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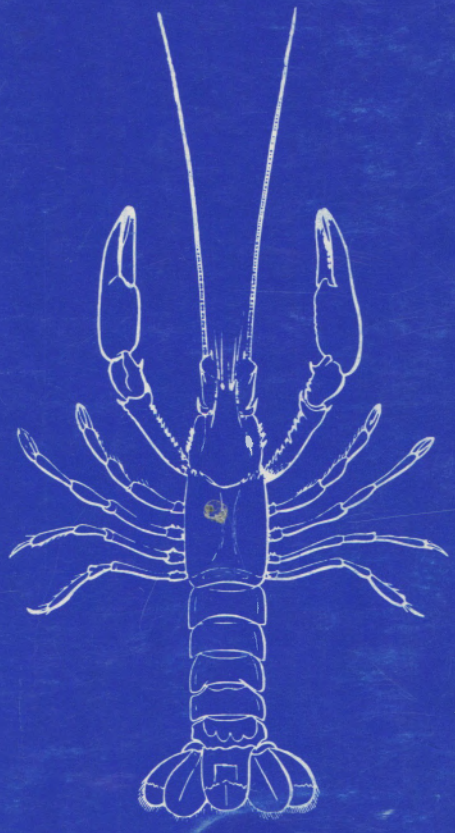

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A LONG-NOSED PECCARY (*MYLOHYUS NASUTUS*) FROM KNOB ROCK CAVE, INDIANA

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A portion of an extinct, Pleistocene peccary, Mylohyus nasutus, *was recovered from cave deposits in southern Indiana. The cave deposits and depositional history are discussed, and the faunal remains are described and compared to other examples of this species.*

INTRODUCTION

Knob Rock Cave is located 10.5 km west of Bloomington, Indiana in western Monroe County (SE ¼, NE ¼, NW ¼, Sec. 5, T8N, R2W). The cave was initially described by Black (1980). In January 1983 four NSS members from the Bloomington area, Kent Wilson, Thomas Bertolacini, Michael Miessen, and Edward Hedrick, discovered a portion of a peccary skeleton eroding from sedimentary fill deposits within this cave. A lower jaw fragment was removed from the cave at this time and brought to the attention of the author, who identified it as an extinct long-nosed peccary, *Mylohyus nasutus* (Leidy). During a subsequent visit to the cave the bones that had already been extracted from the deposit were collected and additional limited excavations were carried out. These excavations yielded more *in situ* peccary bones and a small sample of associated remains of smaller animals.

GEOLOGIC AND PHYSIOGRAPHIC SETTING

The cave is located near the eastern margin of the Crawford Upland, a maturely dissected, westward-sloping plateau that extends north-south through south-central Indiana (Malcott, 1922). Bedrock of the higher elevations consists of alternating units of upper Mississippian (Chesterian) sandstones, shales, and thin limestones. These overlie thick middle Mississippian (Valmeyeran) carbonates assigned to the Paoli, Ste. Geneviève, and St. Louis limestones. The middle Mississippi limestones, which are exposed in the walls and floors of the deeply entrenched valleys, contain numerous caves and other karst features (Powell, 1961).

The Crawford Upland, plus the moderately dissected Mitchell Plain just to the east and the highly dissected Norman Upland still farther east, form a contiguous group of unglaciated highlands in southern Indiana. One or more lobes of the Illinoian Glaciation passed within 13 km northwest of the cave, and the maximum advance of the Wisconsinan (*c.* 20,000 ybp) terminated about 35 km to the north (Wayne, 1961).

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The pit entrance of Knob Rock Cave is on a north-facing slope approximately 238 m asl. Richland Creek lies 0.8 km north and about 30 m below the cave entrance. The topography in the immediate vicinity of the cave consists of relatively high, sandstone-capped hills and ridges (maximum elevation *c.* 300 m) dissected by the steep-walled valleys of Richland Creek and its tributaries. Modern vegetation is classified as Western Mesophytic Forest; beech, maple, oak, and hickory in combination make up about 80% of the tree species.

DESCRIPTION OF THE CAVE AND CAVE DEPOSITS

Knob Rock Cave is a small complex of solution pits, domes, and connecting drains formed in the Paoli and upper Ste. Geneviève limestones. The entrance is a small, twisting, downward sloping hole that originates below a large detached limestone block lying in the bottom of a small sinkhole. Immediately beyond the entrance this hole opens into the top of a shaft about 1 m in diameter which, about 3 m below the entrance, penetrates the ceiling of the largest room of the cave. The floor of this room lies 6.8 m below the ceiling and access to the floor is by vertical, free-hanging rope.

The talus-covered floor of the room slopes steeply downward to the west and north and within 10 m the passage constricts to a small, horizontal crawlway leading to the top of a narrow, 5 m deep canyon. Eastward the canyon leads to 125 m of cave passage. By descending to the bottom of the canyon, however, and then turning westward one enters a walking-sized passage bearing northwest and west. Within 8 m this passage terminates in a complex of small domes. A 3.5 m, nearly vertical free-climb up the wall of one dome allows access to the top of a small natural bridge, and crossing this it is possible to squeeze into the upper portion of the highest of the domes. About 2 m above the top of the natural bridge this dome narrows to a crevice with a maximum width of 25 cm. The dome then expands into a "room" 1 m high, 1 m wide, and 1.5 m long. At this point, some 6 m above the floor of the dome-complex, the dome

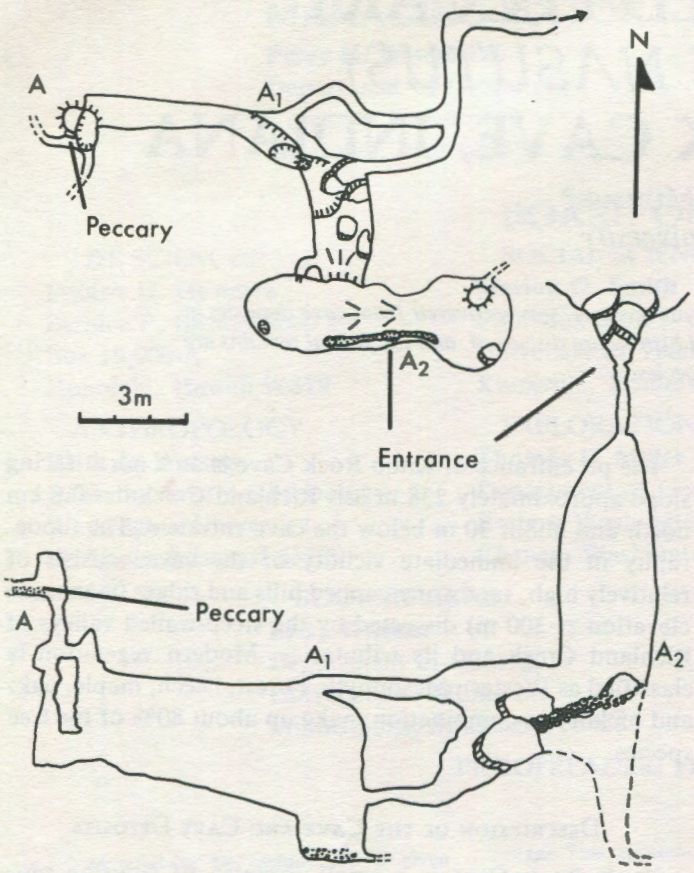

Figure 1. **Map (above) of a portion of Knob Rock Cave (modified from Black, 1980) and schematic cross-section (below).**

intersects a small, abandoned, nearly horizontal drain, which is exposed in cross-section on the south and west walls of the "room."

The drain, which was probably once the conduit for a small, now totally plugged sinkhole that lies about 15 m southwest of this point, is about 60 cm high and varies from 30 to 50 cm in width. Except for that portion that has collapsed into the intersecting dome, the drain is almost totally choked with sediments. The peccary was found in the basal portion of these sediments where they had been exposed on the west side of the intersecting dome.

The basal portion of the sediments is a light yellowish brown, silty clay containing occasional rounded sandstone pebbles. This stratum occurs in discontinuous "patches" up to 12 cm in thickness. Disconformably overlying the basal stratum is a bed 25 to 35 cm in thickness consisting of unsorted pebbles, cobbles, and slabs of limestone in a sandy clay matrix; this stratum is partially indurated by evaporite crusts. Overlying this bed is a layer of reddish grey, sandy silt up to 6 cm in thickness which extends to within 15 cm of the ceiling of the drain.

DEPOSITIONAL AND POST-DEPOSITIONAL HISTORY

During the time that the drain was being formed it apparently carried little sediment. At some time in the past part of the system opened to the surface, most likely within the bottom of the previously mentioned, presently plugged small sinkhole. The peccary entered the drain at this time, either walking (or crawling) to the place where it was found and dying there, or it died in or near the sinkhole entrance and was washed to this location as a complete carcass. It came to rest with its nose downstream (west) and lying on its left side. The fact that the bones were found more or less in their correct anatomical position would argue that the animal was not brought into the cave as a predator kill.

After reaching the location where found, the peccary was then at least partially buried within fine sediments that were washing into the system from the surface. A few bones of small mammals (bats and small rodents) were also incorporated in these sediments, representing remains of animals that were probably living in this small cave or near its entrance. Portions of the peccary skeleton that protruded from the sediments, or which were partially exposed by subsequent erosion, were extensively gnawed upon by some species of rodent (incisor width is approximately that of a woodrat); the lateral margin of the left humerus, the distal left ulna, and perhaps other bones or portions of bones were destroyed by this gnawing.

Subsequent to the gnawing a volume of water sufficient to transport fist-sized cobbles and slabs began entering the drain. It cannot be determined whether the increased water volume resulted from changing climatic conditions or simply from an increase in the size of the surface opening. Whatever the cause, the influx of coarse sediments eroded away much of the peccary skeleton that had not already been destroyed by rodent grawing. As the entrance to the drain became plugged, sediment size decreased and the final depositional episode, which probably occurred shortly before total plugging, resulted in a thin layer of sandy silt capping the underlying deposits and extending almost to the ceiling of the drain.

Following the deposition of sediments, portions of the drain floor collapsed into the underlying dome. Any parts of the peccary skeleton posterior to the forelegs that had survived rodent gnawing and abrasion up to this time dropped into the dome and were either destroyed or lie deeply buried within sediments at its bottom.

No datable materials, other than the peccary bones themselves, were present in the deposits, nor were there associated geological or biological characteristics that would suggest a date or date-range. *Mylohyus nasutus* is thought to have become extinct near the end of the Pleistocene, however, and the magnitude of changes that have occurred in the cave and the drain sediments since the time of deposition would suggest some antiquity.

EXCAVATION AND LABORATORY PROCEDURES

Most of the peccary bones were removed from the deposit at the time of discovery and placed on a nearby ledge. During a subsequent visit to the cave these bones were retreived and limited excavations were carried out in the fossil-bearing deposits to determine if more of the skeleton was present and to recover a sample of sediments to check for the presence of remains of associated, smaller animals.

Excavations were carried out by one individual who squeezed into the small room at the top of the dome and once there loosened the basal, bone-bearing deposits, scraped the loosened materials into a plastic scoop, and then transferred them to a small bucket. When the bucket was filled it was lowered by a cord to a second individual stationed on the top of the natural bridge some 2.5 m below, who then turned and lowered the bucket to a third individual on the floor of the dome 3.5 m below him. The third individual then transferred the sediments into plastic woven mesh feed sacks, and the sacks were eventually carried, dragged, and lifted from the cave and backpacked 800 m to the nearest road.

All recovered materials were returned to the Glenn Black Laboratory of Archaeology (Indiana University). Larger bones and teeth that were extracted at the time of excavation were slowly dried, then brushed clean and preserved with a dilute solution of polyvinyl acetate in acetone. Broken pieces were mended with Duco cement. The 0.02 m^3 (*c.* 40 kg) of sediments that had been removed from the cave, after first being thoroughly dried, were soaked for several hours in a water-trisodium phosphate solution and then gently rinsed over 1 mm mesh, which removed all clay, silt and sand. The residue of small pebbles, pieces of carbonate crusts and small speleothems, and occasional small bones and teeth was then sorted under low magnification. All recovered faunal items are presently curated at the Glenn Black Laboratory under Accession No. 5509.

DESCRIPTION OF THE PECCARY

The bones are not mineralized, and other than being somewhat "chalky" appear almost fresh. While moist, as they occurred in the deposit, they were rather fragile, and several that were not already fragmented were broken during recovery.

All of the *Mylohyus* bones are from a single, young adult individual. Recovered elements are: left lower jaw with permanent (but unworn) dentition, complete except for the crowns of I_2 and P_2 and the ascending ramus; anterior portion of right lower jaw with I_{1-2}, canine, and P_3; premaxillary with left I^1; right and left upper canines; proximal unfused epiphysis and distal ⅔ left humerus; proximal ¾ and unfused distal epiphysis left radius; distal ¼ right radius with unfused epiphysis; mesial left ulna; distal unfused epiphyses left and right ulnae; 7 carpals (right and left lunates, scaphoids, and unciforms, right cuneiform); proximal ⅔ left metacarpals II-IV; left lateral phalanx I.

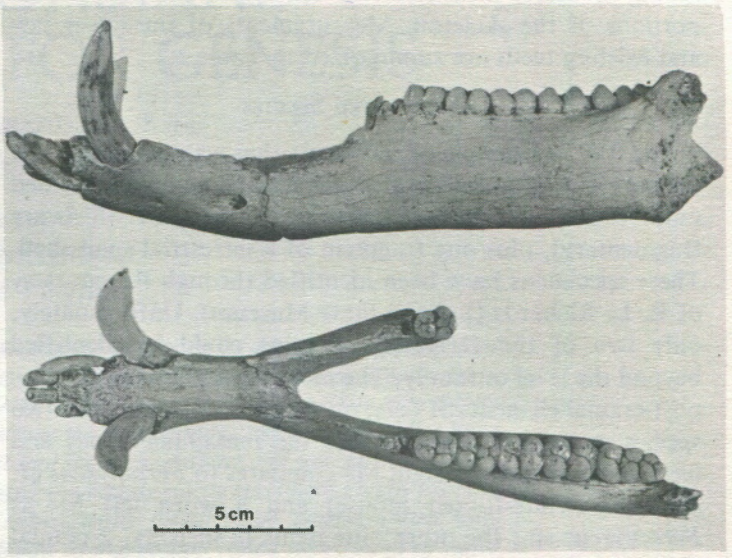

Figure 2. **Lower jaw of *Mylohyus nasutus* from Knob Rock Cave.**

Table 1. Lower jaw and tooth measurements (mm) of *Mylohyus nasutus* from Knob Rock Cave.*

Width between canine alveoli		*c.* 15.0
Length of pre-canine diastema		*c.* 12.0
Length of post-canine diastema		*c.* 68.0
Least depth of post-canine diastema		22.1
Length of symphysis		77.2
Depth of jaw at M_1		34.1
Thickness of jaw at M_1		18.2
Length of molar-premolar series		*c.* 87.0
Length of premolar series		*c.* 36.5
Length of molar series		50.5

		Left	Right
Upper canine	L	12.0	12.1
	W	8.8	8.8
Lower canine	L	10.8	11.0
	W	8.7	8.4
P_2	L	—	—
	AW	—	—
	PW	—	—
P_3	L	11.4	11.3
	AW	8.1	8.0
	PW	10.4	10.2
P_4	L	13.3	—
	AW	11.1	—
	PW	12.6	—
M_1	L	13.3	—
	AW	12.3	—
	PW	12.0	—
M_2	L	16.2	—
	AW	13.2	—
	PW	13.1	—
M_3	L	20.4	—
	AW	12.2	—
	PW	11.0	—

*Abbreviations: L = length, AW = anterior width, PW = posterior width.

The fragmentary condition of many of the bones, plus the lack of fusion of epiphyses on some of them, precludes the taking of useful measurements on any of the post-cranial portions of the skeleton. Measurements of the lower jaw and existing teeth are summarized in Table 1.

ASSOCIATED SPECIES

The 0.02 m^3 sample of sediments that was removed from the cave and subjected to fine-mesh water screening yielded only 34 non-peccary bones and teeth (many of which are fragmentary), plus one fragment of a terrestrial snail shell. These specimens have been identified through the courtesy of R. L. Richards (Indiana State Museum). Unfortunately, only two of the vertebrate remains could be identified beyond the level of family. The most common items (23) are post-cranial elements of bats; on the basis of size at least two species may be represented. Of the remaining bones and teeth (11) one unworn right M^1 compares to *Peromyscus* cf. *leucopus* (white-footed mouse) and a worn left M^2 is *Peromyscus* sp.; the other nine items (2 incisors, 2 cranial fragments, 5 post-cranial bones) are of *Peromyscus*-sized mice.

DISCUSSION

Remains of *Mylohyus nasutus,* frequently as isolated items or portions of single individuals, have occasionally been recovered from late Pleistocene (and early Holocene?) contexts in eastern North America from southern Pennsylvania to eastern Kansas and southward. The type specimen, a palate and upper jaw fragment with right canine and P^{2-3}, was recovered in Gibson County, Indiana (Leidy, 1860; 1869). Tomak (1982) has reported several elements of this species which apparently had been redeposited in a Holocene-age context in Daviess County, Indiana. The Knob Rock Cave specimen is the third record of the species in Indiana.

The size of the Knob Rock Cave peccary, based on measurements of the lower jaw and teeth, compares well with the smaller individuals of *Mylohyus nasutus* from Friesenhahn Cave, Texas (Lundelius, 1960) and is very similar to the individual recovered from Crankshaft Cave, Missouri (Parmalee, *et al.,* 1969).

It has been suggested that *Mylohyus* was primarily a woodland form and that during the terminal Pleistocene, when forests replaced more open, ice-margin environments, *Mylohyus* replaced the open-habitat adapted *Platygonus* peccaries (Martin and Guilday, 1967). Although the Knob Rock Cave *Mylohyus nasutus* has not been dated, the apparent association of the mouse *Peromyscus* cf. *leucopus,* a woodland species presently found in eastern North America from New England to North Dakota and southward (Hall and Kelson, 1959), suggests that it was living at this location during forested conditions when temperatures were comparable to the present or only moderately cooler (i.e. not periglacial conditions). Additionally, the recent discovery (Munson, unpublished) of a population of *Platygonus compressus* in an ice-margin context about 75 km northeast of Knob Rock Cave would suggest that *Platygonus,* rather than *Mylohyus,* occurred in this area during the Wisconsinan full-glacial period.

ACKNOWLEDGEMENTS

Kent Wilson, Thomas Bertolacini, Michael Miessen, and Edward Hedrick discovered the peccary fossil and assisted in various aspects of the investigation. Comments by John Bassett on the geology and cave formation processes are greatly appreciated. Kenneth Tankersley remapped portions of the cave and prepared the illustrations for this report. W. R. Adams, Della C. Cook, and Sebastian Payne assisted in the identification and description of the peccary items. Ronald Richards kindly contributed his time and expertise to the identification of the associated small mammals. James Keith and Cheryl Ann Munson read earlier drafts of this paper and offered valuable and greatly appreciated comments.

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A SPATHITE OCCURRENCE IN VIRGINIA: OBSERVATIONS AND A HYPOTHESIS FOR GENESIS

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Spathites, associated with chiefly aragonitic soda straws, have been found in a new locality, the third for these speleothems. They occur in Roberts Cave, developed in the Shady Dolomite (Lower Cambrian), in Smyth County, Virginia. Microscopy and X-ray diffraction have shown spathite mineralogy to be complex. The outer shell of the spathite form originates as aragonite, but some spathites have altered to calcite. Calcite and aragonite forms were identified for both spathites and soda straws. Observations of these speleothems show that the water drip rate from mainly calcite specimens greatly exceeds that from aragonite specimens. Water samples were subsequently found to be supersaturated with respect to calcite, aragonite, and dolomite. Lower calcium to magnesium ratios were found in water samples from aragonite specimens, but calcite specimens contain more magnesium than aragonite specimens.

Spathite development proceeds from an initial aragonite form not unlike a soda straw. The aragonite shell flairs as it grows until the termination reaches a critical size too wide for a drop of water to extend across. Water dripping from one side results in the development of an opening or "window" into the formation as the next stage is initiated. The admission of cave air into the window is hypothesized to result in a microenvironmental change and subsequent development of a calcite partition. This partition isolates the window from the internal "plumbing" of the speleothem. Sequential development of several stages leads to complex spathites. External encrustation may eventually obscure windows such that multistage specimens appear to be knobby oversized soda straws.

