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Cover: Vinson Cave Entrances, Alabama. See Campbell, Abd El Latif, & Foster, page 163.

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Campbell, C. Warren; Abd El Litif, Mohamed and Foster, Joseph W.—Application of Thermography to Karst Hydrology. Journal of Cave and Karst Studies 58(3):163-167.

APPLICATION OF THERMOGRAPHY TO KARST HYDROLOGY

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Thermography was used to locate hydrological "features" in karst watersheds. The approach was demonstrated by flying a thermal camera over the Keel Mountain area of north Alabama. Known features were identified and features not on United State Geological Survey topographic maps and unknown to the authors were discovered. Springs with flow rates less than 3 liters/sec and a region of strong infiltration in a losing stream were easily identified.

Many authors have discussed the need for karst hydrogeologic inventories preceding quantitative dye traces in karst areas. For example, Jones (1984) recommends collection of all available geologic and hydrologic data for the watershed, including United State Geological Survey (USGS) topographic maps, previous hydrogeologic studies, and data collected by the investigator. All karst features including swallets and resurgences should be located and flow rates should be measured. Unfortunately, topographic maps do not show most of the springs in a watershed, and time consuming and exhaustive field work is often required to find the most important hydrologic features. Any method that could reduce field work is desirable. We will show herein how thermography can focus field work and speed karst hydrology investigations.

This paper describes the application of airborne thermography in locating karst hydrologic features on Keel Mountain in the Cumberland Plateau region of north Alabama. Though the methods described here can be applied in any karst area, Keel Mountain and Horse Cove were studied because the endangered Alabama cave shrimp (*Paleamonaias alabamae)* is found in Hering Cave there and an understanding of the hydrology is important for protection of the species.

Earlier studies have investigated thermography for locating springs. Bogle and Loy (1995) used thermography to locate submerged springs in a reservoir. Rinker (1975) used thermography to investigate the Greenland glacier and the Puerto Rican karst in an attempt to find underground cavities. Warren and Wielchowsky (1973) of the Geological Survey of Alabama used infrared photography, thermography, and side-looking radar to locate sinkholes and ponors, predict potential sinkhole collapses, and map faults, strikes, lineaments, and regional geological structures. These studies have proven the ability of thermal cameras to find karst features. The present study shows that thermography can be used to find very small features in the southeastern United States.

Keel Mountain, an outlier of the Cumberland Plateau, lies in eastern Madison and western Jackson Counties in north Alabama. The mountain is capped by the impermeable Pottsville Formation (sandstone, shale, coal) of Pennsylvanian age which forms the upper 50 to 70 m of the mountain. Below the Pottsville Formation are a series of Mississippian limestones. The mountain stands about 300 m above surrounding land. Numerous cave entrances, springs, pits, and sinkholes are found on the flanks of the mountain. Horse Cove is incised into the southwestern quadrant of the mountain.

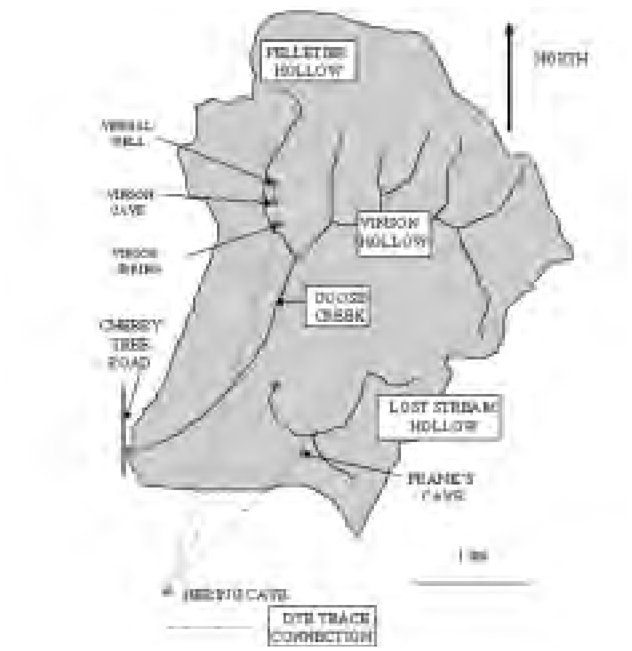

Figure 1. Horse Cove area showing hydrologic connections established by dye tracing.

DESCRIPTION OF HORSE COVE

Figure 1 shows Horse Cove, Hering Cave, and the known connections between caves, sinkholes, and springs which were determined from dye trace studies. The Horse Cove surface watershed is approximately 17 square kilometers (6.5 square miles). Surface topography implies that runoff from Horse Cove would discharge from Goose Creek. Estimates based on runoff for north Alabama show that the average annual flow from Goose Creek at Cherry Tree Road should be about 280 liters/sec (10 cfs) (LaMoreaux and Chermock, 1975). In fact, the flow from Goose Creek is much less than 3 liters/sec (0.1 cfs). Dye trace studies performed by the Geological Survey of Alabama (McGregor et al., 1994) show that most of the Horse Cove runoff (~ 70% to 80%) flows from Hering Cave which is outside of the Horse Cove surface watershed.

