EIGHTH ANNUAL REPORT

of the

CAVE RESEARCH FOUNDATION

For the year ending

December 31, 1966

INTRODUCTION

Throughout 1966 the Cave Research Foundation has continued its broad-based program of research in the cave related science. Some 23 projects were active during the year with a large number of the older projects either being completed or nearing completion.

An event of signal importance in 1966 was the publication of the Flint Ridge Folio. This folio provides the scientist, for the first time, a base map showing approximately 44 miles of passage in the Flint Ridge Cave System which had been surveyed up to 1962. As with any active project, the first edition was out-of-date by the time it left the press. Field work on which the second edition will be based is already well underway and the exploration and surveys of the past several years have already extended the system well beyond the combines of the first edition.

The active projects fall into such diverse fields as hydrology, stratigraphy, mineralogy, geomorphology, ecology, physiology, archaeology, and history. A summary of the year's progress in each is below in the section on scientific programs.

A certain change in direction may be noted in these programs reflecting the Foundation's increasing maturity of outlook. Speleology in the classical sense has limited itself, in the United States, to investigations of caves as objects of interest in themselves. There has been little attempt to evaluate the potential usefulness of speleological information to the remainder of the scientific community. It has been increasingly clear that if cave studies are to be valued by workers in other disciplines they must have relevance to the other fields. The Foundation has placed increased emphasis on two areas in which such relevance is especially evident. These are the areas of groundwater hydrology and systematic ecology.

Water supply and pollution control are matters receiving national concern. Of the various types of aquifers, cavernous limestones are the least understood and yet present the greatest problems particularily in the transmission of pollution. The speleological research is of immense value in the study of this problem because here the cave systems are regarded as observable fragments of an integrated drainage network and from the abandoned systems a picture can be constructed of how the water has moved in the past and thus by inference and occasionally by direct observation how it is moving at present. The lower levels of the cavern system provide sampling points at which the waters which move in the karst aquifer can be sampled and examined directly. To construct a proper hydrological model, one must not limit his attention to a single cave system but must examine the entire drainage basin, thus expanding from the limited Flint Ridge Cave System to an area encompassing hundreds of square miles of the Central Kentucky Karst.

A second way in which a cave system can be studied is to regard it as a small eco-system with a limited but complex community of organisms. The environment is rather special--food is limited; light is absent. How do the animals in the cavern environment react to the limited energy sources? Do they compete? How do they maintain their bodily rhythms in the absence of the time signals provided by the sun and the changing seasons to surface creatures? The answers to these and other questions are sought by the examination of the dynamics of the total cave community. By observing changes in population sizes, migrations, feeding and breeding habits, and reactions to such seasonal fluctuations as are present due to floodings and increased dripping in vertical shafts, answers are provided to questions that are of much import to modern biology, an import not limited to either the cave or to its peculiar fauna.

During August the Foundation was honored by a visit from Professor Herbert Lehmann and Professor Alfred Bögli. The visitors were escorted through the Central Kentucky Karst and were provided with an airplane traverse so that they could obtain an overview of the surface features. Professor Lehmann collected soil samples and observed surface features in preparation for a forthcoming International Karst Atlas Sheet on the Central Kentucky Karst. Professor Bögli was given an inspection trip through the Flint Ridge Cave System so that he could compare it with the Hölloch Cave in which much of his own research has taken place.

Many of the programs operated by the Cave Research Foundation are conducted in Mammoth Cave National Park. The continuing cooperation of the National Park Service through the Superintendent, Naturalist Staff, and Rangers of Mammoth Cave National Park has been invaluable in achieving many of the objectives described in this report.

During the past year the Foundation has again benefited from the financial support of the United States Steel Foundation. This support is gratefully acknowledged.

CARTOGRAPHY PROGRAM

Survey of the Flint Ridge Cave System: (Denver P. Burns, CRF)

The first edition of the Flint Ridge Cave System Folio was published early in 1966. This document culminates more than 10 years of survey effort and reports the first 44 miles of the Cave System surveyed through 1962. The cave is shown on 30 quadrangles each 30 seconds in latitude by 30 seconds in longitude with a scale of 1:3000. Copies of the folio were presented to the National Park Service in a special ceremony on June 25, 1966.

Exploration during 1966 has been concentrated in the newly discovered portions of the cave under Houchins Valley. Here intricate networks of low and sometimes water-filled passages make progress difficult and surveying extremely tedious. The most outstanding discovery has been a small trunk channel paralleling the valley axis. This is in marked disagreement with current hydrological thinking about the development of trunk drain passages and is thus of more than casual interest. Many of the new passages in this area have been surveyed.

Another new discovery in November lies in the northwest corner of Flint Ridge. A glance at the folio will show that this area is remarkably devoid of known cave, a situation which seems unlikely on geological grounds since the cave density in other parts of the ridge is so high. Concentrated efforts have been made to push the exploration across Floating Mill Hollow which acts as an effective barrier to all higher level passages. This barrier has been overcome and about a mile of new walking-height passage has been explored. This trunk channel is also in a key position in the understanding of the hydrology of such conduits and further examination of the area is required.

A first start has been made toward the re-survey of many of the known parts of the cave to provide additional passage detail for future editions of the folio. Work during the past year has been concentrated in Floyds Lost Passage and related areas.

Surface Reconnaissance: (Denver P. Burns, CRF)

Explorations by surface parties to locate new cave entrances and interesting karst features were continued at irregular intervals during the year. Some transit surveys were also run to provide benchmarks for an anticipated leveling program.

Location of Cave Passage by Instrumental Methods: (Alan Hill, CRF)

Various electronic methods are being developed and tested for transmitting highly directional signals from cave passage to surface. These are very useful for locating cave passages with respect to surface features and have been used successfully to close surveys by providing a link between underground and surface survey lines. Several tests have been completed in the Grand Canyon, Argo Junction, and the Overlook Areas with promising results.

THE HYDROLOGY PROGRAM

Hydrology Review: (William B. White and Elizabeth L. White, CRF and Pennsylvania State University)

A review paper is being prepared covering mainly the North American contributions to limestone hydrology and putting these into a conceptual setting. A summary appears below:

Limestone aquifers, with their special problems, are of several types: Diffuse flow aquifers in which flow is through solutionally modified joints and poorly integrated cavities, maturely karsted aquifers where flow is through the channels and conduits of a well-integrated drainage net, and artesian karst aquifers where geologic structure plays a dominent role. Examples of the first type include many dolomite aquifers, particularly in low relief terrains, of the second are the karst of the Appalachians, Interior Plateaus, and Ozark Mountains, of the third, the South Dakota and Roswell Artesian Basins.