INTRODUCTION

Spathites were first observed in Virginia in April of 1982. These speleothems occur in association with soda straws (tubular stalactites) in Roberts Cave, which is developed in the Shady Dolomite (Lower Cambrian) and located in Smyth County (Figure 1). The purpose of this paper is to report this new and third locality of these unusual speleothems and to consider their genesis.

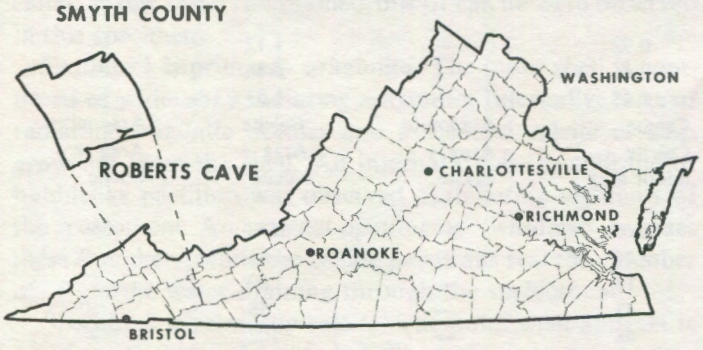

***Figure 1.* Location map for Roberts Cave, Smyth County, Virginia.**

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The term spathite was first proposed by White and Stellmack (1959) for the new speleothem in reference to its appearance. The name is derived from *spathe,* a botanical term which refers to a large sheathlike flower petal, as shown by the calla lily. Simple and multistage spathite specimens have been reported. The multistage specimens consist of several inverted petal-like cones loosely overlapped and situated one beneath another (Figure 2A). The necks of these petal-like cones are similar in thickness to soda straws (0.6 centimeters), but their terminations diverge to a diameter of about a centimeter. The Carroll Cave location in Camden County, Missouri, where spathites were first observed (White and Stellmack, 1959), is in the Gasconade Dolomite (Lower Ordovician). The second locality, reported by Haman (1963), is Porcupine Cave, which is in dolomitic limestone of the Madison Limestone (Lower Mississippian), in Summit County, Utah.

FIELD SAMPLING

During February 1983, a return visit was made to Roberts Cave. The spathites were examined and photographed, and three soda straws and three spathites were selected for detailed observation, measurement, and analysis. The

speleothems were sampled within a meter and a half radius of one another in a single room.

Dripwater samples were collected from the six speleothems over a three- to five-hour period. Acid-washed 50-mL Nalgene bottles were used for sample collection. Two specimens, soda straw 3 and spathite 2, yielded samples an order of magnitude larger than the other specimens. The temperature of these solutions and of the cave air was recorded. After a 2-point pH calibration, a combination pH electrode and a Leeds and Northrop meter were used to measure the pH of water from soda straw 3. The water samples were refrigerated until analyses were performed. The results of the field measurements are listed in Table 1.

LABORATORY ANALYSES AND RESULTS

Water Chemistry

The water samples collected in Roberts Cave were subsequently analyzed in the laboratory: however, the sample volume collected from soda straw 1 was inadequate for analysis. Sample volumes from soda straw 2 and spathites 1 and 3 were exhausted part-way through the analyses. The data are shown in Table 1.

Within 24 hours of collection, pH was measured using a Corning model 135 research pH meter with a Corning semi-micro combination pH electrode on the samples of adequate volume, soda straw 3 and spathite 2. At that same time, alkalinity titrations were performed on 10-mL subsamples using 0.1N HCl. All the samples were then acidified with concentrated HNO_3.

The acidified solutions were analyzed by atomic absorption for Ca, Mg, Zn, Sr, Ni, Pb, and Cu using an Instrumentation Laboratories model 751 dual-beam spectrophotometer. Only samples from soda straw 3 and spathite 2 were of adequate volume to attempt all the analyses. All samples and standards were spiked with a lithium/lanthanum solution to reduce interferences.

The results of the atomic-absorption analyses are shown in Table 1. The calcium concentrations in dripwater samples from soda straw 3 and spathite 2 are considerably higher than for the other three analyzed samples. The magnesium concentrations are all within a limited range with no discernible separation. The molar ratio of calcium to magnesium is roughly 1:3, and samples from soda straw 3 and spathite 2 are at the calcium-rich end of the observed values. Dripwater sample volume was adequate from soda straw 3 and spathite 2 for analyses of Zn, Sr, Ni, Pb, and Cu; however, the concentrations were below the detection limits for all these elements.

Partial pressures of dissolved carbon dioxide were calculated from the measurements of pH and alkalinity using values of Henry's law constant, K_H, and the first dissociation constant of carbonic acid, K_1, corrected for temperature (Stumm and Morgan, 1981). The results in Table 1 show that both samples are supersaturated with $CO_2(g)$ relative to atmospheric conditions for which log $P_{CO2} = -3.5$.

Table 1. Water and mineral samples from speleothems, Roberts Cave, Virginia.

	Soda straw			Spathite		
Property	1	2	3	1	2	3
Water physical properites						
Flow rate (mL/hr)	0.01	0.5	6.2	0.7	5.0	0.7
Temperature (°C) *a/*	—	—	13.5	—	12.0	—
Water chemical properties *b/*						
Lab pH	—	—	7.4 *c/*	—	7.6	—
HCO_3 (mg/L)	—	—	333	—	329	—
Log P_{CO2}	—	—	-1.9	—	-2.1	—
Ca (mg/L)	—	250	300	250	300	217
Mg (mg/L)	—	465	496	489	482	479
Ca/Mg (molar)	—	0.33	0.37	0.31	0.38	0.27
Water saturation index						
Calcite	—	—	0.92	—	1.12	—
Aragonite	—	—	0.66	—	0.86	—
Dolomite	—	—	1.15	—	1.33	—
Shell mineralogy	Aragonite	Aragonite	Calcite	Aragonite	Calcite	Aragonite
Internal mineralogy	Arag + minor calc	Aragonite	Calcite + minor arag	Arag + calcite	Arag + calcite	Arag + calcite
Shell composition (ppm)						
Mg	66	108	6520	—	5130	260
Zn	6	8	>44	—	61	9
Sr	42	64	15	—	29	55
Ni	43	54	43	—	58	50
Pb	81	104	88	—	107	96
Cu	3	3	3	—	5	2

a/—Air temperature = 11.5°C

b/—Concentrations were below detection limits, in mg/L: Zn 10, Sr 20, Ni 50, Pb 100, Cu 10

c/—Field pH = 7.2

Carbonate ion (CO_3^{2-})concentration, using the second dissociation constant of carbonic acid, K_2, and activity coefficients from the extended Debye-Hückel expression, were also calculated (Stumm and Morgan, 1981). The equilibrium constants for calcite and aragonite solubility as a function of temperature were obtained from Plummer and Busenberg (1982). The equilibrium constant for dolomite solubility was taken from Robie, *et al.* (1978). Then using the analyzed concentrations of calcium and magnesium, the saturation index of the water samples with respect to calcite, aragonite, and dolomite were calculated according to

$$SI = \log \frac{\text{Ion activity product}}{\text{Equilibrium constant}} \quad (1)$$

where SI = 0 suggests equilibrium. The results are shown in Table 1. The two dripwater samples were supersaturated with respect to all three minerals considered.

Speleothem Mineralogy

Microscopy and X-ray diffraction analyses revealed that all but one soda straw had both aragonite and calcite components (Table 1). Soda straw 1 is primarily aragonite. The outer shell has a white radiating appearance with the silky luster characteristic of aragonite. Internally, small well-formed aragonite needles and thick prismatic aragonite crystals are present. Massive cleavable yellowish calcite also was observed.

Soda straw 2 is composed of aragonite. The outer shell has a white radiating appearance and the silky luster characteristic of aragonite similar to that seen in soda straw 1. A flattened radiating encrustation of aragonite was observed on the outside of this specimen. Internally, tufts of tiny aragonite needles with a moldy appearance project into the central canal of the speleothem.

Soda straw 3 is primarily calcite. The outer shell has a yellowish appearance with the greasy luster characteristic of calcite. A small flattened radiating encrustation of aragonite was observed on the outside of the specimen. Internally, calcite scalenohedrons were observed projecting tangentially (c axis parallel to soda straw axis) down into the central canal. A few small rhombohedrons of calcite were observed in this specimen.

Spathite 1 is primarily aragonite. The outer shell is composed of white silky radiating aragonite. Internally, tufts of radiating aragonite needles and associated calcite crystals grow out from the shell. An internal calcite membrane or bubblelike partition was observed chambering segments of the speleothem. An external opening or "window" accesses these chambers, while the calcite partitions seal the chamber off from the water draining through the speleothem.

Spathite 2 is primarily calcite. The outer shell appears to have a radiating and somewhat silky appearance, and initial visual observation erroneously identified the primary composition to be aragonite. However, on fracture surfaces a single cleavage plane was observed, and X-ray diffraction determined the composition to be calcite. Flattened radiating encrustations of aragonite were observed on the outer shell of the speleothem. Internally, tufts of radiating aragonite needles and calcite crystals were observed. Calcite partitions seal off windowed chambers in each of the complete stages.

Spathite 3 is primarily composed of aragonite. The specimen has two knoblike projections and no windows but is characteristically wider than the typical soda straw. The outer shell is composed of white silky radiating aragonite. Closer inspection reveals the knobs to be earlier windows which were overgrown by encrusting aragonite. Internally, tufts of radiating aragonite needles project into the central canal of the last stage. The upper two stages contain tufts of aragonite needles and calcite crystals with internal calcite partitions creating windowed chambers otherwise sealed from the interior of the speleothem. Some aragonite encrustation was observed inside the calcite partition. Remnants of a third window were discovered at the top of this specimen. This specimen represents a spathite over which external growth has progressed to the point of disguising the nature of the speleothem and initiating the transition from a tubular to a conical stalactite.

Speleothem Chemistry

Specimens were further disassembled to obtain bulk monomineralic samples weighing at least 0.3 grams for chemical analyses. Reasonably pure samples were obtained from all specimens except spathite 1. Sufficient aragonite samples were obtained from soda straws 1 and 2 and from spathite 3. Calcite samples were obtained from soda straw 3 and spathite 2.

The five bulk samples were each dissolved in 50 mL of dilute HCl. The resulting solutions were analyzed by atomic-absorption spectroscopy in the same manner as the dripwater samples. Concentrations of Mg, Zn, Sr, Ni, Pb, and Cu expressed as parts per million of the solid sample are listed in Table 1.

The magnesium concentration was slightly higher in the calcite speleothems than in the aragonite samples. Magnesium characteristically substitutes for calcium in the calcite crystal structure to a greater extent than it does in aragonite. Higher levels of zinc were also observed in the calcite samples than in aragonite. Strontium values were relatively lower in the calcite samples. The nickel and lead values did not reveal any trends which distinguished calcite from aragonite. None of the solid specimens had copper values above the detection limits of the analytical techniques.

Discussion

Two of the three spathite localities noted in this paper are from caves developed in dolomite. The other locality (Utah)

is from a cave in dolomitic limestone. Spathites originally form as aragonite speleothems. Cabrol and Condray (1982) note that virtually all occurrences of aragonite in French caves are restricted to caves located in dolomite or dolomitic limestone. Deposition of aragonite rather than calcite may be favored by different temperatures and concentrations of magnesium ions (Curl, 1961).

In cave environments, aragonite is more soluble than calcite and hence, less stable (Curl, 1962). A solution which is supersaturated with respect to aragonite is also supersaturated with respect to calcite. Aragonite may be preferentially deposited when magnesium ion concentations are sufficiently high to inhibit calcite deposition by poisoning calcite nucleation sites (Berner, 1975). However, it may seem ironic that the calcite structure accommodates an exponentially higher number of substitutions of magnesium for calcium ions than aragonite (Table 1). Murray (1954) also observed greater substitution of magnesium in calcite than aragonite for the speleothem samples he analysed.

Murray (1954) found that the presence of magnesium in solution favored the precipitation of aragonite rather than calcite. His laboratory experiments and field observations led him to conclude that the aqueous concentration ratio of calcium to magnesium necessary for the precipitation of aragonite is approximately 1.0, which corresponds to a molar ratio of 0.61. He observed calcite precipitating from waters containing less magnesium. The water samples analyzed in the present study do not support his conclusions. Samples collected in Roberts Cave had higher relative magnesium concentrations than any that Murry reported. Molar calcium to magnesium ratios for water samples collected from aragonite speleothems were 0.27 to 0.33 reflecting slightly higher relative magnesium concentrations than for samples from calcite speleothems with molar ratios of 0.37 to 0.38 (Table 1).

The presence of other divalent ions such as Zn, Sr, and Pb may also inhibit calcite or enhance aragonite nucleation. Murray (1954) suggested that strontium and lead may influence aragonite deposition. Cabrol and Condray (1982) suggested that Cu, Zn, Ni, Co, and Fe may influence aragonite deposition. Table 1 shows that a higher concentration of zinc was found in the calcite specimens. Strontium tended to be present in higher concentrations in the aragonite specimens. Nickel concentrations did not demonstrate any trend differences between the two minerals.

As noted earlier, two of the speleothems yielded volumetric water samples an order of magnitude greater than the other water samples. These two samples were from calcite specimens. The slower dripping aragonite specimens had rates of approximately 0.5 to 1.0 mL per hour. Cabrol and Condray (1982) noted that water flow in aragonite stalactites was "not as large as its equivalent in calcite stalactites."

Spathite 2 is an interesting anomaly. As noted earlier, initial examination indicated the outer shell of this specimen to be composed of radiating silky aragonite. Examination of the results of the water samples, Table 1, revealed a similarity of data between spathite 2 and soda straw 3, a calcite specimen. Subsequent X-ray study and more detailed microscopic work determined that spathite 2 consists primarily of calcite. Apparently, this specimen is a pseudomorph of calcite after aragonite. This formation was active and had both calcite and aragonite components growing in its interior. The outer shell of this specimen apparently altered from aragonite to calcite without disrupting the internal aragonite components.

SPATHITE DEVELOPMENT

The development of a spathite is mineralogically a complex process. Spathites form as aragonite speleothems, with an initial diameter (0.6 centimeters) very similar to a soda straw (Figure 2B). As the spathite grows, its outer shell flares not unlike the taper of an inverted pilsner glass. Internally, tufts of radiating aragonite needles grow out from the shell into the core. Some calcite scalenohedrons and rarely rhombohedrons also grow tangentially downward in the internal column (Figure 2C). Eventually the terminus flares enough that a drop of water can no longer extend around the terminus (Figure 2D and E). The water drops hang from one side, and a window into the formation forms as the next stage develops. The admission of cave air into the opening is hypothesized to result in a microenvironmental change and the subsequent development of a calcite partition attached to the calcite scalenohedral crystals. This partition seals the window chamber off from the internal plumbing of the speleothem.

The new stage develops with the characteristic flaring until water drops again can no longer extend across the terminus (Figure 2F). A new stage again develops as the drops hang from one side, and a window is left behind (Figure 2G). Aragonite encrustations may occur in windowed chambers and on the exterior of the spathites. In late stages of spathite development, external encrustations extend over the openings leaving knobs (Figure 2H). Heavy external encrustations are probably due to incresed water migration over the exterior of the spathite. Late-stage specimens are bulky and give the appearance of oversized slightly erratic aragonitic soda straws.

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Roseanne Prestipino and Butler Stringfield assisted in field measurements. William Keene provided assistance on atomic absorption analyses. Special thanks to Ranger Kirby A. Brock of the Jefferson National Forest for his prompt handling of the permit request.

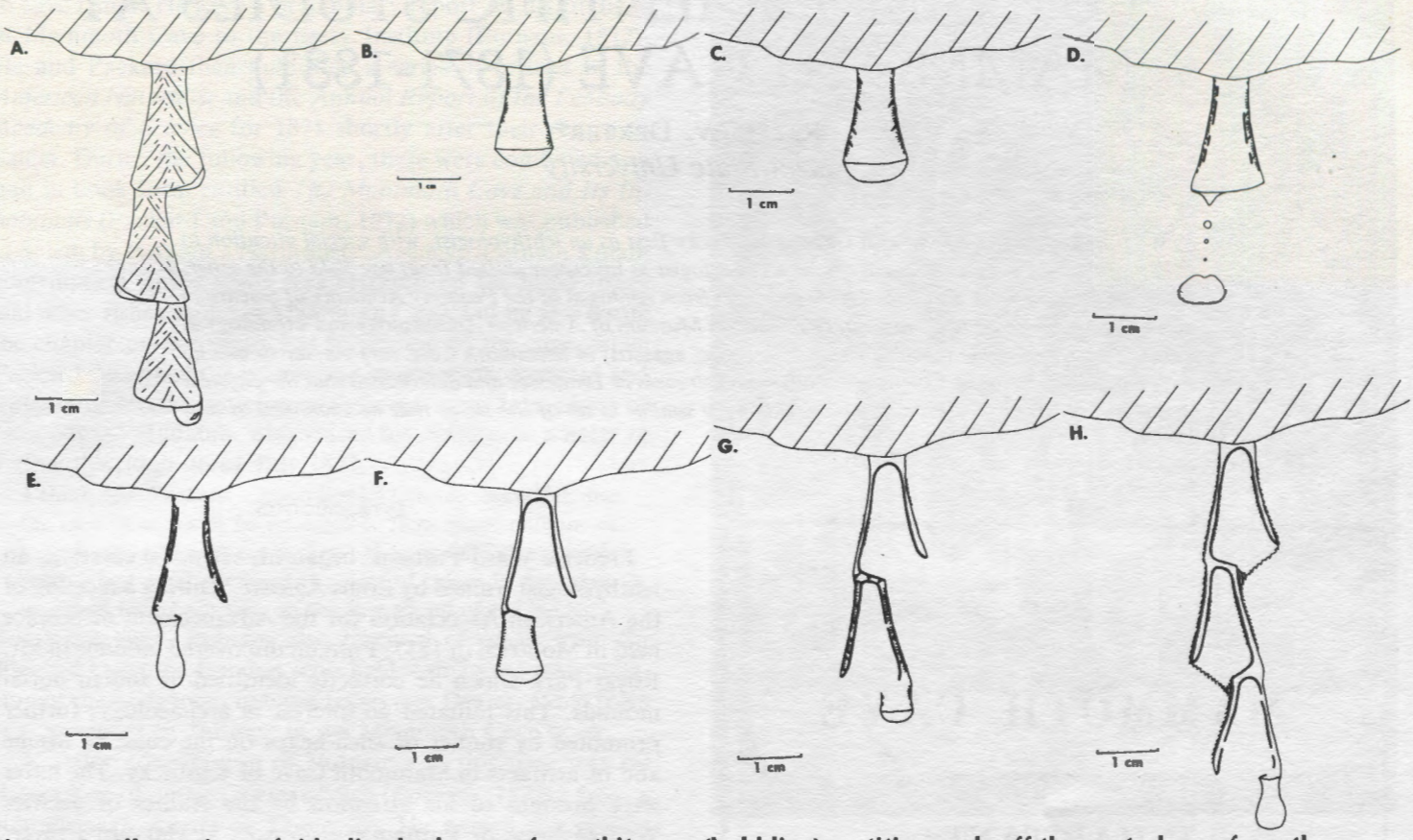

***Figure* 2. Illustration of idealized phases of spathite development showing external (A) and cross-sectional (B-H) views. A. Stylized multistage aragonite spathite suspended from ceiling. B. Early growth form of an aragonite spathite showing flaring termination. Internal growth of aragonite needles that exhibit a moldy appearance. C. Spathite showing continued flaring; calcite scalenohedrons (bold triangles) associated with aragonite needles. D. Spathite has reached the size where a water drop can only extend across its termination as the drop reaches nearly full size. Growth of a calcite partition (bold internal lines) through the coalescence of a number of segments. E. Spathite has grown to the point where a drop can no longer extend across its termination. A calcite (bold line) partition seals off the central area from the active margin of the spathite. A bubblelike chamber with a window is formed; second stage of growth is initiated. F. The chambered first stage of the spathite is shown without internal growth forms of calcite and aragonite. Second stage shows the characteristic flairing morphology and internal aragonite growth. G. Second stage of spathite nearly sealed; third stage undergoing development. Aragonite encrustation is present on the outside as well as inside the windowed chamber of the spathite. H. Late-stage spathite showing development of a fourth growth stage. Extensive encrustation of aragonite has obscured windows of the first and second stages. External encrustations may be due to water migration over exterior of spathite.**

