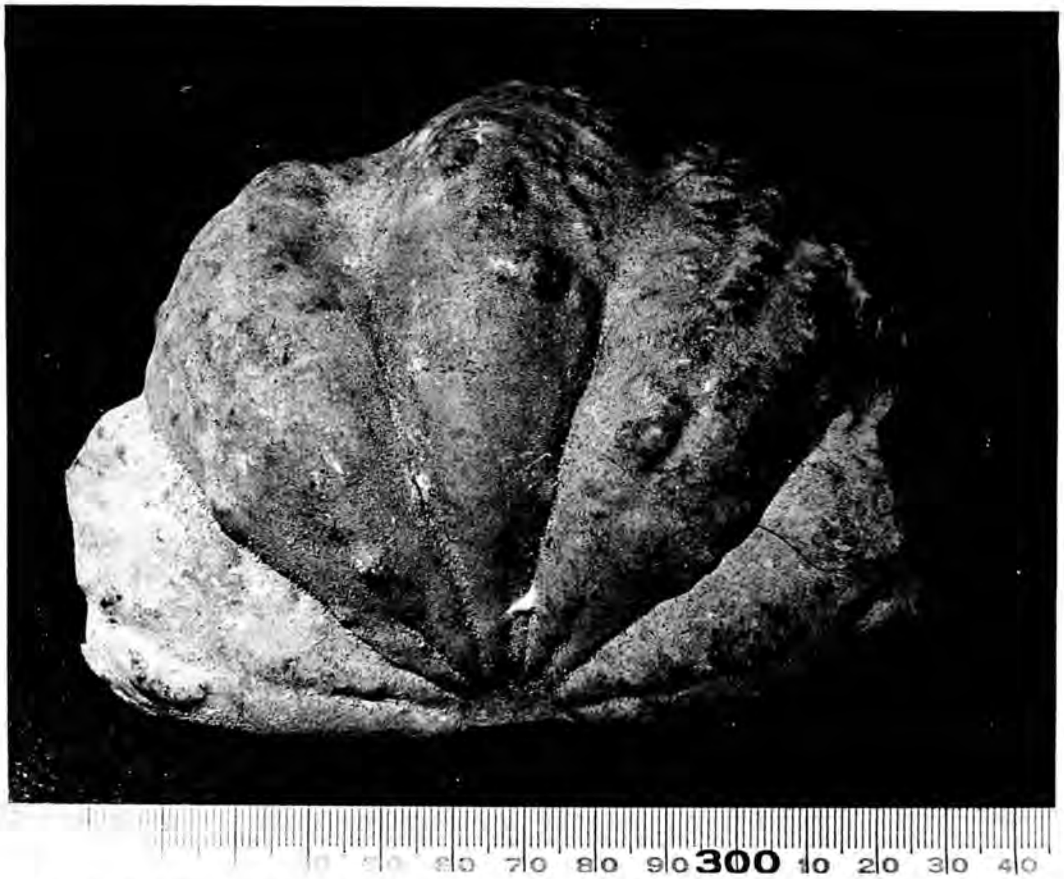


Figure 32. Large fragment of warty squash found in Chief City, Mammoth Cave. Such items are recorded and left in place in the cave. Photograph by James Kurtz.

In addition to the fieldwork just described, laboratory analysis of material recovered from archeological sites (Fig. 31) in and near the Park continued during 1976. As noted in the 1975 report, study of botanical remains from the Green River shell middens has yielded evidence of a very early (approximately 2500 B. D.) domesticated tropical plant, *Cucurbita pepo*, probably the same variety of squash found, together with gourd (*Lagenoria Siceraria*), at a somewhat later time in Salts and Mammoth Caves (Figs. 32 and 33). Charred rind fragments of this squash (which must have been imported from Mexico originally) have now been identified by Gary Crawford and Dick Yarnell in 6 different levels (top, middle, and bottom) at two different shell middens. A series of carbon samples from the two sites has been submitted to the UCLA Laboratory for dating.

The other analyses noted in the 1975 report (p. 64) are continuing except for the molluscan study by Diana Patch, now completed. William Marquardt is editing a monograph describing results of our work in the shellmound area since 1972 and Ken Carstens is completing his dissertation on the surface archeology of the Park and immediate vicinity.

Future work will include research in the Big Bend/Green River area, and recording of aboriginal material in Mammoth Cave (as noted in the 1975 report, this could continue for some time) as well as—we hope—surface survey in the area to be affected by activities called for in the Park Master Plan. We intend to submit a proposal to the NPS for assessment of archeological resources in the affected areas, but this kind of work is open to competitive bidding, so although we believe ourselves to be well qualified, we cannot say, for sure, who will do the job.

Figure 33. Side view of a warty squash fragment from Chief City, Mammoth Cave, Photo by James Kurtz.

History

Saltpeter Production from Cave Sediments—An Important and Early American Chemical Industry

P. Gary Eller

The production of saltpeter (KNO_3) has been an important human activity for more than a millenium, providing an ingredient for meat preservation, ceramics, gunpowder, and many other commodities. For America the availability of saltpetre, especially for gunpowder manufacture, played an important role during the westward movement of the 16th and 17th Centuries and during three major wars (Revolutionary, 1812, and Civil Wars). Effective blockades during these wars forced utilization of our principle domestic reserves of nitrates from cave sediments. Thus, the conversion of nitrates in cave sediments to saltpetre became one of early America's first and most important chemical industries. In our historical research we attempt to trace the history of domestic nitrate production and its influence on American development. Of particular interest is the fascinating role that caves played in this young chemical industry. For example Kentucky saltpetre played an important role in the early stages of development (approx. 1795-1815) of the E. I. DuPont de Nemours Company, which today is the world's largest chemical company. Our recent "action history" experiments at Mammoth Cave National Park, in which the conversion process is documented for the first time in over 100 years, continue to aid the history research since many chemical intermediates, described centuries ago, were identified in these experiments for the first time. Selected historical highlights of the American saltpetre industry, and a list of scientists and statesmen involved in this important work are given in Tables 18 and 19. Publication of this chemical history research is expected in 1977.

TABLE 19. Americans Concerned with Saltpetre

Scientists:	*Statesmen:*
Samuel Brown	Thomas Jefferson
Joseph LeConte	Paul Revere
Joseph Priestley	Albert Gallatin
Ralph Maxson	Samuel Adams
Irenee DuPont	George Washington
Benjamin Rush	James Madison
Benjamin Silliman	Robert Morris
Benjamin Franklin	John Hancock
Charles Weisenthall	Jonathan Trumbull
George W. Raines	Robert Paine
	Charles Lynch
	Evelyn Eve
	Abraham Lincoln
	Jefferson Davis

TABLE 18. Historical Highlights of American Saltpetre Production.

1624	Massachusetts bans cellars and dove houses so that saltpetre production is not impeded.
1770–1885	Thomas Jefferson visits saltpetre caves; George Washington, James Madison, John Hancock, Benjamin Franklin, and others draft Continental Congress directives concerning saltpetre; Charles Weisenthall directs saltpetre efforts through the *Committee of Safety*; blockade runners and nitriary workers maintain saltpetre supplies.
1800–1810	DuPont Powder Works (Delaware) thrives, based on Kentucky cave saltpetre.
1806	Samuel Brown presents "Description of a Cave on Crooked Creek with Remarks and Observations on Nitre and Gunpowder" to American Philosophical Society.
1812–1815	Factory-like cave saltpetre operations established at Mammoth Cave (KY), Big Bone Cave (TN), Sauta Cave (AL), Wyandotte Cave (IN), and Greenville Saltpetre Cave (WV); blockade runners effective.
1861-1865	Northern blockade of Confederacy forces development of massive nitriary shed saltpetre generation and reliance on traditional cave saltpetre preparation; Joseph LeConte and George W. Raines issue treatises on saltpetre production; Union raids force southern production to disperse to more remote sites; Pasteur suggests that nitrification processes are caused by micro-organisms.
1866–1914	World nitrate production relies on caliche beds in Chile, Spain, India, and California.
1915–1918	Allied blockade forces German development of Haber process; Nobel prize awarded to Fritz Haber.
1932	Ralph Nelson Maxson authors "Nitre Caves of Kentucky"; Last known cave saltpetre production ceases
1967	Burton Faust publishes "Saltpetre Mining in Mammoth Cave, Kentucky"
1974	Fixed nitrogen production in U.S. (rank in quantity produced): Nitric Acid (#9) 16.37 billion lbs. Ammonia (#4) 31.4 " " Ammonium Nitrate (#11) 15.1 " "
1976	Ammonia price 8 cents/lb; DuPont remains world leader in fixed nitrogen production; Nitrogen fixation continues to receive attention of world's best chemical minds.