In addition to diffuse recharge many limestone aquifers are recharged by sinking streams. The flow in the channel and conduit types is turbulent gradients are low, and long penetration distances without saturation are possible.

The carbonate equilibria between the groundwater and the wallrock are complex with equilibrium apparently being achieved in the diffuse recharge but not always being achieved in the concentrated conduit flows. In some areas diffuse recharge is depositing travertine while the cofncentrated recharge is dissolving wallrock.

Limestone aquifers suffer from special problems with respect to the transfer of pollution and the development of water supply. The relative importances of diffuse versus concentrated flow is still unknown. Prediction of flow paths is marginally possible to impossible. Calculation of storage is difficult to impossible.

Paleohydrology of Mammoth Cave and the Flint Ridge Cave System: (George H. Deike and William B. White, CRF and Pennsylvania State University)

This study is nearing final completion. A partial manuscript has been written describing the interconnections of the main portions of the drainage nets in the two large cave systems and presenting some calculations of the paleo-flow velocities and discharges from the main trunk passages. Drainage basin areas are calculated from spring discharge data. The hydrologic role of many of the minor passage types has been delineated. It is expected that this study will be submitted for publication early in 1967.

The Hydrological Role of Vertical Shafts: (Roger W. Brucker, CRF)

Vertical shafts have long been recognized as the principle routes by which groundwater moves from the perched aquifer in the overlying caprock to the base level. The exact mechanism by which the development of shaft complexes takes place has remained in doubt. One of the characteristic features of shaft complexes are the very intricate networks of drains. Active drains occur at the bottom of the shafts and abandoned drains occur at many elevations along the shaft. During June a major expeditionary effort was mounted to survey the shaft drain complex in the Overlook Area in great detail. This information will be used to interpret the hydrologic development of this typical shaft complex.

SEDIMENTATION, MINERALOGY, AND PETROLOGY

Petrology of the Mid-Mississippian Limestones: (James F. Quinlan, CRF and The University of Texas)

The object of this study is to determine the petrologic characteristics of the Mississippian limestone sequences from the top of the St. Louis into the overlying clastics. Additional field work was done in the Summer of 1966 and all necessary samples have now been collected. Some six 200-foot sections in Mammoth Cave and in various cliffs, quarries, and roadcuts have been measured and sampled at six inch intervals. Much laboratory work on the preparation of thin-sections, peals, and etched slabs and their examination by petrographic microscope remains to be done. This project will form the central part of the investigators PhD Thesis in Geology at the University of Texas.

Mechanism of Aragonite Deposition: (William B. White, CRF, and Eugene W. White, Pennsylvania State University)

Aragonite is metastable in the low temperature, low pressure environment of the limestone cavern and yet aragonite is a very common cave mineral. Recent work by Siegal in Great Onyx Cave has shown that aragonite is also very common in the Central Kentucky Caves. While it has become quite clear that aragonite precipitates from solutions that are supersaturated with respect to both calcite and aragonite, the mechanism which allows the higher energy aragonite form to persist has not been discovered.

McCauley and Roy, in experimentation with the synthetic formation of calcium carbonate by precipitation from silica gels, have proposed a topotactic mechanism by which the aragonite precipitates on a pre-existing nucleus of an aragonite structure phase. They demonstrated their mechanism for their synthetic crystals by controlled experiments in the gels and by electron microprobe studies of the crystals. Strontium and magnesium ions are both known to enhance aragonite deposition. Strontium functions by precipitation as strontianite which has the aragonite structure and thus forms a nucleus on which aragonite can grow. But magnesium carbonate has the calcite structure. McCauley and Roy propose that $MgCO_3$ precipitates as nesquehonite, a tri-hydrate of magnesium carbonate with an aragonite-like structure.

It would be most interesting to know if this mechanism also applies to natural aragonite and particularly to the precipitation of aragonite from the cave environment. To check this, thin sectipns have been prepared of several dozen aragonite speleothems from a variety of caves in eastern United States including Mammoth Cave. These sections are being examined in the petrographic microscope for growth textures and by the electron microprobe for concentrations of magnesium and strontium in the nuclei of the crystal grains. The existance of such nuclei would suggest that the magnesium and strontium had precipitated first and that the aragonite had grown around it in support of the McCauley-Roy theory. Preliminary results show bright spots in the proble traces for magnesium which may indeed be these early nuclei.

Manganese Mineralization: (James R. Fisher and William B. White, CRF and The Pennsylvania State University)

Many free surface streams in limestone caves contain black coatings of poorly crystallized manganese minerals. These minerals also occur as nodules on the Ocean Floor and have been of great interest to Oceanographers but virtually nothing is known of the fresh-water cavern varities. The object of this study is to collect, analyse, and interpret a suite of these minerals from a wide variety of caves in Eastern United States. Collections from Kentucky, Tennessee, Alabama, and Georgia were made during the field season of 1964. Some laboratory work and the collection of a few more specimens was completed during 1965. During 1966, chemical analyses were completed on 10 of the most promising specimens and x-ray diffraction patterns were obtained.

The results of the emission spectrographic analyses are shown in table 1. and the localities from which these specimens were obtained are shown in table 2. It can be seen that the trace element concentrations vary widely and no particular conclusions can be drawn at the present time. It was not possible to analyse for manganese with the method employed for the trace elements. All specimens examined are very calcium rich, mostly greater than the 10% upper limit of the analytical method. The high calcium concentrations suggest that all of these specimens are of the todorokite type. Barium is present in relatively large amounts in most specimens but not in sufficient quantities to classify the minerals as hollandites or psilomelanes.

All specimens examined by x-ray diffraction were amorphous to x-rays. This lack of crystallinity makes it impossible to identify the minerals on the basis of their structure. It seems likely that the various hydrated manganese minerals differ from one another mainly in chemical composition. With this in mind, it is planned to react each specimen under hydrothermal conditions in the presence of water to see if they will recrystallize into something that will give a recognizable powder pattern.

Table 1.

Emission Spectrographic Analyses of Cave Manganese Minerals. All elements except iron and calcium are given in parts per million.