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F. W. PUTNAM'S SCIENTIFIC STUDIES AT MAMMOTH CAVE (1871-1881)

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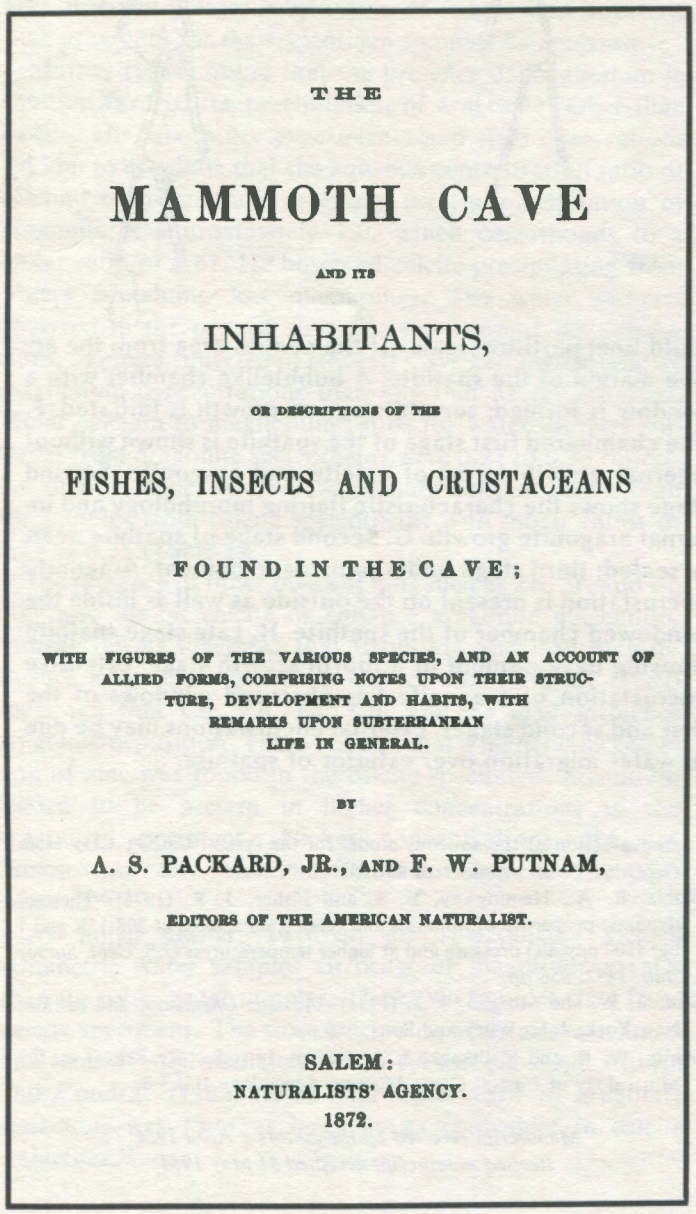
F. W. Putnam studied Mammoth Cave in Kentucky first as an ichthyologist, with special attention to the blind fishes, but later primarily as an archaeologist as his career shifted from one field to the other. His visits to Mammoth Cave mark the transition from zoologist at the Peabody Academy of Science in Salem, Massachusetts, to Curator of the Peabody Museum of American Archaeology and Ethnology at Harvard University. He found a fish (Chologaster agassizi) *in Mammoth Cave very similar to one he had recently described as new from underground streams in Tennessee and determined that the physical character and culture of human inhabitants were similar in all of the caves that he examined in that area.*



THE

MAMMOTH CAVE

AND ITS

INHABITANTS,

OR DESCRIPTIONS OF THE

FISHES, INSECTS AND CRUSTACEANS

FOUND IN THE CAVE;

WITH FIGURES OF THE VARIOUS SPECIES, AND AN ACCOUNT OF ALLIED FORMS, COMPRISING NOTES UPON THEIR STRUCTURE, DEVELOPMENT AND HABITS, WITH REMARKS UPON SUBTERRANEAN LIFE IN GENERAL.

BY

A. S. PACKARD, JR., AND F. W. PUTNAM,

EDITORS OF THE AMERICAN NATURALIST.

SALEM:
NATURALISTS' AGENCY.
1872.

INTRODUCTION

Frederic Ward Putnam[1] began his scientific career as an ichthyologist trained by Louis Agassiz.[2] During a meeting of the American Association for the Advancement of Science held in Montreal in 1857, Putnam discovered mounds in Mt. Royal Park which he correctly identified as Indian burial mounds. This initiated an interest in archaeology, further promoted by studies of shell-heaps on the coast of Maine and of artifacts in Mammoth Cave of Kentucky. The latter were brought to his attention by the studies of Jeffries Wyman,[3] one of Putnam's professors at Harvard University. Putnam's first visit to Mammoth Cave (1871) was primarily to collect fishes, but with succeeding visits his attention was given more and more to archaeology as his career drifted in that direction. On 1 January 1875 he became Curator of the Peabody Museum of American Archaeology and Ethnology on the Harvard campus, and henceforth was primarily an archaeologist, but still maintained an interest in fishes.

VISIT OR 1871

Concerning his first trip to Mammoth Cave in 1871 Putnam wrote:

> After the adjournment of the meeting of the American Association for the Advancement of Science, held at Indianapolis, in August last, a large number of the members availed themselves of the generous invitation of the Louisville and Nashville Railroad Co., to visit this world-renowned cave, and examine its peculiar formation and singular fauna (Packard and Putnam, 1872, p. 5).

Both Putnam and his colleague Alpheus S. Packard, Jr.,[4] at the Peabody Academy of Science in Salem, Massachusetts had been students of Jeffries Wyman at Harvard University. Wyman had published a study on Mammoth Cave (Wyman, 1854), which undoubtedly stimulated interest in the young men.

As an ichthyologist, Putnam developed a special interest

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in cave fishes. He gave a preliminary report on his findings at Mammoth Cave to the Essex Institute (Putnam, 1872). He and Packard then published a series of articles in the *American Naturalist* and the *Annual Report of the Peabody Academy of Science* for 1871 shortly after their return to Salem. During the following year, these were combined as a unit in book form entitled *The Mammoth Cave and Its Inhabitants* (Packard and Putnam, 1872) which was published in Salem by Putnam's Naturalists' Agency.[5] Putnam's main contribution to the study was research on the blind fishes and other fishes found in Mammoth Cave, but he also wrote the chapter on the geological formation of the cave, while Packard described the insects and crustaceans. Packard and Putnam received a criticism of the work from John Sloan of New Albany, Indiana, who voiced his opinion in a letter to Putnam[6] written on 21 July 1872:

> I think Mr. Packard's [evolutionary] theory beautiful, but the facts have yet to be established. How many millions of years it may take makes one dizzy. If Adam or Caine's wife's mother had carefully noted the state of things in their day, we might have been now on the first round of the ladder.

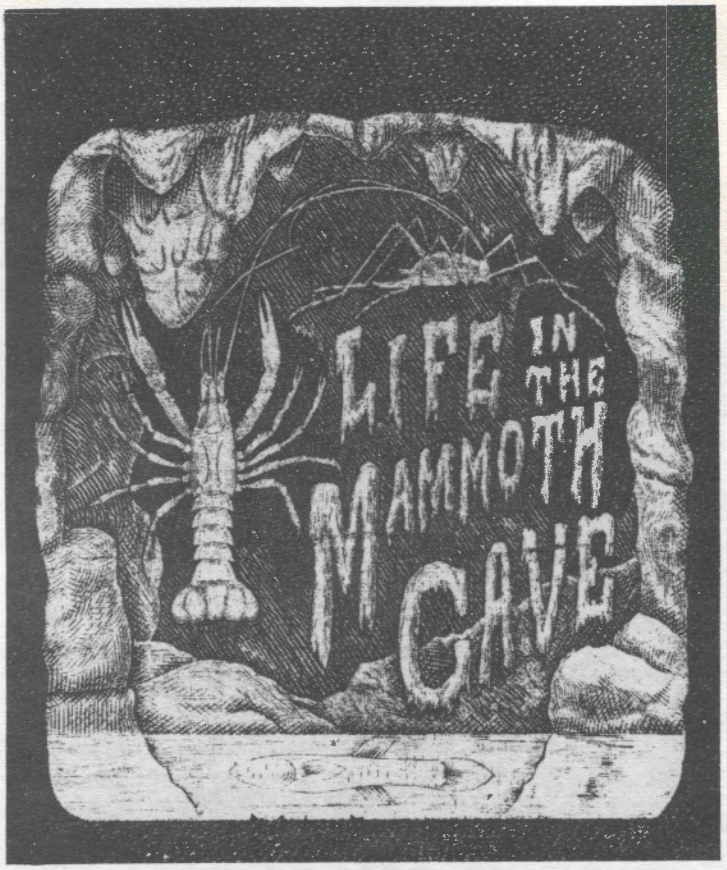
Sometime later, Putnam also received criticism from Sir Richard Owen of London who held a different interpretation of the optic lobes in blind fishes (see Dexter, 1966) from that proposed by Putnam in the Mammoth Cave book.

A major contribution of Putnam's at this time was his description of a new species of fish (Putnam, 1872b) from a subterranean stream in Tennessee. He named the species *Chologaster agassizii* in honor of his mentor, Louis Agassiz, who was teaching at the Museum of Comparative Zoology at Harvard University. Putnam's contributions to systematic ichthyology have been summarized in an earlier paper (Dexter, 1970). Putnam followed Jeffries Wyman's belief that optic lobes of blind fishes are not reduced because they serve brain functions other than sight. Unlike Owen, Putnam did not believe that living in the absence of light would cause the eyes and optic lobes to be atrophied. He wrote in his account of the fishes of Mammoth Cave (Packard and Putnam, 1872, pp. 47-48):

> Again, in regard to the sense of sight, why is it necessary to assume that because fishes are living in streams where there is little or no light, that it is the cause of the non development of the eye and the development of other parts and organs? If this be the cause, how is it that the Chologaster from the well in Tennessee, or the 'mud fish' of the Mammoth Cave are found with eyes? Why should not the same cause make them blind if it made the Amblyopsis and Typhlichthys blind? Is not the fact, pointed out by Prof. Wyman, that the optic lobes are as well developed in Amblyopsis as in allied fishes with perfect eyes, and, I may add, as well developed as those of *Chologaster cornutus,* an argument in favor of the theory that the fishes were always blind and that they have not become so from the circumstances under which they exist?

Contrary to the evolutionary convictions of Packard, Putnam concluded (ibid. p. 52):

> . . . thus I think that we have as good reasons for the belief in the immutability and early origin of the species of the family of Heteropygii, as we have for their mutability and late development, and, to one of my, perhaps, too deeply rooted ideas, a far more satisfactory theory; for, with our present knowledge, it is but theory on either side.

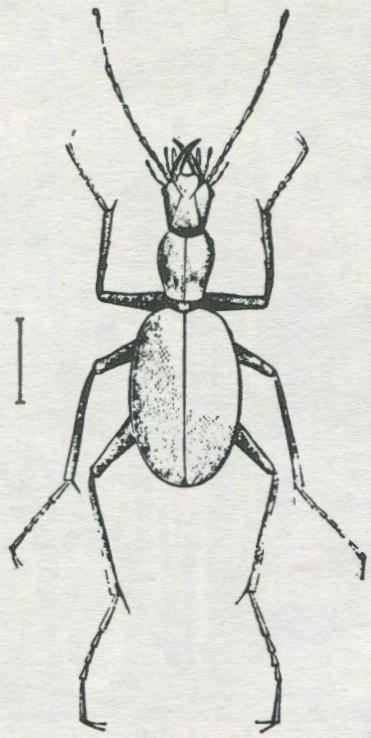


Visit of 1874

In 1874 Putnam was invited by another close friend, and former student under Agassiz, Nathaniel S. Shaler,[7] to become a special assistant to the Kentucky State Geological Survey. Shaler was director of this survey, and he appointed Putnam as of 4 October 1874 to undertake the special study of fishes of Mammoth Cave. Putnam reported to the Essex Institute at a special meeting held 25 November 1874, his observations at the cave and put on display an exhibition of animals he had collected there (Putnam, 1874).

While on his field trip, Putnam wrote frequently in some detail to his family. Somewhat prophetic of his future career in anthropology, which was even at this time occupying more of Putnam's scientific interests, he described his observations of Indian inhabitants in the vicinity of the cave. On 17 October 1874, he wrote:

> This proved a very interesting place and consisted of a circle 450 ft. in diameter and about 4 ft. width and made entirely of broken pottery and bones of animals that had been eaten, clam shells, etc., and only covered by the natural growth of vegetable soil, showing that the ancient inhabitants had



Anophthalmus Tellkampfii.

simply thrown their refuse in a circle about their camp ground and one can only picture to himself, when standing on the field something like this, as the original condition of things viz: a pallisade forming a circle, wigwams in the level space and all this space kept clean by throwing all their refuse around the circle against the pallisades. After the place was deserted the wooden fence decayed, the refuse of bones, pottery, etc., became covered with vegetable growth and decay and we have the place as we found it. The old man, Mr. Robinson, [local guide] was born on the place and says that his father told him that the place was well known to the Indians that were there when his father first had the place, but that they (the Indians) said it was always there so long as they had been and looked upon it as something belonging to "other people" then they. There is no doubt about its very great antiquity and it is a very interesting place.

Five days later he reported on his field studies of ichthyology writing:

I have been out seining all the morning until 1 o'clock and have now seined the Rock Creek pretty thoroughly for about 4 miles. Have caught 19 species in it. Tomorrow we shall take the creek higher up about 10 miles and also go over to Bear Creek nearby.

In addition to special studies on fishes, Putnam also aided in the collection of all forms of cave life. On 27 October he wrote to his wife that

At Richardson Spring we stopped. I got a number of small Crustacea and a lot of little leeches from the water, also two specimens of beetles. At this place we caught a number of crickets, and the walls of the cave had hundreds of bats hanging in clusters. We then pushed on and reached the river. With our small scoop nets we collected several crayfish of various sizes, but did not see any blind fish. [Continued next day] . . . I went into the cave at 8 o'clock this morning . . . direct to the river where I had my seine set since yesterday and made the haul and what do you think I got—an entirely new fish to the cave!—a species of Chologaster . . . either the same as the little fellow I called *agassizii* or an entirely new species . . . I also got a dark colored crayfish from Echo River, in the cave, this morning, which is a good find as it is a different species from the white, eyeless crayfish. So not all the inhabitants of the cave are white for want of sunlight as has been stated.

Putnam proposed the name "Grotto of the Naiads" for this section of the cave. Soon afterwards he wrote again to his wife:

My "big thing" is the finding of an entirely new species of fish in the cave—a species of the blind fish family, but of another genus and with eyes, though it is a permanent inhabitant of the cave. This is truly a very important thing. I have succeeded in obtaining four specimens in five days of cave fishing . . . I now have 22 blind fishes all alive and a lot of the blind crayfish, etc., . . . I have also made some very interesting archaeological researches and have many nice things in that line from the caves. Tomorrow I visit a cave five miles from here for archaeological research . . . I could pass a year in this place to great advantage . . . From Glasgow I shall go to Bowling Green to open mounds there.

Here again we see Putnam's developing interest in archaeology appearing in his field observations. His visit foreshadowed a return to this area in future years when he was devoted entirely to American archaeology.

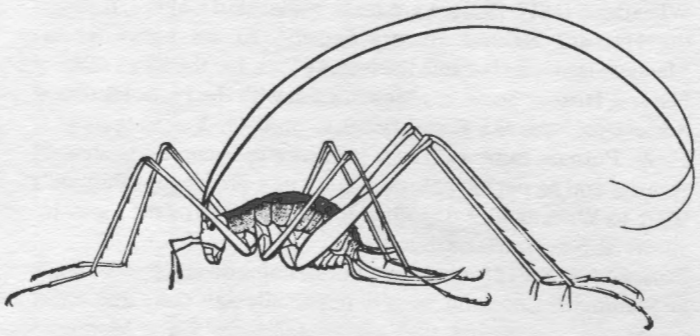
Reports to his family continued almost daily throughout his stay. He described how

We had to wade and crawl flat on our bellies about all the way, but we were well paid for we caught five blind-fish and six cave crayfish and a Daddy-long-legs and some flies . . . Tomorrow I go with Proctor to Long Cave which is about seven miles from here up the river. This is dry cave and contains human bones imbedded in the stalagmitic floor of the cave and some very interesting specimens have been found there.

In addition to field collecting and classification of the cave fauna, Putnam carried out some experimental work. He found that the blind crayfish would not take food as would those with eyes and that they did not acquire pigmentation in subsequent molts even when kept in sunlight. As a result of amputation experiments, he found that appendages were regrown gradually with an additional growth following each molt (Putnam, 1875).

On 1 November 1874, Putnam wrote to Dr. Henry Wheatland,[8] President of the Essex Institute at Salem, Massachusetts:

I know you will be glad to hear of my success here at the cave in obtaining a fish entirely undescribed from cave waters



Hadenœcus subterraneus.

though having its habitat. It is a specimen of Chologaster, and may prove to be the same as the one I described from a well in Tennessee under the name of *C. agassizi,* but I think it is a new species. It has eyes and is very hard to capture. Five days in the cave have only given us four fishes of this species and these were obtained by setting my screen overnight and going in early in the morning before anyone else entered the cave. I have also captured 22 blind fishes of both species and of many sizes and 3 species of fishes with eyes same as outside species viz.—two Pimelodus, one Uranidea and one Leuciscus—also a lot of the eyeless crayfish, one of which is dark colored, but eyeless same as the rest, and agrees in all its characters with the white species except that it is dark colored. Also several males and females of a species with eyes and quite a number of small insects, beetles, spiders, flies, centipedes, scorpions, etc., . . . larvae of insects, small crustaceans, leeches, etc. In fact I have made a fine collection of animals from the cave and shall do still more in that line. . . .

In regard to archaeological matters I have also been quite successful, having found one very interesting Rock Shelter near Grayson Springs where the "Indians" had their dwelling place evidently for a long time. Here I obtained the bones of animals that had been cooked for food . . . a few worked bones, a few flints, fragments of pottery and found two mortar holes cut out of solid rock of the place. I have also collected about 100 arrow and spear points from the surface.

The exploration at Mammoth Cave attracted much attention. Putnam gave a number of public lectures in Cambridge and Salem as well as reports at scientific meetings, on his studies.[9] The public press spread the story even further. From Thomas S. Perry, editor of the *North American Review,* Putnam received at the time a request to make his work known abroad. Perry wrote:

> I have heard so many interesting reports of your lecture on your recent discoveries in Mammoth Cave that I am emboldened to ask you if you will kindly place some of the facts at my disposal for communication to the London Academy of which I am the Boston correspondent.—I would gladly try to give wider publicity to your interesting discoveries.

Visit of 1881

When Putnam returned to Mammoth Cave in 1881 as an archaeologist rather than an ichthyologist, his daughter Alice accompanied him and wrote in her notebook of 1881:

> Papa explored in these caves some years before when on the Kentucky Survey. He lived two weeks in Mammoth Cave with moonshiners watching him, ready to shoot him if he found any of their "stills," but when they found he was after relics of earlier people they became friendly and often took him to places where he found prehistoric sandals, bullrushes, bits of cloth, pottery, etc. . . . There is a chamber named after Papa there, "Putnam's Cabinet."

As already noted, Putnam was convinced from his observations in Mammoth Cave and others nearby that the physical structure and culture of the inhabitants were uniform for the area.

The case of both eyed and blind fishes inhabiting caves continued to have special interest to Putnam and to students of evolution. Putnam at first followed the anti-Darwinism of his teacher Louis Agassiz, but later in life became an evolutionist as did nearly all of Agassiz's students (Dexter, 1979). Alfred Mann, a biologist at Johns Hopkins University, raised some interesting questions based upon Putnam's cave research which might have given ammunition to the Neo-Lamarckian school of evolutionists of which Putnam's friend A. S. Packard was a founder. Mann wrote to Putnam 21 December 1888:

> What I specially care about is the bearing of the development of the eyes [of cave fish] under the influence of light. Do the eyes remain rudimentary when development proceeds in the light—or do they attain more perfect development than when they developed in the dark? The answer to these questions I conceive to have bearing in the question of inheritance of the effects of use and disuse of organs.