Survey Interpretation of the Circa 1810 "An Eye-Draught of the the Mammoth Cave" Map

Duane De Paepe

One of the more significant documents associated with the early saltpetre mining operation at Mammoth Cave is the map with notes entitled "An Eye-Draught of the Mammoth Cave in Warren County, Kentucky." Three traced copies of this map survive and originated from about 1810. Of particular interest are leaching vats illustrated in the entrance vestibule which predate the present existing nitre hoppers in the Rotunda and Booth's Amphitheatre. Meloy (1968) is undoubtedly correct in stating that copies of this map were used to attract capital investment for the planned construction of the pumping system, furnace sites and Rotunda and Booth's Amphitheatre vat complexes. The name "Mammoth" cave first appears at about this time and was probably coined for promotional purposes.

At first glance the map suggests only a fanciful rendition of cave avenues postulated at that early date. However, recent comparative survey reconnaissance has carefully correlated the eye-draught map passages with contemporary place names. Significantly, the farthest extension illustrated on the map is Blue Spring Branch where well-preserved shallow pit excavations and rock stacking can still be noted. Drafted in horizontal exaggeration on the eye-draught map, Lee (1835) later recorded the floor disturbances in his survey of the cave. These excavations are identical to those found in other 1812 era saltpetre caves in and around Mammoth Cave National Park. A possible theory presents itself that this far extension of the cave was being considered for eventual expansion of the mining activity, perhaps with the idea of using the Cataracts as a leach water source for additional vats.

Writing much later, Hovey and Call (1912) document saltpetre mining sites in Blue Spring Branch and in the Side-cuts adjacent to Main Cave. The Side-cuts were investigated but no nitrate mining evidence today can be discerned. Blackall Avenue was also surveyed but widespread later digging, possibly by mummy hunters, removed any evidence that might have been found. Many mining sites were undoubtedly destroyed by CCC trail building efforts. However, good examples of the distinctive rock stacking can still be found in Audubon Avenue and in the Cyclop's Passage. Shallow pit mining, similar to that in Blue Spring Branch, can be seen in Harvey's Avenue.

With the notable exception of the Wooden Bowl Room complex, the eye-draught map is singularly complete with illustrations of features along Main Cave. The Wooden Bowl Room section should have been known at that time although early reports describing Pre-Columbian footprints there suggest that the miners may not have disturbed the sediments despite the location adjacent to the ox cart road tun-around. The Wooden

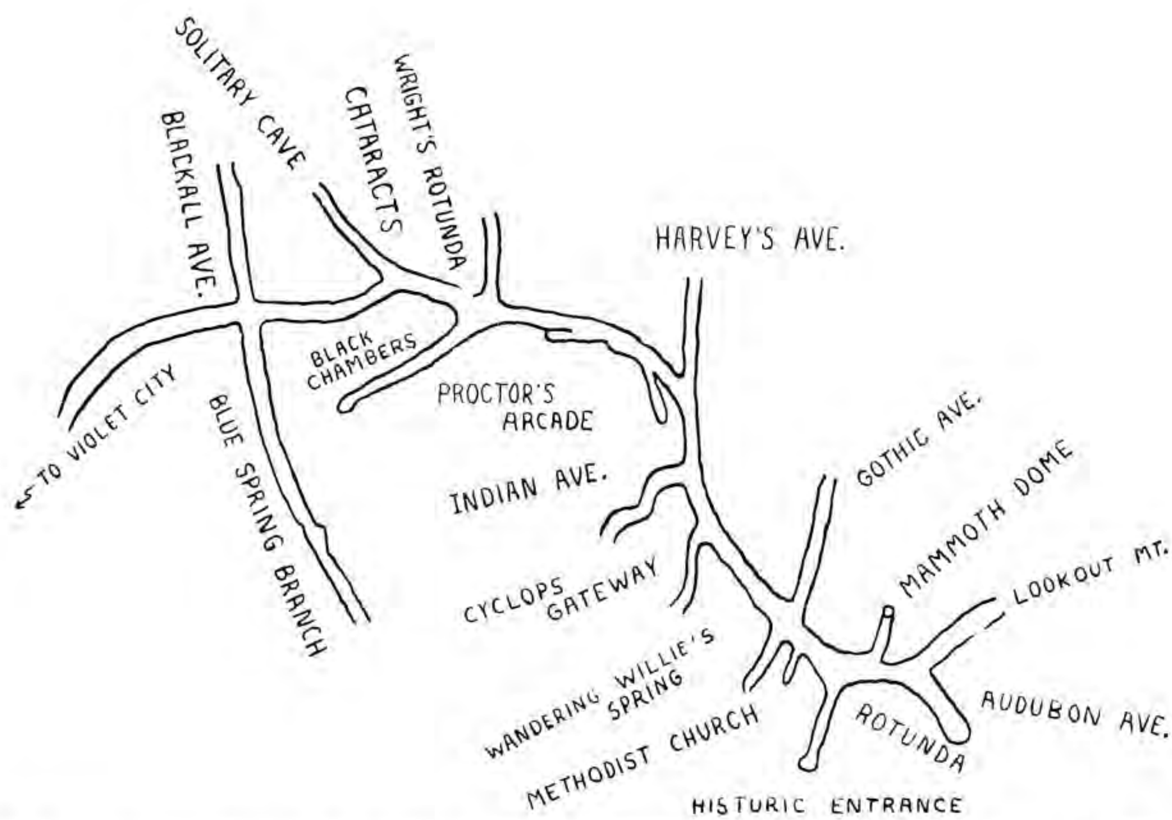


Figure 34. Survey reconstruction of "An eye-draught Map of the Mammoth Cave in Warren County Kentucky," with modern place names.

Bowl Room to Bottomless Pit and associated passages has yet to be searched completely for mining sites. Expansive studies in several regional caves have provided a base of comparison to distinguish saltpetre mining features from other historic or Pre-Columbian excavations. Unfortunately, Main Cave and Gothic Avenue have been extensively altered by decades of visitor improvements. However, investigations thus far point to a pattern that suggests the side passages from Main Cave were the more important nitrate gathering sites and the main trunk served as the transportation artery to the leaching hoppers. The reconstruction of the early historic cave environment from the study of pre-1850 descriptions further substantiates this theory.

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The History of the Peoples and Caves of Flint Ridge, Mammoth Cave National Park

Stanley D. Sides

Four cave trips were made in 1976 to areas of historic interest in the Flint Mammoth Cave System. Special attention was devoted to the Hazen Entrance area of Colossal Cave. It is clear that extensive exploration was done in this area of Colossal Cave in the two-year period, 1896-1897, after the Colossal Cavern Company developed the cave. Blasting and collapse of the Hazen Entrance allows no reconstruction of its original appearance. Today it pirates surface valley water directly to a large sediment-filled trunk that probably continues across the valley as Lower Turner Avenue. Systematic recording of dates and names from the historic portion of Colossal Cave is planned in 1977.