Sample	Copper	Zinc	Chromium	Iron	Magnesium	Calcium	Strontium	Barium
271	900	360	--	2.8	1330	**	70	1760
	915	300	40	2.8	1320	**	55	1900
620	20	--	10	0.8	1370	**	120	3970
	60	60	90	0.6	1450	**	125	3900
580	60	1025	--	1.4	2100	**	190	14.1
	105	1105	--	1.5	2250	**	190	13.2
264	870	270	--	4.6	4200	**	295	2040
	870	310	40	4.6	4000	**	315	2090
214	1490	570	--	8.0	3350	**	175	1960
	1600	710	55	8.0	3400	**	195	2050
209	60	105	--	--	12,200	**	80	13.4
	105	125	--	--	12,100	**	90	14.1
551	3025	600	--	1.0	4400	10.2	960	32.2
	3025	570	--	1.2	4400	10.3	1010	33.9
619	40	1550	--	2.5	5400	**	350	380
	40	1640	--	2.6	5900	**	335	550
636	40	610	5	3.2	6900	**	n.v.	n.v.
	40	560	0	3.2	6700	**	500	10.6
627	400	2650	90	38.	--	9.9	690	--
	400	2600	90	39.	14	10.1	720	--

-- = Below limit of detection

** = Concentration greater than 10%, not measurable by technique used.

n.v. = No value obtained.

Table 2.

Localities of Analysed Minerals

209	Muenster Cave, Iowa	Loose black powder from floor of mineralized cave.
214	Wind Cave, S. Dakota	Loose brown earth-like material from beneath calcite crust in Pearly Gates section of the cave.
264	Wind Cave, S. Dakota	Black manganese mineral from nodule on floor of Attic Passage.
271	Wind Cave, S. Dakota	Brown dirt from geode in boxwork in ceiling.
551	Mammoth Cave, Ken.	Black coating on low ledge in Hawkins' Way near Cathedral Dome.
580	Devil's Icebox Cave Missouri	Thick loose black deposit from main cave stream.
619	Mammoth Cave, Ken.	Manganese mineral-covered chert from Martel Avenue halfway between Pinson's Pass and Nelson's Dome.
620	Snail Shell Cave Tennessee	Coatings from rimstone near main stream passage.
627	Cumberland Caverns Tennessee	Thick loose black coatings from ceiling of Shelah's Bower.
636	Priddy Cave, Ken.	Thin black coating on limestone ledge about 400 feet upstream from entrance.

Humate Deposits: (James F. Quinlan Jr., CRF, and Alfred Traverse, University of Texas)

On the basis of chemical tests, x-ray diffraction, and infrared absorption spectra analysis, varnish-like brown-black coatings that are ubiquitous on the ceiling and walls of parts of the upper-level passages of two caves in Mammoth Cave National Park have been identified as humate that has been concentrated by evaporation of thin films composed of solutions of humic acid in water. At one location in Mammoth Cave the coating is still tacky, but in all the known Salts Cave deposits the coating is completely dry. Along the humate-covered walls are many local "runs" where the humic acid solution coalesced in small, downward-flowing rivulets. Some of these rivulets terminated on projections from which the relatively viscous solution dripped and spattered onto the floor. These isolated deposits on the floor are generally less than an ich in diameter and they are typically composed of cracked and curled fragments that suggest alteration by desiccation-cracking. The humate under consideration is extremely soluble in slightly alkaline water and other weak bases, but it is insoluble in acidic water, acids, and common organic solvents.

The humic acid is probably derived by seepage of an organic accumulation from a swamp (or possibly a sinkhole pond) rather than from percolation of weathering products of a Carboniferous coal. This is suggested by the composition of the portion of the humate which is insoluble in dilute alkali. This alkali-insoluble organic matter makes up about 5 to 10 percent of the total organic matter in our samples. More than 99 percent of this alkali-insoluble residue consists of wood fragments and less than one percent of it is pollen and spores. The pollen and spores are of Recent and/or Pleistocene age. Such a residue would ordinarily be identified as that of a woody peat. Small swamps occur on the ridges overlying the caves, but they have not yet been studied. Additional humate will be collected for carbon-14 analysis.

The black walls of parts of Mammoth and Salts Caves have traditionally been attributed to coatings of manganese and/or smoke from lard oil and kerosene lamps. Recently some of the coatings have been shown to be soot derived from reed torches used by aboriginals. The humate described in this paper is not manganese or soot, nor are its properties similar to most of the amberat (ratite) known from several caves and mines in the western United States, which is generally thought to be dehydrated rat urine. Humate is found in certain contemporary marine and non-marine sediments. It presumably occurs in other caves but has not previously been identified therefrom.

Dynamics of Cavern Sedimentation: (Elizabeth L. White and William B. White, CRF and The Pennsylvania State University)

Groundwater moving through a maturely karsted limestone aquifer may carry, in addition to a dissolved load extracted from solution of the wall rock, a load of clastic material in suspension or as bedload. All of the insoluble residues from the solution of the limestone and in some areas, large quantities of material from overlying or adjacent clastic rocks must be transported out of closed drainage basins by the action of cave streams and sub-water table drainage conduits. Portions of the transported sediments are deposited en-route and form the richly varied cave clastic sediments. These are classified and compared. They vary from fine clays to boulders and form deposits many feet thick.

Standard hydraulic engineering formulae are applied to investigate the type of flow which would have been necessary to transport these sediments to where they are indeed observed, and from this some limits can be placed on past flow regimes. Many free surface streams have beds armored with cobble-sized clastic materials suggesting flow velocities on the order of feet per second. Elliptical tube conduits, where observable in the Central Kentucky Karst, are coated with only a veneer of silt-size sediments suggesting much lower velocities in agreement with the scalloping on the walls. Low gradients and lack of a well-developed system of tributaries implies that most of the sediment load in cave streams moves as bedload and that suspended load is relatively unimportant.

Clastic sediments play an important role in the early stages of solutional development. The silting up of the deeper solution cavities enhances the shallow movement of groundwater. In later stages with a mature drainage net functioning, the clastic sediments on channel floors insulate the bedrock from solutional attack, thus perching flows temporarily above descending base levels and may be responsible for the relative rareity of deep stream-cut canyons in caves.

KARST GEOMORPHOLOGY

Relations of Joints and Fractures to Cavern Development: (George H. Deike, CRF, and The Pennsylvania State University)

The object of this nearly completed project is to relate the orientations of cavern development to various structural controls such as joints, bedding planes, fracture traces and lineaments, After an examination of the structural data collected in previous field seasons it has become apparent that no one control will satisfactorily account for all cave passage. The effort of the past year has been to investigate various statistical models which may mix the structural controls in the proper proportions. A satisfactory model has at last been obtained and will be used to interpret the large amount of field data collected. This work will form the PhD Dissertation of the investigator and the thesis should be submitted sometime early in 1967.