At that time, however, Putnam was far more interested in American archaeology than either ichthyology or evolution. He never adopted Neo-Lamarckian views, and did not pursue the matter of cave fishes any further. While he did not return to Mammoth Cave, this early experience marked a transition in his career. He concluded his special interest in cave fishes, and he expanded his developing interest in archaeology. He then pioneered studies of Indian mounds, stone graves, ancient villages and cemeteries, etc., which led many of his contemporaries to call him the "Father of American archaeology."

Acknowledgements

Acknowledgement is made to the family of F. W. Putnam for permission to quote from his personal papers deposited in the University Archives in Pusey Library at Harvard University, and to the Essex Institute, Salem, Massachusetts, for permission to quote from the papers of Dr. Henry Wheatland deposited at that institution.

NOTES

1. Putnam (1839-1915), a student of Agassiz, specialized at first on fishes, and became one of the founding curators and the first director of the Peabody Academy of Science at Salem, Massachusetts. Turning his attention to archaeology, he was appointed curator for the Peabody Museum of American Archaeology and Ethnology at Harvard University at the end of 1874, where he remained for life. However, he played a leading role in developing museums of anthropology at Chicago (Field Museum of Natural History), New York (American Museum of Natural History), and Berkeley (University of California).
2. Agassiz (1807-1873) came to America in 1846 from Switzerland to give the Lowell lectures in Boston. He remained to develop the Museum of Comparative Zoology at the Lawrence Scientific School of Harvard University, and to train many of the leading American naturalists in the following generation. He became known as the "American Cuvier."
3. Wyman (1814-1874) earned his M.D. degree at the Medical College of Boston. In 1847 he became Hersey Professor of Anatomy at Harvard University where he founded the Museum of Anatomy and Physiology. He developed an interest in archaeology through his studies of Indian shell-heaps in Maine and Florida, and research in Mammoth Cave. At the latter site he made a special study of the blind fishes (Wyman, 1854).
4. Packard (1839-1905), another student of Agassiz, and a colleague of Putnam at the Peabody Academy of Science in Salem, specialized in insects and crustaceans, but also had a special interest in caves. He became one of the leading entomologists in America and eventually a professor of zoology and geology at Brown University.
5. The Naturalists' Agency was organized and operated by Putnam in 1864 to publish his *Directory of American Naturalists* and to offer for sale books, journals, specimens, and equipment to aid naturalists in their studies.
6. All of the letters Putnam received, and those to his family, quoted here, are deposited in the University Archives of Pusey Library at Harvard University, Cambridge, Massachusetts.
7. Shaler (1841-1906), another student of Agassiz, along with Putnam and Packard, specialized in geology. He became a professor of geology and paleontology at the Lawrence Scientific School of Harvard and between 1872-1879 served as Director of the Kentucky Geological Survey. He published a paper on his studies of caves in the Ohio Valley (Shaler, 1876) and prepared the article on Mammoth Cave for Johnson's New Universal Encyclopedia (Shaler, 1878).
8. Wheatland (1812-1893), a graduate of Harvard College, founded the Harvard Natural History Society. At his native Salem, Massachusetts, he became the leading light for the Essex County Natural History Society, which merged with the Essex Historical Society to form the Essex Institute in 1848. It was there that F. W. Putnam came under his influence to become a student of Agassiz and to pursue natural history as a profession. Putnam's letter to Wheatland is deposited in the Archives of the Essex Institute at Salem, Massachusetts.
9. Putnam (1875b, 1876) published brief notes on some of his work at Mammoth Cave and vicinity (especially Salt Cave and Short Cave). He discovered that the "Mammoth Cave Mummy" found 60 years earlier actually came from Short Cave, and that bones and artifacts from all the caves examined thus far were very similar in nature.

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NEW BUSINESS MANAGER

George Huppert is the new BULLETIN Business Manager. He will be responsible for obtaining advertisements in order to subsidize the cost of the publication. In addition, he will be the person in charge of expanding library subscriptions and obtaining corporate sponsorship. Members are urged to contact George about identifying potential advertisers and suggesting the names of libraries, institutions, and corporations that may wish to subscribe to the BULLETIN. Please direct your comments to: George Huppert, Department of Geography, University of Wisconsin-LaCrosse, LaCrosse, WI 54601.

PROCEEDINGS OF THE NATIONAL SPELEOLOGICAL SOCIETY
ANNUAL MEETING, June 25 - June 29, 1984
SHERIDAN, WYOMING
G. Thomas Rea, Editor

CAVE MANAGEMENT AND CONSERVATION SESSION

CAVE MANAGEMENT IN THE SPANISH POINT CAVE SYSTEMS

Bob Barry, Bureau of Land Management P.O. Box 119, Worland, WY 82401

During the last few years, major cave resources have been discovered on lands administered by the Bureau of Land Management (BLM) on the west slope of Wyoming's Big Horn Mountains. These caves are associated with the surface and ground water systems that drain this mountain range. With the assistance of Ozark Underground Laboratory, the BLM has initiated studies of these hydrologic systems. Study results will be used to develop management strategies for protecting cave and watershed values from degradation by surface land uses such as timber harvest and strip mining.

DEALING WITH UNCLE SAM AS A CAVE OWNER

Bob Barry, Bureau of Land Management P.O. Box 119, Worland, WY 82401

Protecting cave resources on public lands can succeed only on a basis of cooperation between cavers and the land management agency. Some factors that affect what management agencies can or cannot do are discussed. The author makes suggestions for how cavers can work with management agencies to promote effective cave management.

STATUS AND GOALS OF THE NSS CONSERVATION COMMITTEE

Jer Thornton, P.O. Box 752, Boise, ID 83701

During the past year the Conservation Committee has undertaken a number of specific goal-oriented projects. The present status of these projects and the future goals and efforts of the committee for the next year will be discussed. These include: (1) Introduction and passage of the Federal Cave Resources Protection Act. (2) Development and implementation of National level cave management policies for the Forest Service, the Park Service, and the Fish and Wildlife Service. (3) Development and initiation of a national cave management training seminar to run on alternate years with the National Cave Conservation and Management Symposium. (4) Development and publication of a conservation/management guidebook. (5) National level exposure of the public to values of cave resources and of the need to protect these resources through proper management.

PROPOSAL FOR THE ESTABLISHMENT OF A CAVE CONSERVATION FOUNDATION

George N. Huppert, University of Wisconsin - La Crosse, La Crosse, WI 54601

Cave conservation and management activities have become so numerous and widespread that there now seems to be a need for an organization to serve as a focal point for funding, research, and volunteer information. This organization should be independent of all existing agencies and groups, including the NSS. However, its governing board should be made up of representatives from all public and private groups involved in cave conservation and management. The duties of such an organization would include the following: (1) To insure the continuity of the National Cave Conservation and Management Symposium every two years. A fund would be maintained as seed money for each symposium. (2) To serve as a clearing house for management and conservation information. (3) To conduct, fund, publish, and generally encourage projects and research on conservation and management.

Enthusiasm for cave conservation and management has greatly increased over the past ten years. Many projects have been attempted and some significant successes have been achieved. Now, the knowledge, leadership, and funding methods which have proven successful should be passed on to others who wish to try a similar project.

REAGANOMICS: A BOON TO FEDERAL CAVE PROTECTION

Jer Thornton, P.O. Box 752, Boise, ID 83701

During the past four years, the Regan administration's policies on Federal land use, coupled with heavy budget cuts for the big four land use agencies, has actually opened the door for more effective protection of Federally owned wild caves.

While the agencies are in fact more tightly restricted in terms of funding and subsequently the ability to devote manpower to cave protection, the mandates contained within the Federal Land Policy and Management require that all natural resources be considered and protected. Without adequate funds, the agencies have been forced to turn to volunteers and Cooperative Management Agreements. This means that the caving community has the opportunity to strongly influence not only the policies for wild cave management but to actually take on the job of administering those management programs.

CAVE RESCUE SESSION

THE LAUREL CREEK CAVE RESCUE, GREENVILLE WEST VIRGINIA

George Dasher, 55 Kalafat Mobile Village, Buckhannon, WV 26201

On the 12th of June, 1982, three Maryland cavers were trapped for approximately 32 hours by high water in Laurel Creek Cave near the community of Greenville in southern West Virginia. This event attracted state-wide media attention and, had not the weather and the cave cooperated with the rescue effort, could have ended on a much less positive note.

This informal paper will be a brief synopsis of the rescue performed the following day by members of the Greenbrier and V.P.I. Grottos. The talk will include a background of the geographic area and Laurel Creek Cave, a critique of actions of the rescuees as well as the leadership of the cave rescue workers and the state police, and an overview of the event. Additionally, potential problems, required equipment, and the subsequent closing of the cave by the landowner will be discussed.

CREVICE RESCUE - IS DEATH INEVITABLE?

John C. Hempel, RD 1, Box 436, Dilliner, PA 15327
Jeff Uhl, 101 First Street, Northampton, PA 18067

In the last four years, three serious crevice rescue attempts have occurred in the eastern USA.

Two have resulted in the death of the victim and one with the extrication of an uninjured person in good enough shape to exit the cave unaided.

The similarities of these rescue efforts are startling in that each took 30 hours to complete from the time of entrapment and that the situation in at least two cases did not appear to be life threatening until it was too late.

This paper summarizes the cause, effect, and problems associated with crevice rescue. In addition, some discussion of special techniques and materials useful to the rescue are given.

ORGANIZING A RESCUE TEAM/NETWORK

John C. Hempel, RD 1, Box 436, Dilliner, PA 15327

In cavernous areas of the Virginias many local fire departments or EMS units handle cave rescue emergencies. In most cases they are successful if the problem is not too demanding or the search too complicated. If a serious problem arises, cavers in the area must be prepared to support their local squads with personnel, equipment, and expertise.

This paper describes methods of interfacing with your local rescue teams and discusses the "nuts and bolts" of setting up a call out system for cave rescue.

In addition, ideas are presented on how to establish, train, and equip grotto rescue teams.

COMPUTER APPLICATIONS SESSION

ALGORITHMS FOR GETTING OUT OF A CAVE

Richard L. Breisch, 4735 Mt. Ashmun Drive, San Diego, CA 92111

Five different algorithms for finding one's way out of a maze (or a cave) have been published in the literature of the mathematical specialty of graph theory. Three more methods have been devised by the author. Each algorithm is a set of simple rules which allow a person, who has no knowledge of the organization of the cave passages, to eventually find his way to an entrance.

Which algorithm is most efficient? How can one compare the relative efficiency of a set of algorithms? Is one particular algorithm more (or less) efficient than the others?

The work to date has centered on defining precise measures of efficiency and using these to compare the algorithms. These procedures have been applied to caves small enough so that the measures of efficiency can be calculated exactly by hand.

It may be too hard to obtain an exact evaluation of the measures of efficiency when the algorithms are applied to large maze caves, so the next step of this investigation is to evaluate the measures on a computer using the Monte Carlo method. To do this, the cave is first described in the computer. Each algorithm is implemented with a subroutine. A random number generator is used to select the passage for the lost person to try. The rules of the algorithm under test are applied, and the distance traversed from the start to an entrance is tabulated. This is repeated a large number of times, say 1,000 to 10,000, for each algorithm. Estimates of the measures of efficiency can be calculated from these repeated trials.

DATA BASE MANAGEMENT FOR CAVE INVENTORY

Dave Derowitsch, 40 Second Street, Christiansburg, VA 24073

A data base management system has been developed that is capable of storing and retrieving pertinent information on caves. Data can be stored as unencoded unique entries or as encoded categories. Fast, efficient multiple field searches are implemented through the use of modified binary search trees on the unencoded fields and linked lists on the encoded fields. the system is easily adapted to a wide range of hardware since all hardware specific code is contained in a few small routines that perform the logical to physical translation. The supporting configuration and utilities programs allow the user to easily design, install, and subsequently modify a specific database.

A FINAL REPORT ON THE SMAPS CAVE SURVEY SYSTEM

Doug Dotson, 118 Washington Street, Frostburg, MD 21532

At the 1983 NSS Convention I presented a talk describing the initial efforts in the development of an integrated system for the reduction of cave survey data for microcomputers. This project, the Survey Manipulation, Analysis, and Plotting System (SMAPS), is now complete. This final report will discuss the features of SMAPS, the design philosophy chosen, and the problems encountered during the development of the system.

AN ANALYSIS OF SURVEY COMPASS ERRORS

Tom Kaye, 4921 Seminary Road, #1510, Alexandria, VA 22311
Bob Hoke, 87278 Hayshed Lane, #12, Columbia, MD 21045

At the 1983 NSS Convention Tom Kaye and Bob Thrun presented preliminary results of a study of over 1,600 observations with various types of survey compasses under controlled conditions. This paper extends the analysis and compares the expected accuracy of the different types of instruments. The human factor in surveying is also analyzed by comparing the instrument reading accuracy of different people under the same test conditions.

THE SURVEYORS vs. THE SOFTWARE

Paul A. Hill, 607 South 1100 East, Salt Lake City, UT 48102

Today many surveyors are using computers to reduce cave survey data. The computer user is presented with the problem, on the one hand, of duplicating the data in the computer in a form similar to what was originally recorded and, on the other hand, formatting the data for use by the cave survey software.

Because of the diversity of caves, the cavers, and the users of the data, it seems an unwise if not impossible task to attempt to standardize cave survey data formats. Given this situation, what is needed is a translator that can understand a wide range of cave survey formats and convert the data to a form understood by different cave survey programs.

A parser specifically designed to convert a multitude of data formats, as entered directly from survey notes, to a multitude of alternate formats for later processing has been constructed. The syntactic properties of cave data including many real examples will be discussed to show that the possibilities, while

varied, fall within limits that are predictable and reasonable.

The function of the translator that was built will be presented to show how data in a mostly original form can be combined with commands to the translator in a way that is both readable by the average cave surveyor and understandable by a reasonable size computer program.

CAVE MODELING

Kirsten Stork, 1155 East 500 S, #30, Salt Lake City, UT 84102

Surface modeling has been receiving increased attention within the computer community in the last few years. This has led to the project of creating a cave modeling system, the first stage of which is presented here.

In this system, the user is provided with a three-dimensional representation of the survey data as well as an interpretation of these data with walls instead of the simple survey skeleton. It is assumed that the data include measurements from a survey point to the left and right wall as well as to the ceiling and floor.

In addition, an editor is incorporated to allow interactively changing the cave walls. Initially, the editing features have been limited to adding, moving, and deleting wall points.

EXPLORATION/EXPEDITION SESSION

PUSHING THE NEW FRONTIERS IN COLORADO'S CAVE OF THE WINDS

Vi Allured, 4231 Eaton Court, Boulder, CO 80303
Rick Rhinehart, 220 Pine Brook Hills, Boulder, CO 80302

Since its discovery in the late 1870s, Colorado's Cave of the Winds has seen a variety of lengthy digging projects which have revealed over 7,900 feet of passage.

An improvement in relations between the cave's commercial management and the five NSS grottos in Colorado has permitted cavers to try their hands at uncovering the hidden secrets of the cave. Since January of 1980, over 400 feet of passages have been discovered by cavers, including the well decorated Silent Splendor.

Generally considered to be the most beautiful passage in the cave, Silent Splendor was reached only after a difficult 30-foot vertical dig through mud and a 20-foot bolt climb up a flowstone wall. On January 14, 1984, five Colorado cavers viewed with awe the delicate beauty of Silent Splendor's massive displays of white beaded helectites. Twisting and turning for up to two feet in length, the beaded helectites are unmatched by anything yet discovered in Colorado. They are considered by many to be the most significant discovery in the history of the Cave of the Winds.

EXPLORING FOR A WATER SUPPLY IN RIO CAMUY CAVE, PUERTO RICO

Russell H. Gurnee, 231 Irving Avenue, Closter, NJ 07624

The municipal water supply for Bayney, Puerto Rico, comes from the underground Rio Camuy. After ten years of operation, silting of the submersible pump catch basin has forced the town to abandon the site.

A search for an alternate location to obtain water has revealed an underground spring—a tributary of the Rio Camuy—that will supplement existing supplies and eliminate the pump maintenance problems.

This paper suggests that alternate sources of fresh water might be tapped in flowing underground streams providing a positive and dependable water source at a minimum of risk. Accurate and thorough surveys are required before venturing into the project; and studies should include the recording of seasonal and periodic variations.

CAVES AND KARST IN THE GROS VENTRE RANGE, WYOMING

Douglas Medville, 11762 Indian Ridge Road, Reston, VA 22091
Charles Plantz

The Gros Ventre mountain range in northwestern Wyoming consists of about 230 square miles within the Bridger-Teton National Forest. Over 60 percent of this area consists of Paleozoic rocks, the most extensive member being the Mississippian Madison Group, 800 to 1,000 feet thick. Although extensive limestone outcrops and well developed alpine karst landforms exist, relatively few caves have been found in the Gros Ventres. Those caves which have been explored to date will be described as will the major karst areas visited to date. These areas are in the upper Tosi Creek basin, the Swift and Shoal Creek drainages, and in the Clear Creek/Darwin Peak basin.

COLUMBINE CRAWL, DARBY CANYON AREA, WYOMING

Rick Rigg, 169 East 25th Street, Idaho Falls, ID 83401
Warren Anderson, Box 517, Wilson, WY 83014
Bob Benedict, 130 East 22nd Street, Idaho Falls, ID 83401

Columbine Crawl has a small entrance at an elevation of 10,000 feet. This entrance leads to a series of 16 roped drops and gradually increasing passage size. The cave passes completely through the thousand-foot thick Madison formation in the first third of its two-mile length. Thereafter, the passage is corraded into the underlying insoluble Darby formation. This produces a sporty downclimbing passage with easily broken handholds and underwater footholds. The passage eventually ends in a mud-and-rock-filled stream crawl at a depth of 1,550 feet, making Columbine Crawl the deepest cave in the United States. The presentation will discuss equipment and logistical innovations developed during the exploration of the system.

FOSSIL MOUNTAIN ICE CAVE, WIND CAVE SYSTEM, DARBY CANYON AREA, WYOMING

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The first few hundred meters of both entrances to the Fossil Mountain Ice Cave-Wind Cave System have been locally known and very popular for many decades. A crawlway dug out at the bottom of the Ice Cave eventually led to three miles of fine canyon and river passage and another dig connecting to the back of Wind Cave. The spectacular ice formations, seven roped drops, and miles of river passage create a truly classic alpine river cave through trip.

THAILAND KARST HYDROLOGIC SURVEY

Rick Rigg, 169 East 25th Street, Idaho Falls, ID 83401
Bob Benedict, 130 East 22nd Street, Idaho Falls, ID 83401
Mike Ingram

For six weeks in late 1983 and early 1984, a group of nine Western cavers explored the speleological potential of two areas in Chiang Mai Province of Northern Thailand. The survey was conducted in cooperation with the National Research Council of Thailand and Chaing Mai University.

The first area was around the village of Chaing Dao. Here, about a half dozen caves up to two kilometers long and 150 meters deep were investigated and mapped. Two of these were basically horizontal resurgence caves followed to upstream sumps, while the others were essentially vertical fissure caves ending in mud plugs.

The second area investigated was in mountains along the Burma border west of the city of Fang and centered around the Thailand Forestry Research Station at Ang Khang. Ten caves were explored, of which seven were significant enough to map. All but two of the caves required extensive rope work. Cave lengths were up to a kilometer and depths were mostly 150 to 200 meters. One of the caves has an entrance drop that is 64 meters free and two rooms that each have a diameter greater than 100 meters. This cave also has commercial potential. All but one of the caves were ended, usually in tightening bedding plane crawls at a particular geologic contact. Most caves showed evidence of major flooding and ponding during the wet season. Bats and invertebrates were collected and have been distributed to specialists for identification.

EXPLORATION OF GENERAL DAVIS CAVE, GREENBRIER COUNTY, WEST VIRGINIA

Scott Robertson, Dept of Astrophysical, Planetary, and Atmospheric Sciences, Univ of Colorado, Boulder, CO 80309

General Davis Cave is described in Davies' Caverns of West Virginia as being a single walkway 2,000 feet long. A survey of the cave was begun in 1967 and in 1969 unusually low water allowed penetration into a virgin passageway. The survey was completed in 1973 with 14,279 feet of mapped passage, most of which is a single trunk channel under Davis Hollow. The main passageway ends in a siphon which dye tests show to connect with Sinks-of-the-Run Cave. At the terminal siphon, 8,000 feet upstream of the first siphon, graffiti states, "Those who want to submerge are welcome to it. NSS 7-28-1944; Wingfield, Merritt, Kiefer."