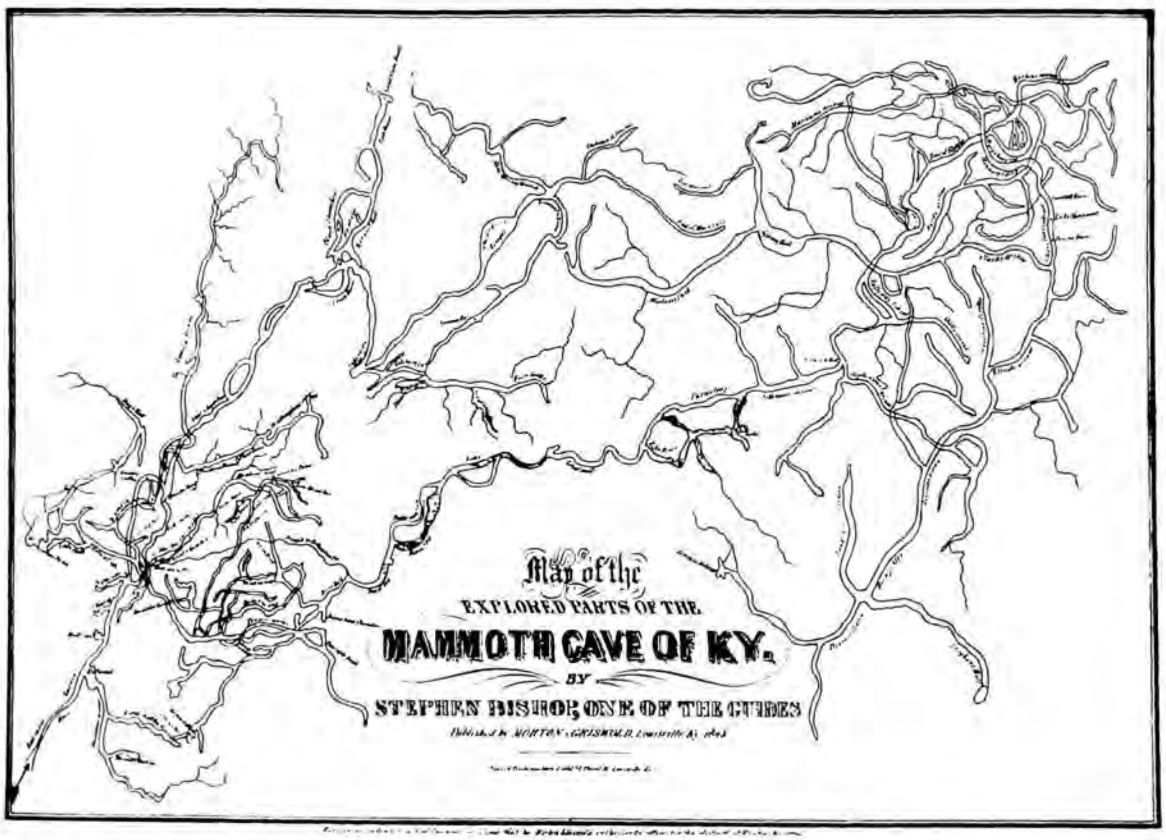

Figure 35. Stephen Bishop's 1842 map of Mammoth Cave published in 1845.

INTERPRETIVE PROGRAM AND SPECIAL PROJECTS

Figure 36. John McLean discussing the geology of Carlsbad Caverns during seasonal training session at Carlsbad Caverns National Park

Earth Crack Investigation at Wupatki National Monument, Arizona

Rondal R. Bridgemon

In August, 1975, the National Park Service requested that the Cave Research Foundation investigate the deep fissures, locally known as earth cracks, found at Wupatki National Monument in northern Arizona. CRF initiated a project at Wupatki in late September, 1975. Five expeditions were conducted through February, 1976. The project included a survey of the major earth cracks in the monument along with biological, archeological, and mineralogical investigations. A 59-page report detailing the results of these investigations was published May, 1976. Copies of this report, several large-scale maps, and a slide presentation were given to the NPS to aid in their interpretation of these unique features.

Geology

The earth cracks at Wupatki National Monument are tectonic features and most of those presently known are associated with three grabens. These faults occur primarily in the Kaibab limestone, although overlying basalt and the lower Coconino sandstone are cut in some locations. Faulted and unfaulted basalt flows in the area suggest a late or post-Tertiary origin for the earth cracks. Large sinkholes in the area resemble karst but are due to the enlargement of earth cracks, primarily by collapse.

Several of the cracks are enterable. Surface expressions can be followed up to half a mile, and they range in width from inches to about 20 feet. The interiors of these fissures are one to three feet wide as they pass through the Kaibab and widen to as much as 15 feet when the Coconino is reached at a depth of 243 feet. Fault displacements are small, not exceeding a few feet. The question of why the fissures have remained open for some depth apparently is explained by two factors: 1. The small displacements have caused minimum stress and dislocation. Any slumping of limestone blocks at ground level will still leave small openings to the fissures. 2. The earth cracks are reverse faults and the downward slumping toward the graben has created a void.

Sipapu Cavern, surveyed to a depth of 500 feet, was the deepest of the earth cracks investigated. Doney Fissure was the most extensive of the cracks with approximately 1500 feet being mapped.

Biology

Calvin Welbourn examined five earth cracks for animal life and found that the fauna was very sparse due to the lack of moisture. The major forms were trogloxenes: snails, bristletails, cave crickets, flies, and spiders. Several troglophiles were found: *Rhadine* beetles, pseudoscorpions, ticks, and mites. The pseudoscorpions consisted of two new species and were significant in that they showed some adaptation to life in the dark. Dr. William B. Muchmore (University of Rochester) is currently describing these species.

In October, 1976, cave crickets were marked and later counted in an effort to determine populations and biomass of the earth cracks.

Mineralogy

The earth cracks are relatively devoid of any secondary mineral displays. Of interest are obscure cotton-like tufts of minute colorless crystals found in Malmquist Fissure. P. Gary Eller and Carol Hill are presently studying this mineral, which appears to be soda nitre or a previously undescribed nitrate mineral.

Archeology

Don P. Morris (NPS Arizona Archeological Center) inspected the cracks for items of archeological interest but little was found. The basketry fragments that he had discovered in 1963 could not be relocated. Individual aboriginal corn cobs were found in several of the cracks.

The most puzzling find was a pile of 38 corn cobs located several hundred feet from the entrance to Doney Fissure (Fig. 23). Their location and the lack of any evidence of ceremonialism may suggest that the Sinagua Indians at times explored the earth cracks simply to see where they went.

Survey

A control surface survey with a theodolite was run under the direction of Robert Buecher. Three areas of high crack density were mapped for a total of 39,600 feet. Surface detail in these areas was added with Brunton survey ties totaling 39,355 feet. The interiors of seven earth cracks were mapped for an additional 3,374 feet.