Review of the Central Kentucky Karst: (Richard A. Watson, CRF and Washington University, William B. White, CRF and the Pennsylvania State University, and E. Robert Pohl and Roger W. Brucker, CRF)

This project has had a long and complex history and it is at last nearing completion. The intent has been to provide a lengthy review paper summarizing previous and present knowledge of the Central Kentucky Karst. To this end considerable field work was done in 1962 and 1963 to famaliarize the investigators with aspects of the area other than Flint Ridge, and from

1963 through 1965 a long manuscript was compiled. The problem has been that knowledge of the Central Kentucky Karst has grown very fast in the past five years and the review manuscript always seemed one step behind the cutting edge of advancing research. The ever-growing manuscript has been brought to a conclusion and is now in a next-to-final draft form with part of the illustrations prepared. The most outstanding accomplishment of the past year has been the compilation by E.R. Pohl of a new stratigraphic column for the area. The new column is a contribution from much other stratigraphic research and is much more detailed than anything previously available. It locates, for example, various dolomite beds, recently discovered to play an important role in the development of vertical shafts, and the Lost River Chert in the Ste. Genevieve which plays a dominent role in the interpretations of the surface features of the Sink Hole Plain.

<u>Role of Vertical Shafts in the Retreat of the Chester Solution Cuesta</u>: (James F. Quinlan Jr. CRF and University of Texas, and E.R. Pohl, CRF)

Vertical shafts (near-cylindrical cavities with fluted walls, typically less than 50 feet in diameter and tens to less than 200 feet in height; initiated by solutional enlargement of joints by percolating waters) are common in the Central Kentucky Karst. The impermeability of their shale and sandstone caprock restricts them to the edges of the Chester Cuesta and solution escarpment and the mesas. In this narrow zone of occurrence, generally no wider than 200 feet, vertical shafts number 200 to 500 per linear mile of caprock outcrop. Previous workers have related maximum shaft development to advancing headwaters.

Subsurface karstification (unterirdische Karstphänomen) at the sandstone-limestone contact has differentially lowered both large and small masses of caprock. The detritus (sandstone, shale, and soil) may either collapse catastrophically into the vertical shafts following primary solutional extension or it may subside concomitantly with solution at a rate either more or less rapid than the down-slope movement of soil and colluvium. Some of the "sinkholes" thus formed do not always have topographic expression; they are types of "structural sinks" or even "geological organs". Such processes of self-engulfment or internal erosion account for the steepness of the escarpment and the mesa slopes. Blocks of detritus are milled by gravity impact, weathered, transported in shaft drains to trunk streams of the caves, and disgorged as sand, silt, and solutes at springs that empty into the Green River.

It has long been recognized that the position and geometry of the dry valleys (karst valleys of Malott, 1939), which in this area are blind or hanging, are due to former streams on the unbreached Upper Mississippian and Pennsylvania sandstones, The processes herein described have greatly aided the headward, lateral, and vertical enlargement of this lineation to form the sinkhole (Pennyrile) plain. The transition from cuesta to mesas and knobs to sinkhole plain can be explained in terms of overburden, structure, paleo-drainage pattern, jointing, and stripped structural surfaces on two widespread chert beds within the Ste. Genevieve Formation. Where the dip is relatively steep (300 feet per mile) the Chester Escarpment is steep and outliers (knobs) are sparse or absent. Conversely, gentle, near uniform or undulating dips favor the preservation of the knobs and degraded interstream areas. These relations explain the abruptness of the north-south transition and the gradualness of the east-west transition shown on the Mammoth Cave, Horse Cave and adjacent 15-minute topographic quadrangles.

Benches are prevalent at the horizon of a minor chert bed high in the Ste. Genevieve, but major control of the sinkhole plain is attributable to the Lost River Chert, a persistent 6-foot unit within the Fredonia Member. Both of these chert beds are also important for their role in determining tops and bottoms of vertical shafts. A detailed discussion of these horizons is in preparation.

Fully recognized as also active in slope retreat in the Central Kentucky Karst is the collapse and truncation of cave passages, solution beneath the soil mantle, the formation of sinkholes of various origins, rainwash, and climatic influences.

<u>Review of the Development of Vertical Karst Features</u>: (James F. Quinlan Jr., CRF, and University of Texas)

There is being prepared a critical review of the world literature pertinent to the classification of sinkholes and related vertical karst features. This will be an approximately 400 page manuscript with a 500 item bibliography. A portion of this with special emphasis on the North American literature has been prepared for the AAAS meeting of 1966 of which the abstract appears below.

Karst is a three-dimensional geomorphic phenomenon that must be considered as the sum of all the processes and forms which develop in rocks as a result chiefly of certain combinations fo corrosional, suffosional, and corrasional processes by water acting under the influence of gravity and it is characterized by specific continua of surface morphologies and/or subsurface hydrologies. With such a definition, karst is properly recognized as being more than just the "typical" landforms of limestone and gypsum terranes.

Karst types may be classified trinomially on the basis of:

A. Cover (its absence, presence, origin, nature, relation to topography, and age.)
   1. Naked karst (developed and maintained without any cover).
   2. Subsoil karst (covered with its residuum and soil).
   3. Covered karst (covered with allochthonous rock or sediments; part of contemporary landscape; older than its cover).
   4. Buried karst (paleokarst; covered with allochthonous rock or sediments; not part of contemporary landscape; older than its cover).
   5. Subsurface karst (covered with autochthonous rock or sediments; may or may not be part of contemporary landscape; younger than its cover.)
   6. Denuded karst (subsoil, covered, buried, or subsurface karst from which the cover has been eroded).
   7. Drowned karst (covered by water).
   8. Littoral karst (including some syngenetic karst; in tidal zone).
   9. Permafrost-covered karst (in rock beneath permafrost; a special type of covered karst or subsurface karst).