The cave has been found to contain a unique troglobitic salamander, Gryinophilus, subterraneus and a unique beetle, Pseudanopthalmus lallemanti, whose lives are protected by upstream and downstream siphons, a perennial stream, and more recently a gate. A one-acre parcel of land around the entrances was donated to the Nature Conservancy in 1981.

1984 PEÑA COLORADA EXPEDITION - HUAUTLA PLATEAU, OAXACA, MEXICO

Noel E. Sloan, M.D., 5243 Luzzane #609, Indianapolis, IN 46220

Dr. Bill Stone, leading an eleven member team, returned to the Huautla Plateau in February, 1984. The goal was to explore the Peña Colorado resurgence upward through the plateau and connect with Sótano de San Augustín. In order to achieve this, the team was equipped with a sophisticated lightweight cave diving system, specialized underwater transport gear, and camping gear all specifically designed for this expedition. The Cueva de la Peña Colorada was explored to a length of 9.1 kilometers, making 7.83 kilometers of progress in the direction of San Agustinín. This exploration involved diving 9 sumps totaling some 1.35 kilometers of underwater passage. Due to the logistics of this exploration, camping beyond the sumps was required and two underground camp sites were established. All of the sumps encountered were perched and resulted from significant and frequent folding of the limestone strata. A nonpermeable grey limestone stratum was apparent throughout the sump areas and appeared to be responsible for baselevel development. Due to the extensive folding, the cave, though basically horizontal, had some 2000 meters of vertical traverse. The main obstacle to further exploration was sump seven, a deep sump at the bottom of a 54 meter shaft. Access to the sump required divers to rappel, wearing full dive gear, directly into the sump. Because of both logistics and depth, exploration was stopped in a basically horizontal tunnel 10 meters by 13 meters at a water depth of 56 meters. The sump continued deeper. Some 2 1/2 tons of gear were hauled through the cave to accomplish exploration to this point. Attempts to find alternate entrances into the system and provide a hopeful bypass to sump seven led to the exploration of eight other caves. The most significant of these were Vine Cave and Cueva de Altar. Vine Cave was surveyed to over a kilometer in length and required diving two sumps. Cueva de Altar—part of an old, dry upper level system—had a large circle of stones in the entrance which may prove to be of archeological significance. Approaches from the top of the plateau yielded Sótano de Don Felix Carrera, a 195 meters deep multiple drop cave. Overall, the new techniques and equipment pioneered on this expedition will hopefully lead to the further exploration in other cave systems, where exploration has been stopped by the logistics of remote sump diving.

GEOLOGY - HYDROLOGY SESSION

MYSTERIES IN MUD: ANCIENT FROST-CRYSTAL IMPRESSIONS AND OTHER CURIOSITIES IN CAVE OF THE WINDS, COLORADO

Donald G. Davis, 5311 309 Road, Parachute, CO 81635

Two new passages have recently been revealed by digging in Cave of the Winds. Undisturbed moist mud deposits there have angular impressions indicating the former presence of crystals growing on the mud. These were apparently ice in the form of large, individual hoarfrost crystals. This indicates much colder conditions than the temperatures (about 48 - 52 degrees F) now prevailing, and suggests that the west part of the system was a cold-air trap when its entrance was more open than in historic times. Other unusual features, including Pleistocene (?) small-animal claw marks and mud folia, are also preserved in the mud wall coatings.

EVIDENCE FOR DEEP-SEATED GROUNDWATER MOVEMENT IN MIDDLE MISSISSIPPIAN CARBONATE LITHOLOGIES OF SOUTH-CENTRAL INDIANA

Donald W. Ash, Dept of Geography and Geology, Indiana State Univ, Terre Haute, IN 47809

Detailed Structural mapping of key marker beds in middle Mississippian rocks in south-central Indiana and central Kentucky indicate that the loci of major sinking streams lie along a specific

lithostratigraphic horizon located in the lower St. Louis Limestone. Water within this lithostratigraphic unit is confined and flows in a downdip direction to resurgences in deeply entrenched drainages located within the Chester cuesta. In Indiana, downdip from these resurgences are several mineral springs which contain high amounts of dissolved sulfates which are related to lower St. Louis evaporite lithologies. Tritium dating of these mineral springs indicates that the residence times for waters discharged from these springs increases exponentially in a downdip direction.

VALLEY-ALIGNED CAVERNS

James Hedges, Big Cove Tannery, PA 17212

The Maquoketa Caves in Jackson County, Iowa possess a trunk channel developed parallel with and directly beneath the remnants of a former small bedrock valley. The side passages of the cave system trend gently upward, branchwork fashion, into the adjacent ridges. The Duttons Cave System in Fayette County, Iowa has also developed parallel with and directly beneath a small surface valley, as has Searryls Cave in Jones County, Iowa and the 7 Caves System in Highland County, Ohio.

The patterns of all of these valley-aligned caverns were determined by the pre-cave configuration of the local water table: Solution was most rapid at or slightly below the level of minimum annual stand of the water table in the areas of largest ground water discharge—beneath the thalwegs of valleys containing seasonal streams.

The Maquoketa Caves and Searryls Cave lie along the Aftonian course of Maquoketa River, at the level of the (Aftonian) Scotch Grove Strath. Duttons Cave lies along the pre-glacial valley of Turkey River and is of pre-Sangamon age. The 7 Caves lie along the Illinoian marginal gorge of Rocky Fork of Paint Creek and are of pre-Wisconsinan age. All of the cave systems, coincidently, are developed in dolomites and limestones of Silurian age.

DETERMINATION OF CARBONATE HARDNESS IN KARST WATERS FROM CONDUCTIVITY MEASUREMENTS

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William B. White, Dept of Geosciences, The Pennsylvania State University, University Park, PA

It has been long established that there is a linear relationship between the specific conductivity of a ground water and the total dissolved solids in the water. In karst areas, the total dissolved solids is composed mainly of $Ca^{++} + Mg^{++} + HCO_3^-$. The anion concentration is linked to total cations by the electrical neutrality principle and so conductivity is related to total cation concentration. Calcium and magnesium are often expressed together as "calcite hardness" = $[Ca^{++}] + [Mg^{++}] \times MW(CaCO_3)$.

In the course of a series of experiments on the kinetics of dissolution of calcite and dolomite, data were obtained that connect specific conductivity with hardness for the pure minerals. The regression equations are:

Hd (ppm $CaCO_3$) = 0.66 Spc - 13 (for dolomite)
Hd (ppm $CaCO_3$) = 0.78 Spc - 21 (for calcite)

Comparison of chemically analyzed groundwaters with measured specific conductance also leads to linear regression equations but with more scatter in the data. An equation based on 57 wells and springs in Central Pennsylvania is:
Hd (ppm $CaCO_3$) = 0.59 Spc - 30

In spite of the different equations for dolomite and calcite from laboratory work, the field measurements do not neatly separate into predominately limestone and dolomite waters. Introduction of other anions, particularly sulfate and chloride produces much additional scatter. However, conductivity is a good field measurement of hardness for relatively pure carbonate waters.

TUBES, CANYONS, NETWORKS, AND MAZES: MULTIGENETIC ORIGIN OF INNER SPACE CAVERN, WILLIAMSON COUNTY, TEXAS

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Inner Space Cavern, a commercial cave adjacent to and beneath Interstate Highway 35 approximately 3 kilometers south-southwest of Georgetown, Texas, has developed within the Edwards Formation (Lower Cretaceous limestone). The morphology of the cave is complex and consists of mazes displaying both network and branchwork patterns. This character stems from the development of three distinct types of passages: (1) long, sinuous master conduits of large cross-section that form a dendritic "backbone" of the system and represent the principal avenues of groundwater flow during enlargement of the cave, (2) relatively short, linear passage segments of small cross-section that form angulate maze-patterns situated adjacent to trunk passages and represent excavation of fractures by periodic flooding, and (3) collapsed passages that are typically curved in plan-view, have one wall composed of collapsed material, skirt the peripheries of debris-cones beneath surfical dolines, and represent diversionary routes of flow around blockages formed by collapse.

During the early stages of speleogenesis, flow was transmitted along the strike through a fault block of the Balcones Fault Zone and within a highly porous member of the Edwards Formation. Master conduits and major tributaries developed under shallow phreatic conditions. The cave was later drained of water as the local potentiometric surface dropped in response to incision of surfical streams. Under vadose conditions, recharge was carried to master conduits along evolving canyon-like tributary passages. Regional denudation of the landscape and stoping of enlarging master conduits caused large-scale collapse and blockage of some flowpaths. In response, passages became periodically flooded by stormwater. This promoted (1) excavation of adjacent joints forming networks of mazes and (2) diversion of flow around zones of collapse, through enlarging diversionary channels at the base of debris cones and at interconnections of extending mazes.

THEORETICAL CONSIDERATIONS IN THE ORIGINS OF EDWARDS AQUIFER CAVES IN THE BALCONES FAULT ZONE

Albert E. Ogden, Edwards Aquifer Research and Data Center, Southwest Texas State Univ, San Marcos, TX 78666

Cavern formation in the Balcones Fault zone region of the Cretaceous-aged Edwards limestone aquifer is controlled by a complex interaction of hydrologic, lithologic, structural, and paleo-erosional factors. Pumping (aquifer) test data and well logs show that the highest transmissivity (T) values and the most caves (intersected by wells) occur just inside the confined-unconfined boundary of the aquifer due to mixing corrosion. Second in importance to this boundary contact for cavern formation are the abundant faults that trend primarily in a northeast direction. Most ground water moves through fault-controlled caves with the interior of the fault blocks having lower T values and less caves. Caves have also formed at the

Edwards limestone-Georgetown limestone unconformity boundary where an internal permeability was formed by subaerial erosion.

Also important are lithological controls. The Regional Dense Bed member and chert horizons perch water in the unconfined zone causing caves to form in the overlying beds. Caves also form where evaporitic layers have been removed by dissolution. Another lithologic control is the presence or absence of honeycombed beds. The honeycombed layers allow water to move in a nearly homogeneous fashion similar to a porous sandstone, and thus caves are not formed. Caves are more likely to form in the dense, non-honeycombed beds where water moves along narrow pathways controlled by structural weaknesses. The boundary between the fresh water and the bad water zone does not appear to be an area of cavern development based on pumping test and well log data, thus eliminating the hypothesis of solution by sulfuric acid-rich waters.

GEOLOGY OF CAVES IN THE BLACK HILLS, SOUTH DAKOTA

Arthur N. Palmer and Margaret V. Palmer, Dept of Earth Science, State Univ of New York, Oneonta, NY 13820

The Black Hills caves, particularly Wind and Jewel Caves, are widely known as among the world's most complex, both in pattern and in variety of geologic features. They are located in the Mississippian Pahasappa Limestone, which consists, in ascending order, of massive dolomite, thin-bedded cherty limestone and dolomite, and massive limestone. These units have hosted narrow fissures below, tubes in the middle and domed rooms (lofts) above. The middle unit accounts for most of the geologic complexity. It formed as a soil and interclastic zone, which was later brecciated by gypsum solution and/or hydrothermal activity, and underwent fracturing and vein filling at least four separate times. All of these events have helped to produce the distinctive boxwork and multi-colored walls in the later caves. Post-Mississippian karst features formed in the upper units and were filled by Pennsylvanian sand and clay. Unfilled voids were lined with white dogtooth spar during deep burial. The paleokarst features were partly exhumed during the main cave-forming event, which probably took place during uplift of the Black Hills in the early Tertiary period. Lack of relationship with surface drainage, paucity of clastic fill, and dolomite and silica replacement suggest that the cave was formed by rising acids of deep-seated origin. Geochemical and isotropic studies by earlier workers also support this idea. Draining of caves allowed deep weathering of the walls. Temporary reflooding forming calcite wall coatings may have resulted from occlusion of springs by the Oligocene White River beds.

HUMIC SUBSTANCES AS PIGMENTS IN CAVE CALCITE DEPOSITS

William B. White, Dept of Geosciences, The Pennsylvania State University, University Park, PA 16802

The characteristic brown, orange, tan, and yellow colors of stalactites and stalagmites have been hypothesized to be due to humic substances acting as organic stains rather than to iron oxide pigments as previously believed.

Humic substances include fulvic acid, humic acid, and humin all derived from the decomposition of vegetable matter in soil. These are high molecular weight molecules built around phenol ring structures with substituted carboxylic acid groups. Because of the high number of ionizable hydrogens, humic and fulvic acid solubilities are sensitive functions of pH. However, they tend to be base soluable and acid insoluable; thus their transport is opposite to the pH changes that take place when CO_2-rich soil water picks up $CaCO_3$ and deposits it in caves by CO_2 loss. pH increases during the calcite depositional process. These substances are strong chelating agents and it is hypothesized that they are transported into the growing speleothems as ligands binding calcium ions.

Characteristic signatures for humic substances are their infrared spectra and (in some cases) their luminescence under ultraviolet or laser irradiation. These have been measured for a suite of colored speleothems from tropical and humid temperate climate caves. Temperate climate caves tend to have speleothems with deeper colors and a richer suite of humic substances because of the high concentration of humic material in temperate climate soils. Tropical caves have less coloration and a more interesting suite of lower molecular weight humic substances because humic substances tend to be oxidized in tropical soils leaving only the iron oxide pigmentation of the terra rosas.

MINERALOGY OF ISLAND FORD CAVE

William B. White, Dept of Geosciences, The Pennsylvania State University, University Park, PA 16802

In the various compilations of cave minerals, Island Ford Cave, Allegheny County, Virginia appears as the location for a suite of unusual zinc phosphate and other minerals not reported from other caves. The mineral deposits of the cave were re-investigated using techniques of x-ray diffraction, scanning electron microscopy, and infrared spectroscopy.

Island Ford Cave is very sparsely mineralized. Most deposits consist of thin crusts and minor coral-like deposits. Of the available deposits, most are carbonate minerals. Rare minerals make up only a very minor portion of the deposits.

PALEONTOLOGY SESSION

FIRST ANNUAL PROGRESS REPORT ON THE PLEISTOCENE FAUNAS OF THE JOHN GUILDAY CAVE PRESERVE

Fred Grady, 1201 South Scott Street, #123, Arlington, VA 22204

In the past year (April, 1983 - April, 1984), significant progress has been made on the collection and study of the Pleistocene faunas of the caves on the John Guilday Cave Preserve. Much of the work has centered on the carnivore sites in Hamilton Cave. Screen washing of matrix from these sites has revealed a rich fauna of small vertibrates indicating a late Irvingtonian age ca. 700,000 years before present for these deposits. Excavations have also started on a rich small vertibrate site in Trout Cave. A paper reporting on the pocket gopher, Geomys sp., from New Trout Cave is in press.

A PRELIMINARY ACCOUNT OF PLEISTOCENE MAMMALS FROM PATTON CAVE, MONROE COUNTY, WEST VIRGINIA

Fred Grady, 1201 South Scott Street, #123, Arlington, VA 22204

Remains of Pleistocene mammals have been recovered from several localities within Patton Cave, Monroe County, West Virginia. The major excavated

site produced bones of at least 22 individuals of the peccary, Platygonus compressus, and 75 individuals of small mammals, several species of which have present ranges north of Patton Cave. Other fossil remains found scattered in several nearby sites include a tooth of the extinct deer, sangamona fugitiva a partial skull of the badger, Taxidea taxus, and a partial mandible of the pine marten, Martes americana. Carbon 14 dates of 13,350 and 22,620 years before present were obtained for the main site and a second site respectively. The main site is believed to represent a now closed natural trap. Tracks and scratches left by bears and possibly other carnivores were discovered near several of the bone sites.

PUBLIC RELATIONS SESSION

PUBLIC RELATIONS AND THE NSS

Jay Jorden

Public relations, the skillful but sincere portrayal of an organization in its best possible light, is a practice which is often employed in nonprofit groups with effectiveness equivalent to that of profit-making enterprises. The differences involved in nonprofit PR are the very concepts which make the challenge even more difficult—and rewarding at the same time. In the case of the Society, PR is being used to plan, develop, administer, and control publicity. Both passive and active types are being undertaken. Some attendant goals in publicizing the Society and caving include convincing uninitiates of the utility inherent in safety and conservation messages, enlisting volunteer aid, and gaining financial resources.

SAFETY & TECHNIQUES SESSION

USING RADIOS UNDERGROUND

Chuck Jopson, 1405 Grant Avenue, Boise, ID 83706

Normally, radio communication is limited to line-of-sight within a cave. The underground range of a low power walkie-talkie can be extended to over 1,000 feet by running a fine wire through the cave. This method has several advantages over cave telephones: (1) It requires only one wire. (2) No stripping of insulation is necessary. (3) One can be moving as he talks.

Experimental results and applications to cave rescue will be discussed.

SURVEY AND CARTOGRAPHY SESSION

PROJECTION TECHNIQUES AND MAP CONSTRUCTION

Stephen Attaway, Georgia Tech, Box 36600, Atlanta, GA 30332

Correlating the entrance locations and principal passage orientations of different caves with their topographic and geographic environment is an important contribution to understanding the geomorphology of caves. One method of achieving these correlations is to produce maps that depict surface topography, cave entrance locations, and horizontal projections of major cave passages. The maps may be examined to visually interpret trends among these parameters. The author has developed a FORTRAN computer program that will use a large, high-resolution vector plotter to generate overlay maps that depict cave entrance locations and their associated map. The overlay maps are constructed using the same projection techniques used by the U. S. Geological Survey (USGS) to make standard 7'30" polyconic topographic maps and the larger 1:1,000,000 metric Universal Transverse Mercator topographic maps.

One may accurately superimpose the overlay maps on standard USGS topographic maps. In addition, programs were developed to produce large-scale maps of cave entrance locations based on projection techniques that do not yield area distortions. This paper presents the fundamental ideas and the equations needed to formulate these types of computer programs for cave entrance locations based on latitude and longitude. Large scale maps of Tennessee, Alabama, and Georgia are used to present the distribution of caves with documented locations in those states.

XANADU: SURVEY AND CARTOGRAPHY CONSIDERATIONS OF A MULTI-LEVEL, MULTI-MILE CAVE SYSTEM

Charles Clark, 5146 Bramblewood Drive, Acworth, GA 30101

Xanadu Cave runs for better than 23 miles beneath the slopes of the Obey River Gorge in Fentress County, Tennessee. Yet, this entire system is contained underneath an escarpment with a total linear extent of just over one mile. Xanadu's entire expanse is contained within two-tenths of a square mile. Obviously, such a dense concentration of cave passage on multi-levels creates serious obstacles the the cave mapper in organizing his survey and drafting his cave map.

Xanadu has been organized for exploration and survey purposes into three major sections (Xanadu, Zoroaster, and Alph) and six subsections. Each section is surveyed and plotted by a master surveyor, and each section is plotted on separate section maps as well as the comprehensive Xanadu map.

The survey and map project has fallen upon the shoulders of two chief surveyors—the project head, Jeff Sims, and Charles Clark. Each surveyor has separate in-cave and cartographic responsibilities. As the survey nears completion, the question of how to produce the final map arises. Jeff Sims advocates publication of the comprehensive Xanadu map, while Charles Clark advocates publication of a portfolio of section maps. Questions of map use, sublimity, or practicality will one day determine which map will prevail.

AN ANALYSIS OF INSTRUMENT READING ERRORS IN CAVE SURVEYS

Bob Hoke, 87278 Hayshed Lane, #12, Columbia, MD 21045

Analysis of data gathered at a survey contest held at the 1983 (West Virginia) Old Timers Reunion revealed an unexpected number of blunders by experienced cave surveyors. Although the contest was held under near optimal conditions, the 39 contestants made over 25 significant errors in reading their instruments. This paper describes these blunders and makes a strong argument for using backsights to detect blunders before leaving the cave. An analysis of the inclination errors (all of which were on Suunto instruments) indicates that a modification to the scale markings (by the manufacturer) might make the instrument less prone to reading errors.

AN OVERVIEW OF CAVE SURVEY PROJECT DATA MANAGEMENT TECHNIQUES

George Dasher, 55 Kalafat Mobile Village, Buckhannon, WV 26201

This short paper will provide a brief synopsis of the different survey data management techniques incorporated in mapping caves of short, intermediate, and long length. The discussion will center on computer and non-computer compiling and storage of the coordinate data, as well as the closing of major loops within a cave system, survey quality control, personal attitudes toward cave mapping, personnel management, and potential and prevalent problems encountered by cave surveyors.

Survey programs for both in-house computers and hand-held programmable calculators will be available for inspection. In addition, slides will be shown and there will be ample opportunities for interested persons to ask questions.