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FIGURE 38

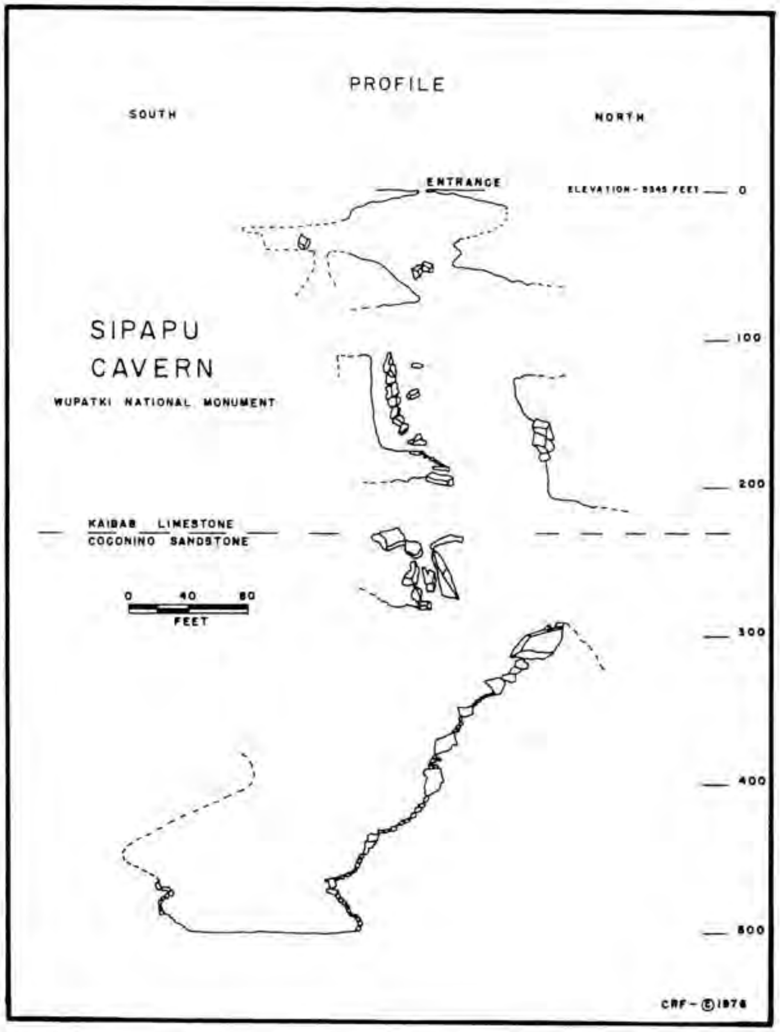
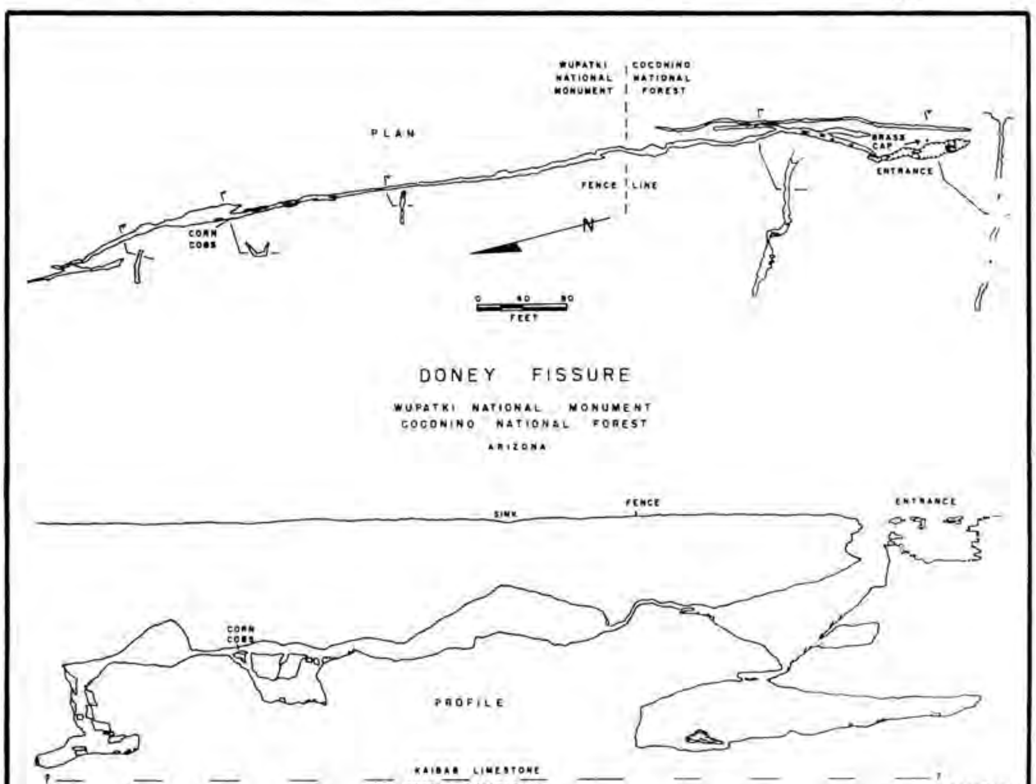


FIGURE 39



New Cave Map Card

New Cave is a large backcountry cave in Carlsbad Caverns National Park which is presently shown in an undeveloped condition to visitors. In 1976, CRF published an interpretive Map Card for New Cave. It contains a map on one side and a descriptive text (with illustrations) on the other side. The complete text is reprinted here.

"New Cave is located in Slaughter Canyon of Carlsbad Caverns National Park. It is one of the three largest caves within the Park and contains a main corridor 357 meters (m) long (1170 ft) with cross sections up to 67 m (220 ft) wide and 11 m (35 ft) high. The total surveyed length of the cave is 2.81 kilometers (1.75 miles) and the total depth is 76 m (250 ft). The entrance lies at an elevation of 1440 m (475 ft) above the canyon floor."

History

"The canyon was named for Charles Slaughter, who in the late 1800's was the second settler of the area. The cave was originally called Slaughter Canyon Cave. It is the most recent cave of the area to be brought to the attention of the general public. In addition to spectacular formations and its vast size, New Cave is historically and scientifically interesting.

"New Cave was discovered by Tom Tucker, a local goatherder, in 1937, 14 years after Carlsbad Caverns was proclaimed a National Monument and seven years after the monument was enlarged and redesignated a National Park. In 1938, R. M. P. Burnet led an expedition during which the main passages of the cave were explored and described, principal cave formations were photographed and named, and animal bones, charred wood, and pottery shards were discovered. A few months later, Burnet's article on his findings was published in Natural History and brought nationwide attention to this remarkable cave.

"Early recognition of the significance of New Cave is indicated by the rapid addition of this land to the National Park in 1939, less than two years after discovery of the cave. Title to the newly acquired lands, however, was subject to all existing mining rights, and within the cave an interesting mining operation developed.

"Early in this century bat guano was a valuable agricultural fertilizer because of its high nitrogen and phosphorus content. Guano mining was a big industry in caves of the Carlsbad area in the early 1900's. The Bat Cave section of Carlsbad Caverns was extensively mined during this time. By 1943, mining of the vast guano deposits in New Cave was begun, with construction of a conveyor for removal of the guano. Mechanical problems and lack of profits caused the operation to be discontinued in 1944.

"In late 1948 mining in New Cave was resumed by the Carlsbad Bat Guano Company under an agreement with the National Park Service. Gasoline engines powered a small guano conveyor inside the cave and generated power for work lights, an intercom system, and signal lights. A fixed cable for transporting guano from the cave was extended about 305 m (1000 ft) from the canyon floor to the cave mouth and about 100 m (328 ft) into the cave. An electric trolley-car powered by a gasoline generator at the cave entrance was capable of four to six trips per hour along the cable. It carried approximately a half ton of material per trip. A tractor was taken up the mountain in pieces, assembled in the cave, and used inside in the mining operation. The trolley car was shoveled full of guano, conveyed to the entrance, and lowered to the canyon floor. There, the guano was dumped into a hopper and transferred to dump trucks for transport to Carlsbad for processing.

"From Carlsbad the processed guano was shipped to southern California by rail for use in citrus orchard fertilizer. Some was sold locally to Pecos Valley residents. More than a thousand tons of guano were mined before mining activities ended in 1958.