B. Lithology
  1. Carbonates
     a. Limestone and dolomite
     b. Chalk
     c. Caliche (kunkar)
  2. Evaporites
     a. Gypsum and anhydrite
     b. Salt
  3. Siliciclastic rocks
  4. Sediments (clastokarst)
     a. Clay
     b. Loess
     c. Sand and gravel
     d. Colluvial boulders
  5. Permafrost (thermokarst)
  6. Ice (glacier karst)
  7. Lava
  8. Igneous and metamorphic rocks (exclusive of lava and marble)

C. Position
  1. Morphogenetic Region (after Peltier, 1950)
     a. Glacial
     b. Periglacial
     c. Boreal
     d. Maritime
     e. Selva
     f. Moderate
     g. Savanna
     h. Semiarid
     i. Arid
  2. Physiography and associated geologic structure
     a. Coasts
     b. Plains
     c. Plateaus
     d. Valley and ridge (typified by the folded Appalachians)
     e. Mountains and isolated massifs

The hydrologies of karsts, their characteristic landforms, and the dominant processes operative, are a function of their cover, lithology, and position; karsts may be subclassified accordingly. Many karst types are transitional to one another. The degree of development of a karst is also controlled by the thickness and purity of karst-susceptibile rocks and the presence or lack of less karst-susceptible rocks and their influence.

Karst phenomena in lithologies 1-d, 3, 4, 5, 7, and 8 have traditionally been considered as types of pseudokarst but such classification is not necessary if the karsted lithology is specified.

THEORETICAL SPELEOLOGY

Statistical Properties of the Flint Ridge Cave System: (Rane L. Curl, University of Michigan)

The object of this study is to develop stochastic models for the Flint Ridge Cave System. These statistical models would be useful in the prediction of new cave passage and for describing in a quantitative way the properties of the cave system. The project has only begun with a study of the maps recently made available by the publication of the Flint Ridge Folio. The techniques employed will be similar to those used by the investigator in other karst areas*.

*Rane L. Curl, Caves as a Measure of Karst, Jour. Geol. 74 798-830 (1966)

ECOLOGY

Comparison of Stream Faunas with Food Supply: (Thomas L. Poulson, Yale University and CRF)

This is a study of the ecological balance between aquatic organisms and their sources of food. Data are taken from direct counts on hands and knees. Each individual is examined for size, age, reproductive condition and pinpointed on a map of the cave stream. A summary of some preliminary results for three different aquatic environments are given below.

A. Eyeless Fish Trail to Union Shafts to Golden Triangle Room: Two censuses were taken with a variation of ± 10%. Counted were 20 *Typhlichthys subterraneus*, 22 *Orconectes pellucidus*, and one *Cambarus bartoni*. This amounts to approximately 0.001 fish and 0.001 crayfish per meter. There is a very low food supply with no visable debris and no isopods. The water input is all from a relatively young group of vertical shafts with perennial water input.

B. Colossal River (= upstream Roman River) to Bedquilt Section in the vicinity of Jones Pit. There were an average of three censuses over a two year period. The populations changed by ± 5%. Counted were 25 *Typhlichthys*, 120 *Orconectes*, and 7 *Cambarus*. *Asellus* (isopods) varied from zero to 15 per square meter. There is a high correlation of crayfish with organic matter distributions, a low correlation of fish with organic matter, and an obligate relation of isopods to organic matter. The averages were roughly 0.002 fish and 0.01 crayfish per meter. There is a large concentration of organic matter settled in low gradient parts of the stream which is fed by inwash from the Bedquilt Area and perennial water from vertical shafts in the area. The maximum size of animals is larger than in (A) and the age distribution of crayfish shifted more toward younger age classes indicating more frequent and more total reproduction.

C. Candlelight River to Bretz River: The situation in this area is intermediate between than in (A) and (B).

Terrestrial Fauna in Relation to Entrances: (Thomas L. Poulson and David Culver, CRF, and Yale University)

This is a study of the relation of terrestrial organism populations to food sources such as entrances, areas of seasonal floods, ect. Data come from direct timed counts and trapping with baited and unbaited traps in the same area over a three to five day period with daily checks. Traps are designed to exclude adult crickets. It is concluded that wet areas have highest diversity with least food and least catholic food habits.

A. Cathedral Cave: Studied for comparison to Flint Ridge because of the large amount of food and the high proportion of troglophiles over troglobites which seems to result from the troglobites losing out in competition when there is a lot of food. Methods used in this study have turned up two to three times as many species as G. Nicholas' study and have shown these animals to be important to an interpretation of the earlier study.

B. Transect from outside Austin Entrance to Pohl Avenue and to other passages:

1. Entrance Area: Young crickets do not migrate out of the cave nightly as do adults. A gradient of numbers caught per day is 0, 5, 15 (entrance itself), 20 (drop into Pohl Avenue), 40 (Cave rat area), 15, 4 (opposite Columbian Avenue). There are no troglobites at all in this area.

2. "Dry" areas away from food sources (counts give similar data to trapping.).

a. Pohl Avenue (Columbian Avenue to Union Shaft crawl), Storm Sewer, and Big Canyon gives roughly 2 to 5 crickets per day and less than one Neaphenops (beetle) per day.

b. Mallott Avenue, Between Overlook and Camp Pit, and entrance to Black Onyx Area: These are gypsum sand areas where crickets probably lay their eggs. Counts give 3 to 10 Neaphenops and zero to three crickets per minute whereas trapping gives 5 to 12 crickets and zero to less than one Neaphenops per day. Since wet areas give counts of 1 to 2 crickets and zero to less than one beetles per minute but give catches of 2 to 10 crickets per day, 1 to 6 beetles per day, and 1 to 2 collembola and thysanura per day, we conclude that beetles will specialize on a good food supply, cricket eggs, when available but be attracted to other baits in areas where crickets do not breed.

3. Wet areas away from food sources:

a. Eyeless Fish Trail and lower Columbian Avenue: Counts are similar to those described in (2_b). These areas had the highest diversity of troglobites even though they are lowest in obvious food. It may be pertinent that these areas flood every few years.

b. Young shafts such as the Union Shafts and the Overlook: The terrestrial fauna is similar to (3-a) but with a higher cricket density. The aquatic fauna consisted of planarians (Sphalloplana percaeca) alone with a count of 0 to 20 per square meter.

4. Wet areas near food inputs such as the Black Onyx Waterfall area: There is a lower diversity than in (3). Crickets and beetles are of one species each. There is a slightly higher density of crickets with trapping rates of up to 15 per day.