VERTICAL SESSION

THE SPELEAN SHUNT

Bill Cuddington

A description of the Spelean Shunt—what it is and how to use it—will be presented.

HUTCHINS RAPPEL STIRRUPS

Cindy Heazlit

This paper will describe the history, physics, and simple construction of rappel stirrups. On long drops (300 feet plus), the legs often lose circulation, causing them to go to sleep. This is more an annoyance than a danger, but does lead to lost time on the bottom. The Hutchins Rappel Stirrups alleviate this problem on any sit harness. These light weight, inexpensive, compact devices could become a standard item in every vertical caver's deep pit arsenal.

A NEW CHEST ROLLER FOR GIBBS SYSTEMS

Rob Landau

A chest roller, designed on the principle of the Simmons roller, but of simpler construction, is described. It uses an unmodified quick-release pin, interchangeable with those on the Gibbs ascender. It is lightweight and all parts are attached together. Complete drawings will be shown.

AN IMPROVED GIBBS SELF-START TECHNIQUE

David R. McClurg

An improved self-start technique for the Gibbs Ropewalker is presented. The trailing rope is looped under the lower boot and up through a carabiner on the chest harness. This makes it easy to maintain even pressure on the boot and self starting becomes a piece of cake.

HOW TO STAY ALIVE WHILE VERTICAL CAVING

David R. McClurg

Ten tricks of the trade for safer vertical caving: (1) Figure 8 loop in the end of the line. (2) Rigging runners. (3) Seat harness (not a seat sling). (4) Chicken loops. (5) Caver's sling. (6) Safety loop. (7) Spelean Shunt. (8) Jumar with an etrier. (9) 8 mm handline. (10) Plastic bag exposure suit.

VERTICAL PITS: HOW TO SELECT THE RIGHT GEAR FOR EACH TYPE

David R. McClurg

Three types of vertical pits—short, medium, and the really big ones—are described along with the gear needed to safely do them. Vertical Short is up to 50 feet (15 meters), Vertical Medium is 50 feet to 150 feet (15 to 50 meters), and Vertical Long is 150 feet to 1,500 feet plus (50 to 300 meters plus).

NEGOTIATING TRICKY LIPS

Janet McClurg

Here are some simple techniques for making your life easier when you get back up to the top of the pit. Rope tail with a figure 8 loop, Jumar with an etrier, and coming out of your top ascender before reaching the lip. The equipment and the techniques will be discussed.

A NEW CAVING ROPE

Dan Smith

A new caving rope combining several of the best characteristics of current ropes will be described. In particular, abrasion characteristics and handling are optimized.

CUT RESISTANCE OF CAVING ROPES

Gary D. Storrick

The recent emphasis of rope abrasion resistance has tended to overshadow the importance of cut resistance in caving and climbing ropes. This session will examine the cut resistance of various rope types by live demonstration.

SOME NEW IDEAS FOR THE EXPEDITION ROPEWALKER SYSTEM

Gary D. Storrick

The expedition ropewalker system is typically assembled with a foot Gibbs, a floating knee Petzl, a Simmons chest roller, and a seat Jumar. This paper presents the results of field testing a modified system including an open side ascender made from a Gibbs (a Gibblet), a chest harness with quick ejection buckles, and prototype single-channel Gossett box with an integral cam.

Craig, Kevin D., Horton, Paul D. and Reams, Max W. (1984)—Clastic and Solutional Boundaries as Nucleation Surfaces for Aragonite in Speleothems: *NSS Bulletin* 46: 15-17.

CLASTIC AND SOLUTIONAL BOUNDARIES AS NUCLEATION SURFACES FOR ARAGONITE IN SPELEOTHEMS

KEVIN D. CRAIG*
University of Wisconsin-Milwaukee

PAUL D. HORTON**
Western Michigan University

MAX W. REAMS***
Olivet Nazarene College

A petrographic study was made of speleothems containing alternating bands of aragonite and calcite. Aragonite layers almost always grow from corrosion surfaces or clastic layers. Experimental precipitates were prepared by release of carbon dioxide from calcium bicarbonate solutions. Calcite was the precipitate, except in the presence of clay size particles, when vaterite was formed. We suggest that clastic layers and corrosion surfaces are common sites for nucleation of the metastable polymorph of calcium carbonate, aragonite, in speleothems.

INTRODUCTION

The origin of aragonite in speleothems and other near-surface environments has been the subject of many studies. A large number of physicochemical factors which may be responsible for the precipitation of this metastable polymorph have been investigated (Dragone, *et al.*, 1975; Garcia-Ruiz and Amoros, 1980; Lippmann, 1982; White, 1976).

Two neglected factors which may be responsible for aragonite deposition are: (1) clastic particles which may serve as seeds for metastable polymorphs (Brunson and Chaback, 1979), and (2) corrosion surfaces which provide a base for metastable polymorphic growth (Lippmann, 1973).

These two mechanisms have not been applied to the calcite-aragonite problem in speleothem deposits before, although Mills (1965) observed that clastic layers and corrosion surfaces are often, but not always, sites of nucleation in banded speleothems. Mills observed three causes for banding in speleothems. The first cause is gas cavities, thought to form when dry periods are followed by wet periods, during which times air is trapped between growing crystals. Kendall and Broughton (1978) described similar fluid inclusions and considered them the result of lateral crystal growth and fluid entrapment. Mills noted that aragonite and calcite both display gas cavities. The gas cavities usually do not cause interruption of crystal growth in most speleothems.

The second cause for banding in speleothems, according to Mills (1965), is the presence of clastic layers. These layers consist of clay, silt, and, sand particles. Mills considered these layers the result of flood events in caves. Kendall and Broughton (1978) did not consider clastic layers to be significant in speleothem layering. Mills observed many such layers, some with sand size particles of quartz and occasionally feldspar. He reasoned that these large particles could only have been transported by energetic stream flow. He found that many of these clastic layers were nucleation sites for new calcium carbonate bands. Other clastic layers did not break crystal growth.

The third of Mill's causes of banding in speleothems is corrosion. Surfaces of corrosion are especially noticeable when highlighted by a clastic layer which filled "V" shaped solutional extensions into corroded crystals. Mills considered these surfaces the probable result of cave flood events. He thought the solution of the speleothem might also have been contemporaneous with sedimentation of the clastic layer. Folk and Assereto (1976) also noted solution effects in a speleothem, but associated this with inversion of aragonite to calcite.

None of the above authors have suggested that clastic layers or corrosion surfaces might be influential in determining the polymorph of calcium carbonate which precipitates in speleothems.

PETROGRAPHY OF BOUNDARY SURFACES

Speleothems from Missouri were studied in ultra-thin sections cut perpendicular to growth axes. Slabs of the same speleothems were etched in hydrochloric acid for examination under a binocular microscope. Etching emphasized clastic particles and layers by causing them to stand in relief. The general description and nomenclature of calcite in

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speleothems is given by Mills (1965), Folk and Assereto (1976), and Kendall and Broughton (1978). Mills (1965) and Tankersley, *et al.* (1984) have described the appearance of aragonite in speleothems. Our study was concerned primarily with the nature of two types of boundary surfaces, clastic and corrosional. We were especially interested in the possible influences these surfaces might have on nucleation of aragonite. We concentrated on the surfaces of nucleation for aragonite bands. In most of the stalactites we selected, aragonite is found alternating with calcite. We observed two fundamental types of nucleation surfaces, corrosion surfaces and clastic deposits (Figure 1). A third and less common occurrence of aragonite involves complex textural relationships with calcite suggestive of recrystallization. Clastic and corrosion boundaries were also found in intimate association, with aragonite growing on the surface. In contrast, calcite grows not only on these surfaces, but on aragonite, on fluid inclusion layers, and on other calcite layers, i.e., on all possible surfaces.

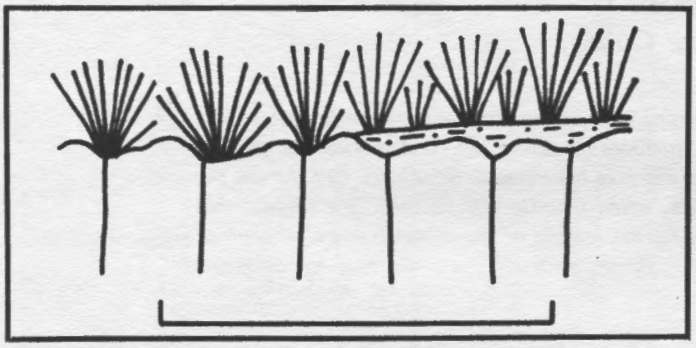

Figure 1. **Generalized textural patterns associated with aragonite nucleating surfaces in Missouri speleothems. The radiating needles are aragonite crystals. The large crystals are calcite, the tops of which are solutionally corroded and support aragonite crystal growth. To the right is a clastic layer of silt and clay which also serves as a nucleating surface for aragonite. The length of the bar is one millimeter.**

Aragonite growing on clastic layers in the Missouri speleothems forms a common texture. Aragonite radiates as needles attached to the clastic layer. Clastic layers were identified and discussed by Mills (1965). We found quartz grains ranging to sand size, as did Mills. We also observed that many clay-rich layers exhibit uniform, parallel extinction, under crossed-polarized light, indicating their oriented micaceous nature. Aragonite may terminate at the next younger clastic layer but may continue through the detrital sediment as well. Aragonite may also grade into or change abruptly to calcite, where traced to the outer part of a band.

Aragonite often grows on the irregular surface of solutionally corroded calcite crystals. Although clastic particles are usually not visible in thin section, lateral tracing of corrosion surfaces in places leads to a clastic layer or a large clastic particle. Some speleothems have sand-size fragments of clay associated with corrosion surfaces but are not readily visible in thin section. Radiating bundles of aragonite emerge from the corrosion surface.

Folk and Assereto (1976) and Kendall and Broughton (1978) are opposed in their interpretation of recrystallization features in speleothems. We have not dealt extensively with this problem but consider recrystallization a possibility in some speleothems displaying intimate mixtures of aragonite and calcite. Microanalytical geochemical studies might resolve the problem of recrystallization in speleothems.

It appears that calcite can nucleate on virtually any surface in speleothems. Aragonite seems much more restrictive in that aragonite bands nearly always radiate from corrosion or clastic surfaces. Aragonite apparently competes better with calcite on such surfaces.

Lippmann (1973) noted that aragonite tends to form on foreign particles and nucleates on scratches on the interior surfaces of beakers during precipitation experiments. Reams (1972) found that mainly aragonite formed on the painted exterior surface of a plastic container left under a stalactite in a Missouri cave for 4.5 years, whereas mainly calcite formed on the unpainted interior. Perhaps corrosion or impurity surfaces on calcite provide a nucleating surface which permits aragonite to compete more favorably than calcite.

The effects of mineral seeds to aid nucleation are known, but only Brunson and Chaback (1979) have said that clastic seeds may influence the precipitation of metastable polymorphs of calcium carbonate from natural materials. Their study of lime precipitation during coal liquifaction indicated that higher concentrations of ash and pyrite favored vaterite (another polymorph of calcium carbonate not yet found in caves) instead of calcite. They tested individual substances by decomposing calcium acetate in the presence of an acidic solution of colloidal silica, bentonite, kaolinite, various grades of quartz, and FeS and FeS_2 mixtures. Only colloidal silica and pyrite resulted in significant vaterite precipitation, instead of calcite. The concentrations of these foreign substances determined the proportions of vaterite and calcite.

EXPERIMENTAL STUDIES

We simulated conditions of speleothem precipitation at room temperature from calcium bicarbonate solutions by loss of carbon dioxide (see Reams, 1974). Crushed, sieved, and washed Burlington Limestone (Mississippian from Missouri) was used as the starting material. Deionized distilled water was added to the limestone, and carbon dioxide gas was bubbled through the mixture. After careful filtration, 50 ml aliquots with various clastic additives were stirred vigorously to release the carbon dioxide and produce carbonate supersaturation. Various experiments were performed with solutions with and without the less than 2 micrometer fraction of a clastic cave sediment from a

Missouri cave. The fine fraction of the sediment contains illite, kaolinite, and chlorite. No quartz or carbonate phase was identified in it. The clastic additives and the experimental precipitates were analyzed using a Phillips x-ray diffractometer.

The experiments yielded calcite when no clastic material was present. The addition of the clay fraction in concentrations starting at 16 mg/liter (0.0008 g added to a 50 ml aliquot) resulted in calcite-vaterite precipitates. Between 16 and 80 mg/liter clay concentrations, the calcite/vaterite ratio decreased until, at 80 mg/liter and higher, vaterite was the sole polymorph of calcium carbonate precipitated. Much higher concentrations of clay inhibited all calcium carbonate precipitation.

Although aragonite was not precipitated during the above experiments, there is clear evidence that clastic materials inhibit calcite or enhance metastable polymorph precipitation. Further studies are planned to test specific clastic substances and their influence on aragonite precipitation.

CONCLUSIONS

Petrographic study of speleothems containing alternating bands of aragonite and calcite reveal that most aragonite bands nucleated on corrosion or clastic surfaces. Experimental evidence indicates that at least one metastable polymorph of calcium carbonate, vaterite, may compete more favorably with calcite in the presence of clastic particles. We suggest that clastic layers and corrosion surfaces may be of considerable importance in determining the presence of aragonite in speleothems.

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ERRATA

Mr. J. Hedges
Star Route 2, Box 103
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Pennsylvania 17212

Dear Mr. Hedges:

I have just noticed a very important omission in the published version of my article, Introgressive Hybridization in the *Astyanax Fasciatus* (PISCES: CHARACIDAE) Population at La Cueva Chica" (*NSS Bulletin* 45:81-85). Right before the last paragraph of the "Discussion" section, on page 84, you omitted a whole paragraph which was included in the galley proofs I checked. The omission of the paragraph creates two serious problems with what I tried to present in my article: first, it makes it sound as if I were in direct contradiction with what I state in the point 6) of that same page regarding "overlap in reduced spawning space and spawning periods"; second, it leaves out what I think is the most interesting point of the whole paper —that there is a more morphological than genetical differentiation in the first stages of cave colonization.

Also, contrary to what I stated in the galley proofs, the volume and page references to Romero, Aldemaro (1984a) (page 85) were misplaced in Romero, Aldemaro (1984b), which is still in press.

Thus, I have to ask you to do everything you can to include in the next issue of the *NSS Bulletin* a note in which the deleted paragraph should be included as well as the correction regarding the misplacing of the volume and page references to the literature cited. This is the only way I can see that the damage made by these printing errors can be partially amended.

Sincerely,

Aldemaro Romero, Ph.D.
Adjunct Assistant Professor of Biology

My sincere apologies. The paragraph inadvertently left out follows:

> It has been proposed that there is more genetic than morphological differentiation between related cave and surface species and/or troglobitic populations (Culver, 1982:95). This is largely based on Barr's (1968) contention that cave adaptation involves considerable reorganization of the genotype, which is, in turn, an application of Mayr's (1970) genetic revolution of the founder principle to the evolution of cave organisms.

—J.H.

CAVE AND KARST ABSTRACTS

BIOLOGY

Aspects of the Ecology, Environmental Physiology and Behavior of Several Australian Cave-dwelling Crickets

Glenn Dennis Campbell, Ph.D.
University of New South Wales (Australia), 1980

Information was obtained from field and laboratory studies on aspects of the life cycle, population biology and ecology, food and feeding relations, circadian activity rhythms, and water relations of a number of Australian cave-dwelling cricket species (Rhaphidophoridea and Grytloidea). Habitat, species, population and individual differences were investigated and discussed in relation to their contribution to an ecological and physiological classification of cavernicolous crickets.

Life history studies revealed the processes of ecdysis, mating, oviposition and development of *Australotettix carraiensis* Richards. There are 10 stages in the life cycle of this species: egg, 8 nymphal instars, and adult. The mean durations for the egg and instars 1-6 were determined at 15°C. The complete life cycle takes between 2 and 2.5 years.

Seasonal changes in the structure and dynamics of the population of *A. carraiensis* within Barnett's Cave (northeastern N.S.W., Australia) were monitored over a 3-year period by systematic visual census. Observed population numbers fluctuate in synchrony with surface temperature and rainfall cycles. The highest population levels within the cave occur during the dry, cold winter months. Temporal and spatial segregations of age groups exist within the population.

Habitat microclimate, population size and fluctuation, and dispersion and movement patterns of individuals of 5 cave-dwelling cricket populations were investigated. Cave microclimate generally fluctuates much less than that of the surface. Population sizes were estimated by a mark-recapture census and ranged from 39 ± 8 *Endacusta sp.* in Pipeline Cave to 2930 ± 1709 *Pallidotettix nullarborensis* in Offset Blowhole during winter. Dispersion analysis indicated significant clumping of individuals in microclimatically stable areas within the caves at most times of the day. Refuging behaviour is highly developed for *P. nullarborensis, Endacusta sp.,* and *Cavernotettix sp.,* with individuals emerging from the caves just after sunset on nights of low saturation deficits and returning before dawn.

Dry-weight diet compositions of 10 species of cave-dwelling crickets were determined by quantitative microanalysis of crop contents. Although all species tested are omnivorous, analyses of variance and a test of diet similarity noted interspecific differences in the diets. Qualitative and quantitative differences in food availability were implicated as determining factors in these differences. When a complete range of food is available to the crickets within the caves or within their normal refuging range, anthropod remains and fungi are selected.

Locomotory activity was investigated for 4 species in the laboratory. An endogenously controlled circadian rhythm was demonstrated for each. An LD 14:10 light/dark cycle entrains the rhythm, and activity free-runs in DD. Interspecific differences were noted in the following: amount and duration of activity, intensity of light-shock reaction, free-running period length, onset precision and phase relationship of free-running rhythm to previously entrained rhythm. Amount and duration of activity significantly increase in LD and DD when food is not provided.

Weight and area-specific transpiratory water loss rates were determined for a range of cave and surface-dwelling cricket species in dry, moving air at 15°C. The mole cricket exhibited the highest rates, and the gryllids were the most water conservative. Cave-dwelling rhaphidophorids exhibited high rates that are intra- and interspecifically proportional to live body weight, but not related to surface climate conditions. Resistance to desiccation is apparently correlated with microhabitat affinity. The effect of condition, temperature, and relative humidity on water relations of the rhaphidophorid *A. Carraiensis* and the gryllid *Endacusta sp.* were investigated in detail. A cuticular permeability change occurs between 20°C and 25°C for *A. carraiensis* and at about 35°C for *Endacusta sp.* Both species are unable to absorb water at near-saturated atmospheres despite prior desiccation.

Competition among Five Species of Cave-Associated Salamanders (Family Plethodontidae)

Daniel Craig Rudolph, Ph.D.
Texas Tech University, 1980. 80pp.
Chairman: Dr. Robert W. Mitchell

Competitive interactions in a larval salamander guild occupying spring habitats in the western Ozarks were investigated. Data from laboratory experiments and field observations demonstrated considerable ecological similarity among the four species (*Typhlotriton spelaeus, Eurycea lucifuga, E. longicauda, E.tynerensis*). Few significant differences were found in prey composition, habitat usage, resistance to flooding, or resistance to fish predation.

Field observation revealed considerable spatial segregation occurring in the spring habitats, primarily in relation to distance from the spring source. Aggressive tendencies were quantified for each species, and the results were consistent with the field observations. These data support the conclusion that interference interactions were responsible for the observed patterns. A series of introduction experiments provided direct evidence that species interactions were responsible for the observed spatial distributions.

The species interactions observed support several predictions of ecological theory. The species occupying the included niche (*T. spelaeus*) is the behaviorally dominant species. The least aggressive species (*E. tynerensis*) essentially avoids competition by divergent habitat and behavior. The most similar of the species (*E. lucifuga* and *E. longicauda*) are exceedingly similar ecologically and may be an example of ecological convergence as predicted by MacArthur and Levins.

Comparison of Acute Toxicity Between Epigean and Hypogean Isopods (Asellidae) to Cadmium, Zinc, and Total Residual Chlorine

Arthur D. Bosnak, M.A.
Tennessee Technological University, 1979

Aquatic toxicology typically deals with the evaluation of pollutants upon epigean organisms. Little attention has been given to the fate of these same pollutants in waters which flow through subterranean karst drainages and the impacts placed on hypogean communities. To provide insight into these needs, studies were designed to test the hypothesis that hypogean organisms would be more sensitive to toxicant materials than ecological similar epigean forms.