"Today trenches and tractor tracks may still be seen in New Cave as evidence of this mining operation. Mining rights now belong to the National Park Service.

Geology

"New Cave is formed in the Capitan Limestone, the deposits of a massive reef or lime bank which ringed an inland sea 250 million years ago (Permian age). Ultimately the reef grew thousands of feet thick, and slumping occurred continuously at the reef edge. Simultaneously, deposition occurred in the protected lagoon behind the reef. These processes and transformation of the sediment into limestone with the passage of time have preserved the form of the ancient reef, forereef, and backreef deposits in the present rock. Each of these depositional units is clearly evident on the east wall of Slaughter Canyon as viewed from the entrance of New Cave.

"Like much of Carlsbad Caverns, nine miles to the northeast, most of New Cave is developed in the massive reef unit and is characterized by large rooms with arched ceilings. Steeply dipping beds exposed in the walls of the southeast part of the cave are expressions of the forereef beds.

"New Cave is best known for its spectacular speleothem decorations, formed when minerals such as calcite crystallized from water solutions. These mineral formations range from fragile, white soda straws only millimeters in diameter to the massive Monarch Column about 18 m (60 ft) in height and 4.5 m (15 ft) in diameter. Highly unusual calcite speleothems, called bell canopies, as well as spectacular flowstone, rimstone dams and a peculiar pool deposit called tower coral, adorn the cave. Minerals identified in New Cave are calcite, brushite, and fluorapatite. The black coating in parts of the cave is primarily derived from bat guano.

Biology

"As in most caves of the area, animal life in New Cave is sparse and consists mainly of arthropods. Among the troglobites (animals which live only in caves) are found isopods, millipedes, diplurans and a spider. Troglophiles (animals which prefer to live inside the cave but can live outside) are represented by spiders, collembola, Rhadine beetles, mites, centipedes, and a cave cricket. Trogloxenes (animals which live in the cave but must spend a portion of their life outside the cave) include harvestmen, cave crickets, and two species of spiders. Various "accidentals" which stray into the cave are occasionally found. Rhadine beetles and cave crickets are the most commonly observed creatures in New Cave.

"Bat, camel, deer, and bison bones have been found in New Cave. Bat bones of a now-extinct species were found under flowstone and proved to be more than 17 thousand years old. Today, however, bats and other vertebrates rarely enter the cave, except for occasional protection in the constant 14-16°C (57-61°F) environment."

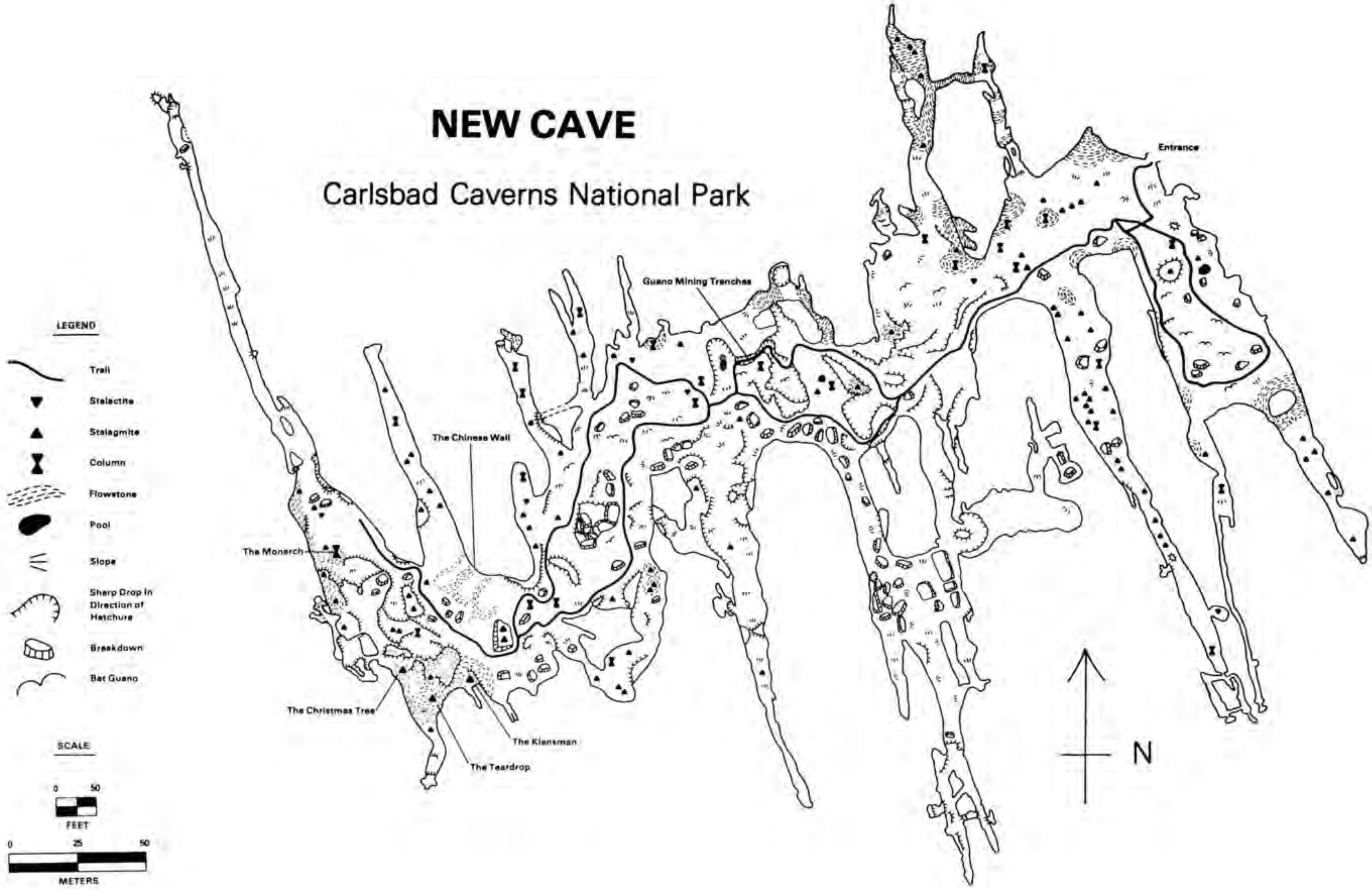


Figure 39. Interpretive Map of New Cave.

The Lilburn Cave Project—CRF Merger

Stanley Ulfeldt

At the November, 1976 Board of Directors meeting, a merger of the Lilburn Cave Project and the Cave Research Foundation occurred. Here we present the rationale behind this association and a description of the Lilburn Cave Project.

Background

The Lilburn Project currently operates in an analogous situation to that under which the CRF operates in Mammoth Cave National Park. The Lilburn project is recognized by the National Park Service as a natural science research project in Kings Canyon National Park, California. The group consists of about six long-term regulars who constitute the "backbone" of the project and about two dozen others who participate somewhat regularly. In order to achieve the status and effectiveness required to pursue a productive research program, merger with the CRF seemed advisable. Combined operation will provide the Lilburn Project with the sanction of a recognized research organization, which will:

1) Provide the organizational framework required to build an effective research project.
2) Insure continuity of research at Lilburn and the continued protection of this large, unique cave system.
3) Enable the Project to deal effectively with government agencies and conservation organizations and to seek project funding.
4) Facilitate recruitment of qualified researchers from the university community and provide the recognition and status to attract serious "project-oriented" cavers.
5) Provide a framework for the evaluation of proposed projects and for the critical review of active projects.

Merger will open to both organizations:

1) A channel for exchange of information and ideas and for contribution to the current body of knowledge of caves.
2) A broader range of cave environments as potential research areas.
3) A larger and more comprehensive manpower base with opportunity for the mobile caving citizenry to continue its interests in project caving.