Is Amblyopsis spelaea a Native Species? (Thomas L. Poulson, CRF and Yale University)

This problem is being investigated by analysing history (books and personal interviews with old timers), present populations (whether competition with Typhlichthys restricts A. spelaea distribution to habitats that it does not occupy in northern Kentucky and southern Indiana, and whether there are extant breeding populations of the species), and patterns of morphological variation (do specimens from the Mammoth Cave area show separate patterns of their own or is it typical of the northern Kentucky and southern Indiana patterns?).

Changes in Faunal Populations at the Baselevel: (Thomas L. Poulson, CRF and Yale University)

Is there a change in fauna going on in areas backflooded by Green River? Before the Brownsville Dam was constructed fish and crayfish were apparently common in Echo River. Since 1958 the number and variety of animals in Styx River, Echo River, in lower Eyeless Fish Trail, and in the Golden Triangle Room has diminished. The possible effect of the brine pollution from the Greensburg Oil Field is being investigated.

PHYSIOLOGY OF CAVE ANIMALS

Bioenergetics: (Thomas L. Poulson, CRF and Yale University)

This is a study of regulation in population size, biomass, and metabolic demand in various cave fish and crayfish to determine whether the most food limited organisms show closer population control. Feeding patterns in relation to assimilation efficiency is measured using micro-bomb calorimetry.

THE ARCHAEOLOGY PROGRAM

Excavations at the Salts Cave Site: (Joseph R. Caldwell, Illinois State Museum, Robert Hall, Illinois State Museum, Patty Jo Watson, CRF and Illinois State Museum, and Richard Yarnell, Emory University and CRF)

This project is now nearly complete and publications describing the results have begun to appear in the literature (see publication list). Work during the past year has been mainly putting the finishing touches on the final report.

One further trip was taken into Salts Cave in 1966 for the purpose of collecting nut debris for further analysis. Work is also being conducted on the recent history of Salts Cave, particularly the historical circumstances surrounding the discovery of the mummies.

A series of radiocarbon dates on material previously collected were completed during the year. The results are given below in Table 3.

Table 3

Radiocarbon dates of materials from Salts Cave.
Dating by David M. Griffin, Museum of Anthropology, University of Michigan

Dried human feces		
M-1573	2240 ± 200 B.P.	Upper Salts, near P-54
M-1574	2570 ± 140 B.P.	Upper Salts, at P-63 - 64
M-1777	2270 ± 140 B.P.	Upper Salts
M-1577	2350 ± 140 B.P.	Middle Salts at A-60
M-1770	2660 ± 140 B.P.	Middle Salts at A_42
Wood, Cane, Etc.		
M-1584	2510 ± 140 B.P.	Upper Salts, Test A, 6-10 cms.
M-1585	2430 ± 130 B.P.	Upper Salts, Test A, 30-40 cms.
M-1586	2840 ± 150 B.P.	Upper Salts, Test A, 70-80 cms.
M-1587	2520 ± 140 B.P.	Upper Salts, Test A, 140 cms.
M-1588	2720 ± 140 B.P.	Lower Salts, Indian Avenue
M-1589	3140 ± 150 B.P.	Lower Salts, Indian Avenue

The youngest date of the present series is 290 B.C. The oldest date is 1190 B.C. (close to the soot date of 1125 B.C.) There is thus a 900 year spread of dates but nearly all fall into the first millenium B.C.

THE HISTORY AND ECONOMICS PROGRAMS

Oral History Recording: (Louise Storts and James Dyer, CRF)

This program has as its objective the recording on magnetic tape of the oral tradition and history of the people of the Central Kentucky cave region. The project has been largely dormant during the past year with activity limited to cataloguing and transcribing tapes.

Development of the Map of Mammoth Cave: (James F. Quinlan Jr, CRF and University of Texas)

This is a continuation of the project on the history of the maps of Mammoth Cave prepared by the investigator in 1964. The outstanding Kaemper Map and the Nelson map have been traced and re-lettered. It is planned to issue these maps in a limited edition sometime in 1967.

Bibliography of the Mammoth Cave Area: (James F. Quinlan Jr., CRF and University of Texas)

This is a long term project which has as its objective the compilation of a more complete bibliography of the writings on the Central Kentucky Karst than is available either in the Jillson or the Wilkes bibliographies. Through the cooperation of Mr. Harold Meloy of Indiana, some 1200 items have been collected thus far.

THE ADVISORY PROGRAMS

PROBLEMS OF RECREATIONAL CAVING

Regional Protective Associations: (Philip M. Smith and William B. White)

The rapid growth of caving as a sport has put severe strains on the nations supply of wild caves and on the public relations with cave owners. One suggested solution to the problem was given to the National Speleological Society at its annual meeting of which an abstracts appears below:

Predicted cave usage in the year 2000 illustrates the need for a nation-wide system of controlled access caves for recreational, scientific, and wilderness purposes. Present-day protection, mainly through governmental or tourist cave ownership, is not conserving sufficient cave resources to meet predicted needs. In those regions where insufficient resources are now being conserved, additional protection can be provided through the formation of associations composed of the National Speleological Society, Grottoes, and other conservation groups. These regional associations will serve as cave management agencies for one or several caves. Data from state cave surveys, the locations of currently protected caves, predicted population and urban-ization patterns, and projected outdoor recreational developments make possible a national study pinpointing priority projects for regional associations. Possible organizational techniques for establishing protective associations and future cave management techniques are discussed.

THE CAVE WILDERNESS

The Nature of Wilderness: (Philip M. Smith and Richard A. Watson)

Several important pieces of writing are being prepared on wilderness in general and cave wilderness in particular. One of these is an article describing the Flint Ridge Cave System in the American Alpine Club Journal. The other is a book length piece describing the role of wilderness in modern America.

Wilderness in the National Parks (P.M. Smith, R.A. Watson, and W.B. White)

The Foundation is cooperating with such organizations as the National Speleological Society, The Wilderness Society, The Issak Walton League, Etc. in preparing for the Wilderness Reviews of the cave-containing National Parks.

PAPERS GIVEN AT SCIENTIFIC MEETINGS IN 1966

National Speleological Society (Sequoia National Park, California, June)

James F. Quinlan Jr. and Alfred Traverse; Humic Acid and Humate Deposits in Salts Cave and Mammoth Cave, Kentucky: A Preliminary Report.

Philip M. Smith and William B. White; Regional Protective Associations: A New Force in Cave Conservation.

American Association for the Advancement of Science: (Washington, D.C., Decem.)

Denver P. Burns; Explorations in the Flint Ridge Cave System.