During the late summer and early fall of 1978, *Asellus alabamensis,* a blind hypogean cave isopod, and *Lirceus alabamae,* an epigean isopod, were collected from similar hydrological habitats and tested in the laboratory to establish 96-hour LC 50 values for cadmium, zinc, and total residual chlorine in flow-through toxicological assays. In efforts to maintain water quality integrity, dilution water was taken from the same hydrological cave system and *Asellus* isopods from Merrybranch Cave, White County, Tennessee. Dilution water and *Lirceus* isopods were taken from their site-specific location in DeKalb County, Tennessee.

Resulting 96-hour LC 50 values and their 95% confidence intervals for each toxicant were derived by Log-Probit and 10% Trimmed Spearman-Karber Analyses. All tests indicated that epigean *Lirceus* isopods were more sensitive to the toxicants than were the hypogean *Asellus* isopods.

HYDROLOGY

An Application of Systems Analysis to Karst Aquifers

Shirley Jean Dreiss, Ph.D.
Stanford University, 1980. 209pp.

Kernel functions which represent the behavior of a karst aquifer system were derived from computed input and output records for different storms for four gaged springs in southeastern Missouri. The input record, groundwater recharge, was calculated by removing evapotranspiration and change in soil moisture from precipitation measurements using a Thornthwaite moisture balance and setting the volume of this excess precipitation equal to the volume of storm discharge of the spring. The output record, the direct storm response of the springs, was estimated by subtracting the baseflow portion of spring discharge during a storm from the total storm discharge. Kernels were derived using a parametric linear programming deconvolution technique. The technique uses linear programming to identify the discrete kernel function that reproduces a system response with minimum error. The derived kernels can be smoothed if necessary.

The kernel functions reproduce the storm responses from which they were derived with about three percent error. Storm averaged kernel functions for the springs predict the storm responses with an error of about eighteen percent. The peak values, the lag times of the peaks, and the predictive accuracy of both the average kernels and the kernels for individual storms vary.

The error and variability of the kernel functions are principally due to (1) limited data availability; (2) inaccuracies in data measurement and representation; (3) simplifying assumptions in the groundwater recharge and direct runoff calculations; and (4) errors in the conceptual model of the spring system. Inaccuracies in the data are caused by measurement errors, the representation of continuous processes as discrete series, and the spatial averaging of precipitation and soil moisture properties. Assumptions related to the area of recharge of each spring, the soil moisture conditions, the storm response length and method of baseflow separation, and the method of estimating the rapid groundwater recharge component of the excess precipitation also lead to errors and incompatibility in the input and output series. The largest source of error in kernel derivations may be the inadequate description of the spatial variability of rainfall and recharge conditions.

Because the shape of the kernel functions varies greatly with a number of factors and is strongly influenced by errors in the input and output series formulation, the kernel functions cannot be easily interpreted physically. Also, until a

satisfactory methodology for the separation of the groundwater recharge from the calculated excess precipitation is developed, the kernels can reproduce, but not predict, storm responses.

ANTHROPOLOGY AND ARCHEOLOGY

TECHNOLOGICAL STRATEGIES OF STONE TOOL PRODUCTION AT TABUN CAVE (ISRAEL)

HAROLD LEWIS DIBBLE, PH.D.
The University of Arizona, 1981. 219pp.
Director: Arthur J. Jelinek

The ability to interpret variability in chipped-stone artifacts is fundamental to an understanding of past human behavior. There are four major factors that contribute to lithic variability: raw material, technology, function, and style. This dissertation addresses itself to basic technological relationships that operate during the production of lithic artifacts and the stategies employed by prehistoric knappers in controlling them.

Through the technique of controlled experiment, a number of variables that affect flake dimension and other observable lithic attributes are isolated and described. A similar analysis is then performed on artifactual material from the Paleolithic site of Tabun Cave. These studies demonstrate that variability in flake form can be explained on the basis of observable characteristics of platform preparation. In particular, the manner in which the knapper varies the exterior platform angle, platform width, and platform thickness have predictable consequences on the resulting flake morphology.

The manner in which prehistoric knappers control the independent variables of the platform is also discussed. The Tabun collections afford a unique opportunity to examine changes in these strategies through time. In addition, the author performs an exploratory study of the Levallois industries of Tabun in order to examine other aspects of variability and suggests possible interpretations concerning the relationship between them.

STRONTIUM AND DIET AT HAYONIM CAVE, ISRAEL: AN EVALUATION OF THE STRONTIUM/CALCIUM TECHNIQUE FOR INVESTIGATING PREHISTORIC DIETS

ANDREW SILLEN, PH.D.
University of Pennsylvania, 1981. 201pp.
Supervisor: Francis D. Johnston

Determining the diets of prehistoric peoples is fundamentally important to physical anthropologists, archaeologists, and to others who seek information about the human biological and cultural past. An outstanding problem is the determination of the proportionate amount of meat vs. vegetable foods in paleo-diets. The measurement of strontium in human and animal bones from archeological sites has been proposed and applied to gather this information.

Two major areas of difficulty with the technique are identified. First, there is a lack of information on the distribution of strontium within fresh bone mineral when diets are constant, and when they change, and the degree to which these differences are a source of error when whole bones are analyzed. Second, there is a lack of information on the chemical changes bones undergo during interment, and the degree to which these changes obscure the original strontium values of the bones.

To investigate the first area, an *in vivo* study was conducted to measure the Sr/Ca ratios of bone density fractions of growing rates maintained on diets varying in strontium content. It is concluded that, if adult dietary strontium can be assumed to have been relatively constant, then whole bone is an acceptable subject for strontium analysis. If, on the other hand, it cannot be assumed that diets have been relatively constant, it must be realized that the strontium values obtained from bone are, at best, a summary of dietary strontium during the period in which the mineral was deposited.

With regard to the second area, the technique was tested at Hayonim Cave, an archaeological site in the Western Galilee previously determined to meet certain criteria necessary for a test of the technique. This criteria included (a) the presence of both herbivore and carnivore bones in numbers from at least two different strata, (b) the presence of well-characterized human bones from the same strata, and (c) other information about the diet of the sites inhabitants.

In the Natufian level, excellent discrimination between herbivore and carnivore species was found on the basis of Sr/Ca ratios. The figures obtained conformed to the prediction that carnivores should have lower Sr/Ca ratios than herbivores. Moreover, the Sr/Ca values of the omnivorous humans fell midway between that of herbivores and carnivores.

However, in the Aurignacian level, no difference between the Sr/Ca ratios of herbivores and carnivores was observed. Moreover, Aurignacian bones differed from Natufian bones in their density, and in the apparent obliteration of histological structure.

The results indicate that the use of Sr/Ca technique may provide important new information about paleodiets. However, it is necessary to employ stringent faunal controls in conjunction with the technique to ensure its successful and convincing application.

THE PALAEOETHNOBOTANY OF FRANCHTHI CAVE, GREECE

JULIE MARIE HANSEN, PH.D.
University of Minnesota, 1980. 466pp.

Franchthi Cave is located on the southwest tip of the southern Argolid, Greece. It was excavated by Professor Thomas W. Jacobsen, Indiana University, between 1967 and 1976. Through the use of a systematic water sieving system, a large quantity of carbonized botanical material was recovered from a long stratigraphic sequence inside the cave. This sequence covers a span of occupation from about 25,000 to 3400 b.c. This thesis is the result of an intensive study of these botanical remains from this entire sequence.

The study of the botanical remains revealed a sequence of wild and domesticated species that can be divided into seven zones based on the changes in the quantity of material and the taxa represented. Zones I through V are comprised almost entirely of wild species. Predominant among these are *Lithospermum arvense, Lens* sp., *Pistacia* cf. *lentiscus, Prunus* cf. *amygdalus, Pyrus amygdaliformis, Avena* sp., and *Hordeum* cf. *spontaneum*. These first five zones are correlated with the Upper Palaeolithic and Mesolithic periods at the site.

Zones VI and VII are correlated with the Neolithic period at Franchthi. Zone VI sees the first appearance of domesticated emmer wheat (*Triticum dicoccum*) and hulled two-row barley (*Hordeum distichum*) at this site. In Zone VII domesticated einkorn wheat (*Triticum monococcum*) is found in fairly large quantity. Many of the wild species present in zones I through V are also found in zones VI and VII suggesting some continuity in plant exploitation throughout the occupation of the cave.

The sudden appearance of domesticated wheat suggests a new influx of this crop at least in zone VI. The presence of both large and small seeded lentils and wild barley in the earlier zones, however, succeeded in zone VI by primarily large-seeded lentils (*Lens* cf. *culinaris*) and domesticated barley may point to incipient domestication at Franchthi. The evidence for this is inconclusive, however, a careful examination of the size distribution of the lentils throughout the sequence reveals a gradual increase in lentil diameter from zone II through zone VI. On the other hand the dichotomy seen in the disappearance of wild barley and the appearance of domesticated barley suggests that this latter crop may have been introduced along with the wheat. The possibility remains that in the earlier zones the lentils and barley, as well as the oats, may have been cultivated with no recognizable change being manifested in the cereals.

In addition to this problem of the origins of agriculture, the possible regional distribution and annual availability of the species is examined. On the basis of ethnographic information on the uses of wild plants, and the flowering and fruiting time of the species represented at Franchthi, it is determined that these plants would have been available in the spring, summer, and early autumn. Year-round plant utilization would have been possible through the use of storage facilities and additional vegetation resources not preserved in the archaeological record. The possibility of seasonal movement must also be considered.

A survey of similar botanical remains from comparably dated sites in the Eastern Mediterranean and Near East puts the Franchthi material into a wider geographical context and shows how this material has augmented our knowledge of the man-plant relationships through time. Here again, the question of the origin of agriculture must be considered as a key problem in understanding these relationships. The evidence suggests that Franchthi may be among the earliest sites to show evidence of incipient domestication of lentils and possibly barley. In addition, because Franchthi is among the earliest sites on mainland Greece to have produced domesticated emmer and einkorn wheat, a sea route rather than the overland route previously suggested may have been the course for the introduction of these new crops to Greece.

GEOLOGY AND GEOGRAPHY

THE HYDROGEOLOGIC STUDY OF THE GREENBRIER LIMESTONE KARST OF CENTRAL GREENBRIER COUNTY, WEST VIRGINIA

SARA ANNE HELLER, PH.D.
West Virginia University, 1980. 204pp.

The study area covers approximately 80 square miles of the outcrop extent of the Middle Mississippian Greenbrier Group in central Greenbrier County, West Virginia. This sequence of sedimentary rocks, primarily limestones, is approximately 800 feet thick, stikes about N25°E, and generally dips less than 10 degrees to the northwest. The study area

is predominated by broad, asymmetric, and northeast-trending folds of low plunge, and several roughly en echelon reverse fault-fold complexes. A major photolineament trend exists at N30°E to N45°E. Areas of high photolineament density roughly correspond to mapped structures.

Three major aquifers were identified in the Greenbrier Group by way of inventorying and sampling 74 water wells during the period from September 1977 to July 1978. The Maccrady-Hillsdale aquifer, confined at the base of the Greenbier Group, is ordinarily an adequate and reliable supplier of ground water. However, wells pumping from this aquifer are somewhat expensive because of the great depth to this zone. The Taggard aquifer is associated with the red shales of the Taggard Formation near the center of the carbonate stratigraphic column. It is the least reliable and lowest yielding aquifer. Where the Pickaway-Union aquifer exists, it is the highest-producing of the three. The water in this aquifer is associated with the shaley strata of the upper Pickaway Limestone and is not confined. Flow movement within the aquifers is believed to parallel stratigraphic strike. Ground-water discharge occurs at large baselevel springs and from well springs.

Wells with a high-yield-to-depth ratio are in an area of high photolineament density, although eight wells located within 100 feet of photolineaments did not show significantly higher yields than other wells. Statistical tests also show that well yield increases with increasing stratigraphic dip (up to 30 degrees) as well as away from the axial traces of folds or faults. Well yield is not significantly influenced by surface topography in the study area.

Well waters of the study area are of a very hard calcium-magnesium-bicarbonate type, although in some well waters, sulfate, chloride, or sodium are also important. In eight wells, water containing unusually high sulfate concentrations are believed to be contaminated from dissolution of gypsum and pyrite in the strata.

Slight increases in pH, saturation indices for calcite and dolomite, conductivity, chloride concentration, and a decrease of temperature and carbon dioxide partial pressure were found to occur in well waters the winter of 1977-1978. Compared to the other aquifers, well waters of the Maccrady-Hillsdale aquifer seem to be most influenced by the presence of dolomite, sulfur-bearing minerals, and the cation-exchange properties of the shales in the Maccrady Formation. The Maccrady-Hillsdale well waters are also least influenced by contamination from surface pollution sources, such as road salts or septic tanks. Comparison of the chemical qualities of the well water to that of Davis Spring showed the well water to be much more concentrated in many ions, probably because of its slower, diffuse flow. R-mode factor analysis of the water chemistry variables showed the importance of carbon dioxide partial pressure to the degree of carbonate saturation. The factor analysis showed the existence of conductivity, dolomite dissolution, water pollution, and water temperature factors.

Porosity in Oolitic Limestones

David William Rich, Ph.D.
University of Illinois at Urbana-Champaign, 1980. 195pp.

In oolitic limestones the individual grains are microporous, and the microporosity consists of irregular equant pores 1-3μm in size which are located between the rhombic to anhedral carbonate crystals which make up the ooid cortex. These equant micropores are locally constricted to plates or tubes only 0.1μm in their short dimension(s), which are "throats" between the larger equant micropores. If the interparticle space is tightly cemented, any fluids passing through the rock must pass from grain to grain through the microporosity.

Eleven laboratory experiments were performed in which samples of a tightly cemented Mississippian oolitic calcarenite were submitted to simulated burial conditions, and undersaturated carbonic acid solution was forced to pass through them. The result was selective dissolution of the ooid cortical layers, with the sparite cement preserved undissolved. It is concluded that oomoldic porosity can result from textural variation between components and does not necessarily imply that the ooids had an unstable mineralogy. Variation of the specimen orientation, using horizontal and vertical samples, produced no change in the result. Two values of the partial pressure of carbon dioxide were used (9.35 and 17.27 atm) and both produced similar results. These pressures, which exceed values found in nature by one or more orders of magnitude, were used to increase the degree of undersaturation to compensate for the time factor. It was also found that an excessive pore pressure difference across the specimen, especially near the end of a test, tended to cause channeling due to mechanical breakage, which destroyed much of the dissolution texture.

Twenty-three samples of oolitic limestone ranging in age from Devonian to Pleistocene were studied petrographically and petrophysically. Fourteen porosity types were identified: primary intraparticle with ooids, lithic clasts and bioclasts (both constructional and destructional by boring); primary interparticle, both normal and shelter; secondary eogenetic in ooids; secondary mesogenetic due to fabric-selective dissolution of ooids, lithics, bioclasts and cement; secondary mesogenetic partly fabric-selective; secondary mesogenetic not-fabric-selective; and secondary telogenetic resulting from neomorphism. The porosity values ranged from 2.5 to 35.9%, the permeabilities from 0.011 millidarcies to 6 darcies, and mercury-injection capillary pressure measurements showed a range of behavior from mercury invasion mostly at low pressures to mostly at high pressures,

and some specimens had invasion over a range of pressures. Comparison of capillary pressure curves with scanning electron microscope photographs of resin pore casts indicates that the mercury invasion of oolitic limestones is controlled by the pore throat size rather than the pore size.

THE STRATEGIC PETROLEUM RESERVE—ENVIRONMENTAL IMPACTS ASSOCIATED WITH THE LEACHING OF SALT CAVERNS

CATHLEEN MARIE FITZGERALD, D.ENV.
University of California, Los Angeles, 1981. 137pp.
Chair: Professor Malcolm S. Gordon

In order to diminish the vulnerability of the United States to a severe petroleum shortage, the Strategic Petroleum Reserve (SPR) was created in 1975 to provide for the storage of up to one billion barrels of crude oil. Phase I of the program involved the modification of existing underground salt caverns in Texas and Louisiana to provide 248 million barrels of storage for use during an emergency interruption in foreign imports. The crude oil will be pumped from the caverns and transported via pipeline to nearby refineries and terminals for nationwide distribution.

In Phase II of the program, an additional 290 million barrels of storage capacity will be developed by leaching new underground caverns at Bryan Mound, Texas and West Hackberry, Louisiana, and acquiring an existing 10 million barrel cavern at Bayou Choctaw, Louisiana. Seven barrels of fresh water are required to leach one barrel of cavern space. Therefore, large volumes of fresh water will be required during the leaching process, with a potential impact on water quality and the aquatic population in the waterways from which the water is withdrawn. Similarly, the leaching process will require the disposal of large quantities of brine with a potentially adverse impact on the marine environment. However, the Department of Energy (DOE), in conjunction with the National Oceanic and Atmospheric Administration (NOAA) and Massachusetts Institute of Technology (MIT), has developed a multiport diffuser system to efficiently disperse the brine in the offshore waters of the Gulf of Mexico. Predictions of model runs and actual operational experience at the Bryan Mound site show excess salinities around the diffuser of no more than the five parts per thousand (ppt) above ambient conditions. The first six months of biological monitoring data collected at the Bryan Mound diffuser indicate no significant changes in the benthos, nekton or plankton in the area.

This report describes in detail the environmental impacts associated with the leaching of salt caverns, using the West Hackberry, Louisiana SPR site as an example. A discussion of the SPR system and site facilities is followed by a description of potential impacts associated with fresh water withdrawal and brine disposal in addition to the results of physical biological studies conducted at the operating Bryan Mound diffuser.

MODELING SINKHOLE SUSCEPTIBILITY IN DOUGHERTY COUNTY, GEORGIA FROM SINKHOLE AND FRACTURE DISTRIBUTION DATA

TERRY LEE ALLISON, M.A.
University of Georgia, 1980
Director: Dr. George A. Brook

Sinkholes in Dougherty County present problems to urban planners, developers, engineers, and to the general population. Water resources are threatened with serious pollution caused by the dumping of wastes near sinkholes. This thesis attempts to provide detailed information on sinkholes, their relation to fractures in the bedrock, and the relative susceptibility of areas within the county to their development. Although similar investigations in other areas have made use of the relation between sinkholes and fractures in bedrock, this is the first time that such information has been integrated in a geographic information system for the purpose of modeling sinkhole susceptibility.

Major conclusions can be grouped into two categories: those pertaining to sinkholes and those pertaining to fracture lineaments. Sinkholes in Dougherty County are arranged over the land surface in non-random fashion. Measurements of sinkhole long-axes indicate three major trends: N 45° W, N 5° E, and N 30° E. These trends are similar to orientations of joints reported by other workers. This information indicates that, to a large extent, sinkholes in the area are controlled in location and shape by fractures and fracture intersections in the bedrock.

The relationship between sinkholes and fractures was used to produce a fracture lineament map. Lineaments were drawn from sinkhole alignments and shapes. Analysis of the lineament map indicates the presence of three major trends: N 35° W, N 5° E, and N 40° E. These trends also coincide with reported major orientation peaks of joints. It is probable that the N 5° E trend is composed of extension fractures while the N 35° W and N 40° E trends form a conjugate set of shear fractures. Origin of the fractures is not clear, but strain and stress ellipsoids arranged to fit observed patterns indicate horizontal compressive stress oriented N 5° E.

From an integration of sinkhole and lineament distribution data, eight sinkhole susceptibility models were produced. Dougherty County had previously been viewed as an area of uniform sinkhole potential, but findings here indicate otherwise. According to the models, there is definite variability in the susceptibility of areas within the county to sinkhole development.

CONFERENCE REPORTS

BERMUDA MARINE CAVE SYMPOSIUM

During the week of 1-7 October 1984, scientists from seven countries met on the island of Bermuda for a symposium sponsored by The Bermuda Biological Station for Research, Inc., and The Crustacean Society—and partially funded by a grant from the National Science Foundation to The Crustacean Society. The purpose of this "International Symposium on the Biology of Marine Caves" was to address numerous global questions related to the biology—biogeography of marine troglobitic crustaceans. Participants stayed at the Bermuda Biological Station (BBS) (near St. George), the site of all formal and informal presentations.

The Bermudas are a beautiful and quaint group of semi-tropical islands (>150) located 1000km east of Cape Hatteras, North Carolina near latitude 32 N and longitude 65 W in the northwest Atlantic Ocean. The islands are sitting atop a volcanic seamount and are composed of marine and indurated eolian, Pleistocene and Recent, limestones appoximately 75m thick. More than 200 caves are known and are believed to have a syngenetic origin, in the early Pleistocene Epoch. Recent investigations of numerous inland marine caves on Bermuda have revealed a large number of invertebrate endemics. Because of the high concentration of caves, anchialine habitats, many troglobitic endemics, and good facilities offered at the Bermuda Biological Station, Bermuda was ideally suited for a conference of this nature.