An Overview of the Lilburn Project

The Lilburn research project was organized to explore and study a cave system in a manner consistent with its fragile, non-renewable nature. It is conducted under the auspices of The National Park Service as Natural Science Research Project SKC-N-33, Lilburn Cave and the Karst of Redwood Canyon. The thrust of the project is to acquire knowledge of a cave system's resources, environment and ecology and to assemble and publish this knowledge so that it may be applied by others in their management of our limited cave resources.

The project is divided into two parts, the development of basic information regarding the area and the pursuit and/or support of detailed research on specific problems which can be effectively studied in the Lilburn system. The compilation of basic information on the cave system and the surrounding karst includes: 1) the exploration and mapping of the cave and the surrounding surface area; 2) basic studies of the geological, hydrological, paleontological, archeological and biological resources of the cave system; and 3) the identification of opportunities for specific research projects.

The generation of basic information must obviously precede detailed work and it is now well advanced. Mapping of the major portions of the cave and karst area is nearly complete. Field work on the geology, geomorphology and geohydrology of the system is also well advanced. Preliminary work on the biology of the system has yielded a new species of troglobitic isopod and established the extension of the range of a sun spider.

Since 1969, a water flow recorder has been maintained at Big Spring, the resurgence of the cave stream. A micro-computer data logging and experiment control system is planned for installation. This system will be able to handle numerous diverse experiments and monitoring stations with specific programmed control for each. It will initially be used to monitor water flow and temperature. Instruments to measure conductivity, pH, specific ions and turbidity will be added later.

The Lilburn Cave System is ideally suited as a "laboratory cave" because its entire watershed area is situated in an uninhabited and seldom visited section of Kings Canyon National Park. This provides the long-term protection from human development that is essential for many types of research.

Lilburn Cave is one of the most significant of the Sierran caves. It contains examples of most of the features found in western caves and an active stream system with the only known ebb and flow spring that is accessible from inside the cave. This provides a unique opportunity for basic research into karst hydrology and hydrodynamics. Studies of the sediments in the cave by pollen analysis and paleomagnetic dating look promising. These studies may yield information on the chronology of cave development and the paleoclimatology of the area.

Lilburn cave is not only the largest known cave in California, it is also the most complex and contains areas which are among the most difficult and/or hazardous to enter. Exploration and survey work for scientific purposes, unlike sport caving, precludes the avoidance of such areas. Thus, underground work for the Lilburn project not infrequently requires a much greater seriousness of approach on the part of the personnel involved than is common elsewhere.

Unfortunately, caution and skill cannot eliminate the possibility of accident, only render it improbable. Steps, therefore, have been taken to prepare against such a contingency. Emergency planning and collection of the specialized equipment needed for cave rescue has been given priority over other tasks. A specialized underground evacuation stretcher, more advanced than others used in America, has been developed. It will be kept at the Grant Grove Ranger Station for use at Lilburn and other caves.

The Lilburn project provides many opportunities for individuals to contribute to our knowledge and understanding of caves, but the delicate nature of many cave features dictates the need to protect study areas from interference.

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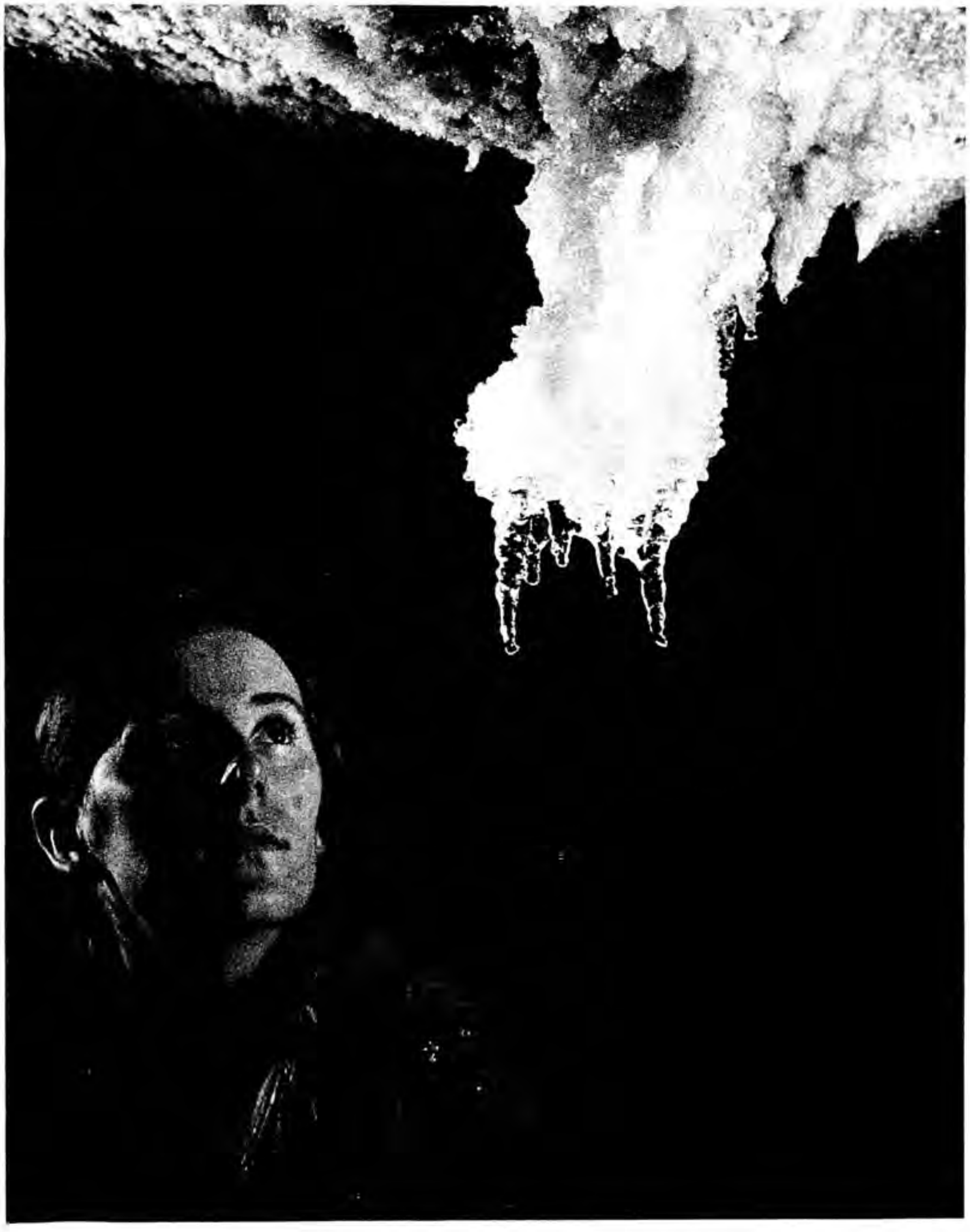

Figure 40. Judy Parker examines an extremely rare crystalline formation with transparent ends. The mineral is tentatively called bruckerite, and was first described by Fred Benington as composed of sodium hemicalcium sulfate dihydrate. Location is Benington Grotto in Turner Avenue of the Flint Mammoth Cave System.

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———— (in press). "Role of solution kinetics in the development of karst aquifers." *International Assoc. Hydrogeol. Memoir 11.*

———— and E. L. White (1976). "Base-level control of underground drainage in the Potomac River Basin." *Proc. 4th Conf. on Karst Geol. and Hydrol.* H. W. Rauch and E. Werner, Eds., *W. Va. Geol. Survey*: 41-53.

Yarnell, R. A. (1976). "Early Plant Husbandry in Eastern North America," in *Cultural Change and Continuity: Essays in Honor of James B. Griffin*, C. Clelland (Ed.), Academic Press, New York, pp. 265-273.