Thomas L. Poulson: Biospeleology: Past, Present, and Future.

James F. Quinlan Jr.; Classification of Karst Types: A Review and Synthesis Emphasizing the North American Literature, 1941_1966.

James F. Quinlan Jr. and E.R. Pohl; Vertical Shafts Actively Promote Slope Retreat and Dissection of the Solution Escarpment and the Chester Cuesta in the Central Kentucky Karst.

Elizabeth L. White and William B. White; Dynamics of Sediment Transport in Limestone Caves.

William B. White and Elizabeth L. White; The Speleological Approach to Limestone Hydrology.

ABSTRACTS OF 1966 PUBLISHED CONTRIBUTIONS

During 1966, ten papers of various types were published by the Foundation. Of these seven appeared in the regular scientific journals. Abstracts for those papers for which reprints were available are reproduced below.

Truncated Cave Passages and Terminal Breakdown in the Central Kentucky Karst

By Roger W. Brucker

ABSTRACT

In the Flint Ridge and Mammoth Cave Systems in Mammoth Cave National Park, Kentucky, *truncated cave passages* are segments of formerly continuous passages which have been terminated at one or both ends by a process of collapse. Valley erosion truncates an impermeable caprock, concentrating vertically seeping water along specific areas of descent. Solution weakens the rock which collapses into cave passages. *Terminal breakdowns* are piles of rock debris which terminate passages as a result of this process of truncation. Segments of formerly continuous passages have similar size, shape, elevation, alignment, and cross-section. Wall scallops indicate a former common direction of water flow. Segment ends are usually within a few hundred feet apart, though farther separations are within the known limits of continuous passages. Understanding of the process, and recognition of its results leads to reconstructions of past cave patterns essential to studies of cave genesis, and to the location of existing, but unknown passage segments.

Bedding-plane Anastomoses and Their Relation to Cavern Passages

By Ralph O. Ewers

ABSTRACT

Bedding-plane anastomoses (braided solution tubes) occur in many sizes and appear to form a continuum from channels several millimeters in diameter to the spaces between the largest roof pendants. Bedding-plane anastomoses are common in areas of poorly jointed limestone and appear on the undersides of the strata. The features extend over large areas of a bedding surface and are strongly influenced by minor fractures. Bedding-plane anastomoses are unquestionably phreatic in origin and often certainly predate adjacent or confluent cavern passages. In many cases it appears that a cavern passage results either from an extension of the anastomoses along a route predetermined by the presence of a minute fracture or from the breaching of a stratum by growth of anastomoses from below where two or more sets exist superimposed on adjacent bedding surfaces.

Reprinted from PHYSIOLOGICAL ZOÖLOGY
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RELATION OF THERMOREGULATION TO SEASONALLY CHANGING MICROCLIMATE IN TWO SPECIES OF BATS (MYOTIS LUCIFUGUS AND M. SODALIS)[1]

ROBERT E. HENSHAW[2] AND G. EDGAR FOLK, JR.
Department of Physiology, University of Iowa, Iowa City

SUMMARY

The relation of the body- to ambient-temperature differential ($\Delta T = T_B - T_A$) to the temperature of the microhabitat was studied in the laboratory in two closely related species of bat, *Myotis lucifugus* (the little brown bat) and *M. sodalis* (the Indiana bat). Both species overwinter in the same caves in Kentucky, but during the summer *M. lucifugus* forms colonies in hot dry lofts, while *M. sodalis* returns daily to caves.

Myotis lucifugus appeared to be adapted for warmer habitats, being able to maintain a negative ΔT for extended periods at experimental temperatures above 35 C. Body temperatures as high as 42 C were readily tolerated, and one juvenile tolerated a T_B of 48 C for more than 15 min with no apparent deleterious effects. At low experimental T_A, *M. lucifugus* became increasingly torpid and would frequently freeze to death without arousing. In the hibernaculum this species exhibited a deeper torpor than *M. sodalis* at all times.

Myotis sodalis appeared to be adapted for colder temperatures, since it was stressed by experimental T_B of 41 C most of the year and, in May and June, by a T_B of 35 C. However, at experimental T_A below 0 C this species responded with augmented heat production to increase the ΔT such that T_B remained near 0 C. In the laboratory this species could arouse if stressed by cold, confirming the field observation of frequent arousal and movement within the hibernaculum.

Myotis lucifugus showed a pattern of acclimatization in the reduction of its ΔT starting in early hibernation, whereas *M. sodalis'* ΔT did not change significantly throughout hibernation.

The mechanisms responsible for acclimatization are obscure at present. From several lines of evidence, species differences at all times, as well as reactivity to small changes in T_A, suggest neural mechanisms may augment hormonal changes.

Central Kentucky Karst Hydrology

By R. A. Watson

ABSTRACT

Three aspects of underground flow in the Central Kentucky Karst are considered. First, the underground drainage pattern is examined as a set of systems tributary to the Green River. The relation of inputs such as vertical shafts to horizontal passages is delineated, and the extent to which structure determines passage alignment is evaluated. Calculations based on rainfall and spring-flow measurements indicate that a substantial portion of the input cannot be accounted for by the discharge of presently known springs and underground streams. Second, the quantity and quality of water flowing underground is examined, and new evaluations are made of the location, character, and extent of limestone solution in the area. Known and extrapolated cave passages cannot account for the amount of lime-

stone removal indicated. Third, the underground drainage is examined as a set of transportation systems for mechanical sediment. Estimates are made of the amount and character of sediment moving from the surface of the region underground to the Green River. This sediment far exceeds the amount brought into the systems by back-up water during floods of the Green River.

It is concluded that the active underground drainage systems are more complex than their known parts indicate, with major water channels probably existing beneath the present-day base level; that a major amount of solutional activity occurs in the mantle and on the bedrock surface below it causing a general lowering of the land surface through removal of limestone which far exceeds that removed during the formation of cave passages; and that most of the sediment in the cave passages, even in back-up areas near the Green River, is provided by the flow which moves from the surface through the cave systems to the Green River.

Pollen Analyses of the Sediment From Sinkhole Ponds in the Central Kentucky Karst

By H. E Wright, Jr., Barbara Spross, and R. A. Watson

Discussion

The failure of the ponds sampled in the Central Kentucky Karst to provide a long record of sedimentation suggests that pollen analysis and other stratigraphic methods cannot furnish the information on vegetational and climatic history that was the objective of the investigation. Such history will evidently have to be extrapolated from sediment studies of lakes of different origin in other regions. The nearest possibilities are the southernmost glacial lakes in Indiana and Ohio 150 miles to the north, which may have formed as much as 20,000 years ago with retreat of the Wisconsin ice sheet (Goldthwait *et al.*, 1965). It might even be possible to find on the still older Illinoian glacial drift of southernmost Indiana and Ohio an old depression completely filled with local sediments, not only of the last glacial age but also of the last interglacial age.