Twenty-seven scientists from the Bahamas, Bermuda, France, West Germany, the Netherlands, Norway and the United States registered for the Symposium. A total of 24 papers covering a variety of subjects was presented in five formal paper sessions. Topics covered dealt with ecology, systematics, phylogeny, zoogeography, ecophysiology, trophic relationships, evolution, and structural and behavioral adaptations of anchialine crustaceans. In addition to the morning formal papers, informal presentations, slide shows, a movie, demonstrations, and discussions were held in the evenings. These were of interest because of their broad application to many aspects of (and problems currently recognized in) anchialine environments.

Following the morning paper sessions, afternoon field trips were made to various karst features. The majority of caves on Bermuda are concentrated in the Walsingham area (eastern Bermuda—between Harrington Sound and Castle Harbour). All participants were introduced to the Walsingham karst region on Monday, 1 October. A number of caves were visited and pool waters sampled, demonstrating the relative ease of access to the subterranean waters. A tour of the commercial Crystal Cave and a reception by their most gracious Cave Management was a pleasant ending to an interesting field excursion. At least 20 caves were visited by the participants during the remainder of the week, with forays ranging from visiting beautifully decorated air-filled passages, examining anchialine pools, making cavern dives, to making extended cave dives. One dive turned up a rare specimen of a species of the genus *Procaris*, a troglobitic shrimp.

All the participants extend their appreciation to C. W. Hart, Jr., Raymond B. Manning (Smithsonian Institution), and Tom M. Iliffe (BBS) for their efforts in initiating, organizing, and handling the Symposium. As host, the BBS was most generous and cooperative and gratitude is extended to Wolfgang Sterrer, Director. A special word of thanks is directed to Mary van Soeren (BBS) for her patience, energy, and uncanny ability to "run a smooth ship."

The highlight of the Symposium was exchange of information, hypotheses, techniques, and the establishment and renewal of friendships among scientists from different countries. Undoubtedly, all participants departed the island with an enlightened view of the Bermuda karst, with a better understanding of anchialine systems, and with a renewed stimulation for conducting further research in marine cave systems.

The papers presented at the Symposium will be published in Issue 3 of Volume 1 of the journal, *Stygologia*.

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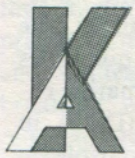

INTERNATIONAL MEETING ON APPLIED PROBLEMS OF KARST TERRAINS

The logo that introduces this report signifies an international karst symposium and excursion held in Belgium and Germany May 31-June 6, 1984. Resplendent in red and black on a yellow-gold background (the national colors of both Belgium and Germany), the logo appeared on signs, banners, and even ladies' scarves. The major theme of the symposium was applied karst studies, hence the KA (or AK in English) for Karstologie Appliquée.

Nuts-and-bolts organizing of the 4-day symposium was by Camille Ek of the University of Liège, Belgium. Karl-Heinz Pfeffer of the Geographical Institute, University of Köln (Cologne), organized the 3-day post-symposium field excursion. The symposium was organized through Liège University's Laboratory of Geomorphology and Quaternary Geol-

ogy and Laboratory of Physical Geography. It was held in collaboration with the Province of Liège, and under the patronage of the International Union of Speleology and the Belgian Center for Karst Studies.

The symposium was attended by approximately 100 people, including more than 40 speakers. At least 15 nations were represented by the participants. Following the meeting, a smaller group (a busload) participated in the field excursion to northwestern Germany.

On Wednesday evening, May 30, a formal reception was held in downtown Liège, at the ancient but well-preserved Palace of the Government of the Province of Liège. Under a fantastic chandelier, cordial speeches of welcome were made by various provincial government and symposium officials while the guests sipped local libations, including champagne. Then the group went a few kilometers out of town to Wégimont Castle, part of a vacation complex operated by the provincial government. Complete with a courtyard, surrounded by a watery moat, and guarded by raucous peacocks, the old castle has a recently remodeled interior. Meeting rooms, bedrooms, bath facilities down the hall, dining room, and pub provided a most amiable setting for the symposium.

Thursday, May 31, saw the meeting open with two options available for an all day field trip. One option, taken by the majority, was the Cave of Remouchamps, a commercial cave with anticlinal and faulted structure and a (flood-swollen at the time) river at the lowest level. Morphological evolution of the cave, its relation to structure, the time-scale of its sedimentary history, and geochemistry of cave water were featured. This trip concluded with a tour to several dry valleys bordered by sinking streams.

The other option for Thursday was a wild cave trip in the Cave of Fontaine de Rivîre (Spring by the River), which contains a lake of one thousand square meters and beautiful aragonite crystals. Emphasis was on hydrology, paleohydrology, cave morphogenesis, underground climatology, and isotope dating.

Closing the day was a fine banquet, then a musical presentation by "Mantekangel," a trio of singing, guitar-playing young men. Getting into the spirit and onto the stage, symposium organizer-secretary-host Camille Ek showed he had a talent for impromptu song and guitar as well as karst.

Friday, June 1, began with the official opening of the two days of paper sessions. First was a bilingual welcoming message by Albert Pissart, symposium co-chairman (along with M. J. Alexandre). Then came a groundwater talk (in French) by Ernest Laurent, an advisor to a regional government agency. Camille Ek concluded the official opening by giving a bilingual overview of the Belgian karst and its problems. Two more talks, one by Hubert Trimmel in German and my own in English rounded out the linguistically challenging first hour and a half of the meeting. Most of the later papers were presented in French, regardless of nationality of the speakers.

The forty or so papers were grouped into nine theme sessions, with only one morning session in two days requiring concurrent presentations. Applied problems were emphasized on Friday, and on Saturday, June 2, the papers concerned the dynamics of karst processes. The sessions and their chairpersons are listed below:

1. Applied Karst Research I (V. Panoš substituting for A. Eraso)
2. Applied Karst Research II (K.-H. Pfeffer)
3. Geophysical Methods (M. Sweeting)
4. Applied Problems of Karst Terrains I (J. Nicod)
5. Applied Problems of Karst Terrains II (A. Droppa)
6. Karst Dynamics I (A. Bögli)
7. Karst Dynamics II (B. Gèze)
8. Karstic Erosion Measurements (H. Trimmel)
9. Isotopes (R. Dilamarter)

A wide variety of papers on karst hydrology, management, exploration and socioeconomic factors were concerned with applied problems. Karst dynamics papers demonstrated processes in many types of environments around the world. The papers are to be refereed and published in a special number of the Annals of the Belgian Geological Society (Annales de la Société Géologique de Belgique).

Other gatherings featured talks and slides by D. Ford of Canada and M. Pulinas of Poland, and meetings of the International Union of Speleology (U.I.S.) Bureau and U.I.S. Commissions on Karst Denudation and the International Atlas of Karst. And, of course, numerous informal gatherings in hallways, courtyard and pub were constantly under way. The courtyard was the scene of a Saturday evening barbeque, featuring sausages and shish kebab.

On Sunday, June 3, another field trip was conducted. In the morning, we visited an area where subterranean shortcuts occur in a meander of the Lesse River. After lunch the group viewed apparent Tertiary fills in karst depressions in Carboniferous limestone. The clay and sand fills sparked some interesting conversation about relict versus modern processes.

The following day, Monday, June 4, the theme of Tertiary processes was continued as the 3-day post-symposium excursion began. Several German students and professors aided organizer K.-H. Pfeffer in demonstrating karst features of northwestern Germany. I went only on the first day of the excursion, during which the regional karst geomorphology was emphasized. Quaternary incision into Tertiary erosion surfaces and weathered residue was demonstrated.

In general the symposium paper sessions and all excursions were well planned and executed. The organizers and their staff of professors, students and secretaries deserve plaudits for a job well done. The theme of applied karst studies was appropriate, in view of the increasing use of karst regions by a growing world population. There are likely to be more applied karst meetings elsewhere in years to

come. May they all be as interesting, useful, and satisfying as this one.

Ronald R. Dilamarter
Department of Geography
Western Kentucky University

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Association of American Geographers, April, 1984 Washington, D.C.

The AAG convention had several activities of interest to cave and karst enthusiasts this year. Along with the usual paper sessions, William Davies, Susan Moorlag, and John Whittman led a fieldtrip entitled "The Physical and Historical Geography of the Eastern Panhandle of West Virginia." Of course Davies added the karst color by stopping at several karst features and caves. The trip is written up in the AAG Field Trip Guide, ISBN 0-89291-180-8 and is available from the AAG Office in Washington, D.C. Anyone interested in the geology and geomorphology of the West Virginia Panhandle and adjacent parts of Maryland and Virginia, and the human adjustment to this physical landscape, should get a copy.

The karst paper sessions lasted a whole day and included a diverse array of topics including: Cave-radon-temperature relationships (Quinn), Central Kentucky karst megalineaments (George), Terrain modeling of karst regions (Passmore), Pollution of karst aquifers (Smart), Urbanization of karst aquifers (Veni), Post-eruption pseudokarst: Mt. St. Helens (Halliday), Cave maps by computer (Conover), Marble weathering rates in Philadelphia (Meierding), Sinkhole marginal plain: Kentucky Pennyroyal (Dilamarter), Distribution of U.S. cavers (Oatman), and Speleogenesis of Sinking Valley, Kentucky (Dougherty). Abstracts of the papers are available in GEO^2.

Since the convention was held in Washington, D.C., where there are many cavers and karst researchers, an open house was held in the evening after the paper sessions. Doug Dotson gave a presentation on computer mapping, Bob Gulden showed slides and discussed the Friars Hole System, followed by presentations on Fisher Ridge Cave by Myles Drake, and Papoose Cave by George Huppert. A social was held for the cave and karst people following the presentations.

A Cave Map Exhibition was also held in conjunction with the meeting. Most cartography professors are members of the AAG and hold their business meeting and present papers at the convention. The Cave Map Exhibition enabled them to see what cavers have been doing in cartography and hopefully this will motivate them to become involved. The maps exhibited were past winners in the NSS Cartographic Salon and showed a variety of styles.

Percy H. Dougherty
Department of Geography
Kurtztown University

1984 National Cave Management Symposium

The 1984 National Cave Management Symposium, the 7th since 1975, was held in Rolla, Missouri, on the campus of the University of Missouri-Rolla during October 11 to 14, 1984. The conference was sponsored by the Missouri Department of Natural Resources and the Ozark National Scenic Riverway (NPS). Co-sponsors were the National Speleological Society, the Missouri Speleological Survey, the Missouri Caves Association, the National Cave Association, and the Missouri Department of Conservation.

The interdisciplinary meeting included, geologists, geographers, biologists, resource managers, recreation specialists, foresters, historians, archaeologists, and others. The Symposium consisted of 14 sessions given over two days with some 46 papers presented. Paper topics covered a broad range of research interests from hydrology, computers, interpretation, and history to paleontology and rescue. Proceedings of these papers are to be published in the near future, hopefully within the next six months.

A major tone of the meeting seemed to reflect a feeling that while cave resources are being put under increasing use, there is hope that a greater interest is being taken by state and federal agencies. This was shown by the great number of those agencies represented in the 114 participants.

Two days of field trips were also scheduled during the conference. These included visits to many of the nearby commerical and wild caves as well as a canoe trip on the Current River. The evenings were not without activity also. A Wednesday night reception allowed the attendees to revive old friendships and make new ones. After dinner on Thursday night a multi-media show on the Ozarks, entitled "Sassafras," was very well received. Friday night we were enlightened by Merlin Tuttle's talk on "Bats, Myths and Reality." On Saturday evening a wine and cheese social featuring local wines was held. This was followed by the Symposium banquet. The dinner speaker was Brother Nicholas Sullivan and his topic was "Cave Management Worldwide." It was a sobering look at management problems outside the United States, with particular emphasis on a karst area in Australia.

A National Cave Management Committee was formed during the conference. The idea of the committee originated with several people and was formalized into a working group with Rob Stitt appointed as chair. The purpose of the

committee is to be a clearinghouse of cave conservation and management information and to be a mechanism to insure the continuation of the management symposium.

The next National Cave Management Symposium is tentatively scheduled for the fall of 1986 in the Black Hills of South Dakota. Kay Rhode of the National Park Service (Wind Cave) offered to look into this.

In conclusion, the meeting was a worthwhile experience, with many new ideas exchanged and debated. It left me encouraged about the individuals who are responsible for many of the country's caves. Most of them are concerned about their caves and doing the best job of protecting them.

George Huppert
Department of Geography
University of Wisconsin/La Crosse

CONFERENCE ANNOUNCEMENT

THE LEGACY OF GROUNDWATER IN KARST AREAS: IOWA, MINNESOTA, WISCONSIN

April 16–17, 1985
Midway Motor Lodge
LaCrosse, Wisconsin

The Minnesota Project, a center for public policy study and community development, and several government agencies are sponsoring a conference to examine the causes of contamination of karst groundwater in the surrounding region. Presentations will be given by government officials, researchers, and educators. Registration for the conference is $45. For further information contact the Minnesota Project at (507) 765-2700 or (612) 378–5179.

NEW BOOK REVIEW EDITOR

Betty Wheeler has agreed to be the new BULLETIN Book Review Editor. Your help is needed for she is interested in receiving reviews on cave and karst publications in any discipline. Please send your reviews or suggestions of material to be reviewed (books, proceedings, dissertations, theme issues of periodicals, etc.) to: Betty Wheeler, Department of Geology and Geophysics, University of Minnesota, Minneapolis MN 55455.

NEW HISTORY/SOCIAL SCIENCE EDITOR

The new History/Social Science Editor, Marion O. Smith, is soliciting articles on spelean history, saltpetre mining, psychology, cultural geography, economics, or any other related social science area. If you are doing research in this area or know of anyone doing research in these areas, please contact: Marion O. Smith, History/Social Science Editor, P.O. Box 8276, University of Tennessee Station, Knoxville, TN 37916.

1985 NSS CONVENTION

Frankfort, Kentucky — June 23 — 29

REGISTRATION FORM

Name _____ NSS # _____

Address _____

City _____ State _____ Zip _____

Pre-Registration Deadline: June 1, 1985

REFUNDS: A full refund is available on request before June 1.
A 50% refund is available from June 2 to June 15. No refunds will be made after June 15. DO NOT MAIL to our Box Number AFTER JUNE 15.

REGISTRATION FEES:
Registration Fees include the Banquet, Howdy Party, Campground Party, Program Book, Photo Salon, and all Sessions. Exceptions are for children under 8: They don't receive Program Book or Banquet ticket unless paid extra. The larger books *(Caves & Karst of Kentucky* and 1985 Convention Guidebook) are included only with Full Registrant's fees. They may also be purchased as extras. Children and Accompaniers who register with an NSS Member qualify for the Member Rate. Non-NSS Members who agree to buy an "Instant Membership" at the Convention, payable at Registration, may register at the NSS Member rate. Any Full or Accompanier registering after June 1, 1985 will pay an extra $10.00 Late Registration Fee. Registrants may deduct $7.00 from their Registration Fee if they will be unable attend the Friday night Banquet.

NAME TAG INFORMATION

(Please PRINT)

Check Box if Child under 8:

	Name	NSS #	Affiliation
☐			
☐			
☐			
☐			
☐			
☐			

In case of emergency, contact:

_____ (____) - _____
Name Phone

(Emergency contact should NOT be someone at the Convention with you).

Are you a:
_____ Physician _____ Nurse _____ EMT _____ Paramedic

(Please complete REVERSE SIDE of form)

(A) REGISTRATION

	Before June 1	After June 1	# Pers.	Total
NSS MEMBERS:				
Adult	40.00	50.00	____	_____
Accompanier	25.00	35.00	____	_____
Youth (Age 8-15)	10.00	10.00	____	_____
Child (Age 0-7)*	Free	Free	____	_____
No Banquet Option	−7.00	−7.00	____	_____
NON-NSS MEMBERS:				
Adult	50.00	60.00	____	_____
Accompanier	35.00	45.00	____	_____
Youth (Age 8-15)	10.00	10.00	____	_____
Child (Age 0-7)*	Free	Free	____	_____
No Banquet Option	−7.00	−7.00	____	_____

*CHILD does NOT include Banquet ticket.

(B) ACCOMMODATIONS

Camping (Tent or Trailer) (No Hook-Ups)
All over Age 3: $10.00/wk. x ____ pers. = _____
RV (w/Full Hook-Ups) $ 7.50/nt. x ____ nites = _____

Campus Dorm Rooms: (without linens)

		# Nites	
Single occupancy	$12.00 x	____	= _____
Double occupancy	$24.00 x	____	= _____
Triple occupancy	$36.00 x	____	= _____

(Note: Only 200 persons accepted)

☐ I/We will stay in a motel. (Make own reservations)
☐ I need motel information.

(C) MEALS

		# Pers.	
Meal Ticket Package	$48.75 x	____	= _____
Extra Banquet Tickets	$ 8.75 x	____	= _____

(D) CHILD CARE for Pre-Schoolers
Full Time Care (all week) $40.00 x ____ = _____
Name (& Ages) _____

____ Might sign up for Hourly Care (pay later)
____ Might sign up for Evening Care (pay later)

(E) EXTRAS

	Cost	# Items	
Additional Guidebooks	7.00 x	____	= _____
Additional Caves & Karst	10.00 x	____	= _____
Additional Program Books	3.00 x	____	= _____
Convention Baseball Caps	4.00 x	____	= _____
Convention Tote Bags	5.00 x	____	= _____
Convention Patches	3.00 x	____	= _____
Convention T-Shirts	6.00 x	____	= _____

Please Specify Sizes:
___S ___M ___L ___XL

(F) WORKSHOP/EXCURSION COSTS
Copy Total Cost from Right Side of Page = _____

TOTAL AMOUNT ENCLOSED ☐

(F) WORKSHOP/EXCURSION FEES

Name	Cost	# Pers.	Total
1) Geology Field Trip	$20.00* x	____	= _____
2) Biology Field Trip	20.00* x	____	= _____
3) Hydrology Field Trip	10.00* x	____	= _____
4) Horse Park Excursion	5.00* x	____	= _____
5) Shakertown Excursion	5.00* x	____	= _____
6) Caving Short Course	5.00* x	____	= _____
7) Red Cross CPR	5.00 x	____	= _____
8) Red Cross First Aid	5.00 x	____	= _____
9) Intro. Cave Cartography	5.00* x	____	= _____
10) Karst Chemistry Workshop	5.00* x	____	= _____
11) Vertical Tech. Workshop	5.00* x	____	= _____
12) Reading Topos/Aerial Pix	5.00 x	____	= _____
13) Bat Identification WS.	2.00 x	____	= _____
14) Cave Fossil Id. Workshop	2.00 x	____	= _____

*Deposit: May be slight additional charge.

NOTE: All Workshops on Space Available basis.

TOTAL WORKSHOP/EXCURSION FEES = ☐**
**Copy to Section (F) in Left-Hand Column.

*****A SPECIAL NOTE ABOUT WORKSHOP FEES:**
The Workshop fees are to cover special materials needed for the course. These are "Hands-On" workshops. You will be given materials pertinent to the subject. PLEASE don't let these low charges keep you from these rewarding classes.

OTHER SPECIAL COURSES
To help us plan for Materials and Room Requirements, please list the number of Special Courses or Workshops you are seriously planning on attending, assuming no scheduling conflicts. There are NO fees for these sessions.

COURSE/WORKSHOP	# PERSONS
Cave Biology Short Course	_____
Cave Geology Short Course	_____
Cave Photography Workshop	_____
Cave Rescue Workshop	_____
Intro. to Computer Cave Mapping	_____
Intro. to Surveying Workshop	_____
Water Tracing Workshop	_____

ARRIVAL PLANS:
I/We expect to arrive at Registration on
_____ (date) at about _____ (AM) (PM).
I/We are arriving via:
☐ Private Vehicle
☐ Train (station _____ at _____ on _____)
☐ Plane (city _____ at _____ on _____)
☐ Bus (station _____ at _____ on _____)
☐ I/We need transportation to Registration from our arrival point.

Make Checks Payable to **"1985 NSS CONVENTION".**

Mail your completed Registration Form, with payment, to:
1985 NSS Pre-Registration
c/o Gary Bush
P.O. Box 5176
Cincinnati, Ohio 45205

THE NSS BULLETIN

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