PAPERS GIVEN AT PROFESSIONAL MEETINGS

American Institute of Biological Sciences Meeting. (Corvallis, Oregon, August, 1975).
Ellen S. Levy
"Scavengers on Stilts."

55th Annual Meeting of the Central States Anthropological Society. (St. Louis, MO, March, 1976).
Kenneth C. Carstens
"Recent Investigations in the Central Kentucky Karst: A Preliminary Temporal Ordering of Several Surface Sites in the Mammoth Cave Area, Kentucky."

79th Annual Meeting, Texas Academy of Science. (College Station, TX, March, 1976).
Ernst Kastning
"Development of Pseudokarst Features, with Examples from East, Central, and Northwest Texas."

International Symposium on Hydrologic Problems in Karst Regions. (Bowling Green, Ky, April, 1976).
Ernst H. Kastning
"Faults as Positive and Negative Influences on Groundwater Flow and Conduit Enlargement within Karst Aquifers."

International Symposium on Hydrologic Problems in Karst Regions. (Bowling Green, KY, May, 1976).
W. B. White
"Conceptual Models for Carbonate Aquifers: Revisited."

American Institute of Biological Sciences Meeting. (New Orleans, LA, June, 1976).
Ellen S. Levy
"Feeding Selectivity of the Cave Cricket, *Hadenoecus Subterraneus.*"

Barbara Martin and T. L. Poulson
"Bat Guano Arthropod Communities."

T.L. Poulson
"Cave subcommunities based on food payoff and on risk."
"Ecological Convergence in Terrestrial Cave Communities."

National Speleological Society Meeting. (Morgantown, W. Va., June, 1976).
P. Gary Eller, Carol Hill, and Peter Hauer
"Recent Investigations into the Origin of Nitrates in Cave Sediments: Replication of the Saltpetre Conversion Process at Mammoth Cave National Park."

P. Gary Eller, Peter Hauer, Carol Hill, and Duane Depaepe
"Saltpetre Production from Cave Sediments—An Important and Early American Chemical Industry."

John W. Hess
"Interpretation of Chemical Hydrographs for the Central Kentucky Karst."

Ernst H. Kastning
"Cave Hermits: Vignettes of America's Past."
"Hydrologic and Geomorphic Aspects of Karst Features in the Blaine Gypsum (Permian), Red River Basin, Northwest Texas."
"Granite Pseudokarst, Llano County, Texas, with Special Reference to Enchanted Rock Cave."

W. B. White and G. H. Deike
"Hydraulic Geometry of Solution Conduits."

American Chemical Society National Meeting (Centennial Meeting). (San Francisco, CA, August, 1976).
P. Gary Eller
"Saltpetre Production from Cave Sediments—An Important and Early American Chemical Industry."

Twelfth American Water Resources Association Meeting. (Chicago, IL, September, 1976).
G. Aron and E. L. White
"How Feasible is Interbasin Water Transfer?"

Second National Cave Management Symposium. (Mountain View, AR, October, 1976).
James Keith
"Underground Nature Preserves in Indiana."

T. L. Poulson and T. C. Kane
"Biological Diversity and Ecosystem Stability: Principles and Management Applications."

75th Annual Meeting of the American Anthropological Association. (Washington, D. C., November, 1976).
G. Crawford and Richard A. Yarnell
"The Paleoethnobotany of the Carlston Annis and Bowles Sites, Kentucky."

First Conference on Scientific Research in National Parks. (New Orleans, LA, November, 1976).
W. Calvin Welbourn
"Fauna of the Earth Cracks of Wupatki National Monument, Arizona"

Geological Society of America Meeting. (Denver, CO, November, 1976).
E. L. White and W. B. White
"Quantitative Morphology of Landforms in Carbonate Rock Basins."

W. B. White
"Karst Landforms in the Wasatch and Uinta Mountains, Utah."

Midwest Regional Meeting of the Animal Behavior Society. (Chicago, IL., November, 1976).
Ellen S. Levy
"Feeding Biology of the Cave Cricket (*Hadenoecus Subterraneous*)."

Southeastern Archaeological Conference (Tuscaloosa, AL, November, 1976).
William Marquardt and Patty Jo Watson
"The Research Potential of Shell Middens: Methodological and Analytical Considerations." "Excavation and Recovery of Biological Remains from Two Archaic Shell Middens in Western Kentucky."

THESES

Keith, James H. (1975) "Biotic and abiotic studies of a terrestrial cave ecosystem in Indiana," Ph.D. dissertation in Ecology, Indiana Univ., Bloomington, IN.

Levy, Ellen S. (1976) "Aspects of the biology of *Hadenoecus subterraneus* with special reference to foraging behavior." M.S. Thesis in Biological Sciences, University of Illinois at Chicago Circle, Chicago, IL.

Patch, Diana C. (1976) "An analysis of the archeological shell mounds of freshwater mollusks from the Carlston Annis Shellmound, West Central KY." Senior Honors Thesis in Anthropology, Washington University, St. Louis, MO.

Van Zant, Terry (1976) "Resource partitioning in carabid cave beetles: Body size, substrate, and habitat characteristics." M.S. Thesis in Biological Sciences, University of Illinois at Chicago Circle, Chicago, IL.

PROFESSIONAL, INTERPRETIVE, AND ADVISORY PRESENTATIONS

Bridgemon, Rondal R., "Wupatki Earth Cracks", May 1976 talk at Wupatki National Monument, Arizona.
——————— "Underground Wilderness", Nov. 7 talk at Arizona Wilderness Study Comm. Leadership Workshop, Lake Pleasant, AZ.

Brucker, Roger W., "Cave Conservation." February 1976, Sierra Club Meeting. Dayton Natural History Museum.

——————— "The Longest Cave." July 1976, public lecture, Mammoth Cave National Park.

——————— July 1976, Led a Field Trip of The Nature Conservancy to Mill Hole Farm.

——————— "Writing the Longest Cave." September 1976, Cash Limited Economic Club, Yellow Springs, OH.

——————— "The Longest Cave and How it Got That Way." September 1976, Adult Discussion Group, Presbyterian Church, Yellow Springs, Ohio.

——————— "The Longest Cave." October 1976, talk presented at the University City Library, St. Louis, MO.

———— "Kentucky's Cave Resources: Why Protect Them?" Annual Meeting of The Nature Conservancy, Kentucky Chapter, Natural Bridge State Park, KY.

———— Several appearances on radio and television describing experiences in relation to *The Longest Cave*.

DePaepe, Duane, "Historical Geography of the Mammoth Cave National Park Saltpetre Industry." June 11, 1976, presentation for Seasonal Orientation Program at Mammoth Cave National Park.

Hill, Carol A., "Minerals of Mammoth Cave." July 8, 1976, public lecture at Mammoth Cave National Park.

Meloy, Harold, "Historic Maps of Mammoth Cave." June 10, 1976, presentation for Seasonal Orientation Program at Mammoth Cave National Park.

———— "Historic Maps of Mammoth Cave." July 17, 1976, public lecture and part of the Mammoth Cave National Park Association annual meeting.

Palmer, Arthur N., "Cave Geology." July 1976, public lecture, Mammoth Cave National Park.

Poulson, Thomas L., "Experimental analysis of community organization: Insights from the biology of cave species." Seminars at the following institutions:
Stanford University, Biol. Sciences Dept.
University of Nebraska, Division of Life Sciences
University of Cincinnati, Dept. of Biological Sciences
Northwestern University, Dept. of Biology
University of Illinois at Urbana, Dept. of Entomology
University of Illinois at Chicago Circle, Dept. of Biological Sciences

———— "Cave Communities and the Biology of Cave Animals." August, 1976, public lecture, Mammoth Cave National Park.