The sediment study of the sinkhole ponds does provide further evidence, however, that the sinkholes are actively forming and are subject to rapid sedimentation. Extensive cultivation in the area during the last century has permitted rapid erosion of the residual clay from the hill slopes, followed by deposition in surface depressions, in crevices and cave passages underground, and in other areas of slow water movement. The removal of soil cover exposes the jointed bedrock to more rapid infiltration of water. Practically all the surface water in the area goes underground; few streams reach the Green River on the surface. Much of the clay and silt found throughout the region in cave passages, particularly those close to the surface, must have been deposited in recent times by water entering through sinkholes. Considering the amount of soil erosion in the region, and the thousands of sinkholes that do *not* support ponds and thus conduct water and sediment underground, it may be wise to reexamine the conclusions of Collier and Flint (1964) that the clay and silt in the lower levels of the cave systems were deposited predominantly by flood waters of the Green River backing up into the caves. Whatever the detailed effects underground, the area is one with relatively rapid change on the surface, a regime that has probably accelerated since land disturbance began.

Conceivably the pollen-bearing sediments of earlier sinkhole ponds dating from the glacial period were similarly conducted underground and may have been deposited by stream diversion. If the pollen of such sediments has been protected from deterioration by conditions of extreme dryness, then perhaps a record of past vegetation may yet be found in the area. But the depositional irregularities in strictly alluvial sediments, along with problems in sampling, the low pollen concentration, the chances of damage to pollen grains during transport by underground streams, and difficulties in dating, make success in such an investigation very unlikely.

PUBLICATIONS OF THE CAVE RESEARCH FOUNDATION

List of December 15, 1966

Contributed Papers:

1. Roger W. Brucker; Recent Exploration in Floyd Collins Crystal Cave; Nat. Speleo. Soc. Bull. 17 42-45 (1955)

2. Philip M. Smith; Discovery in Flint Ridge, 1954-1957; Nat. Speleo. Soc. Bull. 19 1-10 (1957)

3. Fred Benington; Preliminary Identification of Crystalline Phases in a Transparent Stalactite; Science 129 1227 (1959)

4. Frederick Benington, Carl Melton, and Patty Jo Watson; Carbon Dating Prehistoric Soot from Salts Cave, Kentucky; Amer. Antiquity 28 238-241 (1962)

5. Philip M. Smith; The Flint Ridge Cave System: 1957-1962; Nat. Speleo. Soc. Bull. 26 17-27 (1964)

6. Richard A. Watson; Similitude in Direct and Thought Experiments in Cave Geology; Nat. Speleo. Soc. Bull. 27 65-76 (1965)

7. Brother G. Nicholas and Roger W. Brucker; Establishment of a Quadrat System for Quantitative Ecological Studies in Cathedral Cave, Kentucky; Nat. Speleo. Soc. Bull. 27 97-103 (1965)

8. E. R. Pohl and William B. White; Sulfate Minerals: Their Origin in the Central Kentucky Karst; Amer. Mineral. 50 1461-1465 (1965)

9. Michael F. Ehman; Cane Torches as Cave Illumination; Nat. Speleo. Soc. News 24 34-36 (1966)

10. Richard A. Watson; Notes on the Philosophy of Caving; Nat. Speleo. Soc. News 24 54-58 (1966)

11. Roger W. Brucker and Denver P. Burns; The Flint Ridge Cave System; Folio, Cave Research Foundation, 3 pp. plus 31 plates (1966)

12. Roger W. Brucker; Truncated Cave Passages and Terminal Breakdown in the Central Kentucky Karst; Nat. Speleo. Soc. Bull. 28 171-178 (1966)

Supported Papers:

1. Douglas A. Wolfe and David G. Cornwell; Carotenoids of Cavernicolous Crayfish; Science 144 1467-1469 (1964)

2. M. Reams; Laboratory and Field Evidence for a Vadose Origin of Foibe (Domepits); Internat. Jour. Speleo. 1 373-390 (1965)

3. Frederic R. Siegel; Aspects of Calcium Carbonate Deposition in Great Onyx Cave, Kentucky; Sedimentology 4 285-299 (1965)

4. Robert E. Henshaw and G. Edgar Folk Jr.; Relation of Thermoregulation to Seasonally Changing Microclimate in Two Species of Bats (Myotis Lucifugus and M. Sodalis); Physiol. Zoo. 34 223-236 (1966)

5. Ralph O. Ewers; Bedding-Plane Anastomoses and their Relation to Cavern Passages; Nat. Speleo. Soc. Bull. 28 133-140 (1966)

6. R. A. Watson; Central Kentucky Karst Hydrology; Nat. Speleo. Soc. Bull. 28 159-166 (1966)

7. H. E. Wright Jr., Barbara Spross, and R. A. Watson; Pollen Analyses of the Sediment from Sinkhole Ponds in the Central Kentucky Karst; Nat. Speleo. Soc. Bull. 28 185-188 (1966)

8. Patty Jo Watson; Prehistoric Miners of Salts Cave, Kentucky; Archaeology 19 237-243 (1966)

9. Patty Jo Watson and Richard Yarnell; Archaeological and Paleoethnobotanical Investigations in Salts Cave, Mammoth Cave National Park, Kentucky; Amer. Antiquity 842-849 (1966)

Advisory Reports:

1. Cave Research Foundation; Speleological Research in the Mammoth Cave Area, Kentucky; Yellow Springs, Ohio, 18 pp. (1960)

2. Roger W. Brucker; Groundwater Problems in Flint Ridge; Cave Research Foundation, 11 pp. undated.

3. Philip M. Smith; The Flint Ridge Cave System: A Wilderness Opportunity; Cave Research Foundation, 15 pp. (1961)

4. Philip M. Smith; The Role of the N.S.S. in the Cave Related Sciences; Nat. Speleo. Soc. News 20 160-162 (1962)

5. Richard A. Watson and Philip M. Smith; The Mammoth Cave National Park Research Center; Yellow Springs, Ohio, 50 pp. (1963)