Sides, Stanley D., "The Longest Cave." September 18, 1976, Banquet address, Mississippi Valley-Ozark Region Convention of the National Speleological Society, Perryville, MO.

Watson, Patty Jo, and Louise Robbins, "Archeology of the Mammoth Cave Area." June 11, 1976, presentation for Seasonal Orientation Program at Mammoth Cave National Park.

————"Archeology of the Mammoth Cave Area." July 13, 1976, public lecture, Mammoth Cave National Park.

Watson, Richard A., "Outdoor Adventure and Caving." September 8, 1976, talk at Washington University, St. Louis, MO.

Welbourn, W. Calvin, "Cave Fauna of Carlsbad Caverns National Park." February 1976, seminar for National Park Service employees at Carlsbad Caverns National Park.

———— and P. Gary Eller, "Natural Resources Seminar No. 7: Research Programs of the Cave Research Foundation in the Southwest Region, National Park Service." May 1976, Presentation at NPS Southwest Regional Office, Santa Fe, NM.

SPECIAL PUBLICATIONS

New Cave Map Card, map and interpretive text, Cave Research Foundation, 1975.

Wupatki National Monument-Earth Cracks, 59 pp. with maps and illustrations, Rondal R. Bridgemon (Ed.), Cave Research Foundation, 1975.

Contributions to *Proceedings of the First National Cave Management Symposium, Albuquerque, NM, October 1975* (published 1976(:
Roger W. Brucker, "Caves and Cavers—An Overview," pp. 2-5.
Carol A. Hill, "Mineralogy," pp. 24-27.
John W. Hess, "A Review of Cave Geology and Hydrology," pp. 28-31.
Thomas L. Poulson, "Management of Biological Resources in Caves," pp. 46-52.
Roger W. Brucker, "Comments on Carrying Capacity," p. 72.
W. Calvin Welbourn, "Physical Controls for Visitor Management," p. 89.
"Cave Research Foundation Joint Venture Agreement," pp. 102-103.
John Corcoran III, "Cave Surveying—Basic Techniques and Purposes," pp. 123-124.
James M. Hardy, "Control Surveys and Computer Processing of Cave Surveys," p. 125.
P. Gary Eller, "Agency Objectives and Philosophies—The Cave Research Foundation's Viewpoint," p. 146

Management Structure

DIRECTORS

Roger W. Brucker, President
Dennis E. Drum, Treasurer
Stephen G. Wells, Chief Scientist
Charles F. Hildebolt, Operations Manager for the Central Kentucky Area
Patricia P. Crowther, Cartographer
W. Calvin Welbourn, Secretary and Operations Manager for the Guadalupe Escarpment Area
R. Pete Lindsley, New Projects Operations Manager
Stanley D. Sides, Historian
Rondal R. Bridgemon, Conservation Affairs

OFFICERS AND MANAGEMENT PERSONNEL

Guadalupe Escarpment Area Management Personnel:

Manager	W. Calvin Welbourn
Personnel	Rondal Bridgemon
Cartography	James Hardy
Field Station	Ron Kerbo
Finance and Supply Coordinator	Karen Welbourn
Log Keeper and Survey Book Coordinator	Len Jelinek

Central Kentucky Area Management Personnel:

Manager	Charles F. Hildebolt
Cartography	Patricia P. Crowther
Field Station	Robert O. Eggers, Roger L. McMillan
Log Keeper	Jennifer A. Anderson
Personnel	L. Greer Price
Safety	Norbert M. Welch
Vertical Supplies	Donald E. Coons
Supplies	Tomislav M. Gracanin

Lilburn Cave Project Management Personnel:

Project Director and Northern California Coordinator	Stan Ulfeldt
Southern California Coordinator	Ellis Hedlund
Central California Coordinator	Allen Meyer

Operating Committies

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

R. Pete Lindsley, Chairman
Roger W. Brucker
Stephen G. Wells
John P. Freeman
Rondal R. Bridgemon
W. Calvin Welbourn

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

Dennis E. Drum, Chairman
Stanley D. Sides
Roger W. Brucker
Patricia P. Crowther
Charles E. Hildebolt
W. Calvin Welbourn
Karen Welbourn
Gordon L. Smith

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

Thomas L. Poulson, Chairman
John W. Hess, Jr.
William B. White
Patty Jo Watson
Carol H. Hill
Steven G. Wells

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

Rondal R. Bridgemon, Chairman
Joseph K. Davidson
William P. Bishop
Stanley D. Sides
Philip M. Smith
Richard A. Watson

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

Stanley D. Sides, Chairman
Richard A. Watson
P. Gary Eller
W. Cal Welbourn
Philip M. Smith
Denver P. Burns

FIELD OPERATIONS

The Guadalupe Escarpment Area:

Nine expeditions were fielded in the following areas:

Carlsbad Caverns National Park (5)
Guadalupe Mountains National Park (1)
Lincoln National Forest, Guadalupe District (1)
Bureau of Land Management, Roswell District, Fort Stanton Cave (1) Dry Cave (1)

The Central Kentucky Area:

Ten expeditions were fielded from the Flint Ridge Field Station, Mammoth Cave National Park.

Numerous small, special purpose expeditions were also fielded in both the Guadalupe Escarpment and Central Kentucky areas.

List of Past Fellowships (F) and Grants (G) Awarded

Each year the Cave Research Foundation mails announcements of its fellowship and grant program to university graduate departments of natural and social science, and to others. Applications are screened and evaluated by a committee of scientists. Awards are made on the basis of the possible contribution of the proposed study to knowledge and the promise of the individual as a scientist.

1976 (G) David L. Bechler, Saint Louis University, "A Genetic Analysis of Epigean and Hypogean Populations of *Gammarus* and *Crangonyx* (Amphipoda: Gammaridae)."

(G) Stephen A. Chomko, University of Missouri—Columbia, "Small Mammalian Fauna as Environmental Indicators: A Case Study in Northwestern Wyoming."

(1975) (F) Mickey W. Fletcher, Southwest Missouri State University, "Microbial Ecology of Bat Guano."

(G) Barbara J. Martin, University of Illinois at Chicago Circle, "Cave Communities around Bat Guano."

(G) Jim I. Mead, University of Arizona, "Pleistocene Plant and Animal Remains in Vulture Cave, Arizona."

1974 (F) Stephen O. Sears, Pennsylvania State University, "The Inorganic and Stable Isotope Geochemistry of Groundwater Recharge through Unsaturated Soils in a Carbonate Terrane."

(G) Kenneth C. Carstens, "Surface Archeology of the Mammoth Cave National Park Area."

(G) Glenn D. Campbell, Texas Tech University, "Activity Rhythm of the Genus Centhophilus (Orthoptera)."

1973 (F) Thomas C. Kane, Notre Dame University, "A Comparison of Foraging Strategies: *Neaphaenops tellkampfii* vs. *Pseudanophthalmus menetriesii.*"

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

(G) David Jagnow, University of New Mexico, "Factors Controlling Speleogenesis in the Capitan Reef Complex, New Mexico and Texas."

1972 (F) Russell S. Harmon, McMaster University, "Ages and Paleoclimates of Karst Areas based on Isotope Distributions in Speleothems"

1971 (F) Horton H. Hobbs, III, Indiana University, "A Study of the Crayfishes and Their Epizootic Ostracods in Pless Cave, Lawrence County, Indiana."

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

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

1968 (F) Alan P. Kovich, Yale University, "Paleoecology of Lacustrine Bored Shells and Ultrastructural Diagenesis"

(G) David C. Culver, Yale University, "The Ecology of Cave Crustacea from West Virginia

1967 (F) David Culver, Yale University, "The Ecology of Cave Crustacea from West Virginia

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

Contributors To This Report

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