Developing a hydrologic model for pollution studies requires the identification of as many hydrologic “features” as possible. This includes locating as many springs, swallets, cave entrances, and infiltration points in streams, which may affect the water quality within the Hering Cave system.

Researchers from the University of Alabama in Huntsville have done many hours of field work in Horse Cove. The terrain is rough, and landowners limit access to some areas. This field work has resulted in the discovery of two swallets, two previously unknown caves, several infiltration points in stream beds, and several springs. None of these were indicated on USGS topographic maps.

We believed that airborne thermography could locate even more karst features. Since caves and springs are often warmer than the surroundings, thermography could be used to locate these features during times when the surface air and water temperatures were much lower than the springs.

Keel Mountain Thermography

Every object emits thermal radiation. Our eyes are sensitive to wavelengths as long as 0.7 *u*m (10^{-6} m). The light emitted by a surface depends on its physical characteristics and on its temperature. As a surface warms up, it emits at shorter wavelengths and higher energies. Neglecting changes in the emission properties of materials, warmer objects appear brighter on thermal images.

The MICOM thermal camera is similar to a Camcorder except that it is sensitive to thermal infrared wavelengths. The camera has a starring focal plane containing a fixed array of tiny radiation sensitive elements (“eyes”). This camera has a square array with 512 rows of 512 elements (~262,000 elements total). The adjective starring indicates that the matrix of “eyes” is fixed. The camera provided gray level data on VHS format with a field of view of 11º by 14º and a 2 to 5 mm sensitivity, yielding a temperature sensitivity of less than 0.1º C.

Three flights were conducted for this study. Flight altitudes ranged from 150 m to 800 m above ground level (AGL) with an average of about 500 m AGL. Typically, the images covered areas on the ground of approximately 1 hectare. The first two flights were at low altitude to assure enough resolution to see at least some features. A cloud deck at 1000 m AGL forced the third flight to low altitude.

Figure 2. White Spring thermography.

Because of budgetary constraints, the flights were not in the best weather nor during the best time of day. The best conditions would be just before sunrise on a very cold clear winter day.

The first flight was between 6:00-7:00 PM CST on February 24, 1995. The weather was clear and with a flight time temperature at Huntsville Airport of 5º C (40º F). Despite the less than ideal conditions, the first flight identified the double spring (White Spring) shown in Figure 2. This image was captured when flying at an altitude of 650 m above mean sea level (MSL) (150 m - 500 m above ground level [AGL]). We interpreted the image to be a large double spring which joined and flowed down the mountain.

One of us (CWC) found the spring with help from landowners a week after the flight. From its size on the thermograph, we expected a very large spring, instead, it was very small, the right (west) fork being an area of seepage. On this day, the flow was approximately 2.8 liters/sec (0.1 cfs) or less. When we returned in the late spring to photograph it, the spring was dry.

The second flight was on February 27 between 9:30 AM and 11:15 AM with overcast weather and periods of drizzle and heavier rain with a temperature of about 15º C (58º F). The rain equalized surface temperatures and no significant features could be seen.

The third flight was on March 9 between 8:00 and 9:00 AM. Very heavy rain had fallen on the previous day with some

Figure 3a. Vinson Cave thermography.

Figure 3b. Vinson Cave entrances.

Figure 4a. Saturday Cave thermography.

tornadoes in the area. The flights began with a temperature below 0º C. A cloud deck over Horse Cove forced flights at altitudes below 1 km MSL. This flight produced the most useful data showing both known and previously unknown features. The known features included Saturday Cave (AL 563) and Vinson Cave (AL 561).

Saturday Cave is located on the bottom of a stream bed. When water is very high, the stream above Saturday Cave flows into the main entrance. 200 m from Saturday Cave is Vinson Cave. Vinson Cave has two main entrances separated by 10 m. The stream in Vinson Cave flows just inside the two entrances shown in Figure 3b. The thermal imagery shows both infiltration near Saturday Cave and water flowing from both entrances of Vinson Cave.

Figure 3a shows the Vinson Cave thermography, and Figure 3b the entrances to the cave. The north entrance is at the top center of Figure 3b, and the smaller south entrance is at the right side of the picture. The dry stream bed coming from the north entrance is shown clearly in the picture. During high water, the stream will flow from the south entrance. During very high water, streams will flow from both entrances into the normally dry stream bed. The thermography of Figure 3a was taken during very high water. Also visible on the image are two warm spots. These were not identified, but may be an area of seepage on the cliff above the cave. The subject to the left of the north entrance in Figure 3b is looking toward the seepage area.

The thermography of Figure 4a shows infiltration at or near Saturday Cave. Saturday Cave is approximately 200 m up the stream bed from Vinson Cave and 20 m higher in elevation than the Vinson Cave north entrance. Figure 4b shows Entrances 1 and 3 to Saturday Cave. Entrance 3 is a crawl-in just to the left of the large boulder in front of the subject. These two entrances lie in a small sink in the bottom of the stream bed. During spring floods, water falls over the lip above Entrance 1 and into the cave. Figure 4c shows Entrance 2 to Saturday Cave with water flowing in just below the subject. This entrance is a 7 m pit and is a main infiltration point in the stream bed during storms and is clearly visible on the thermography.

Figure 4b shows a large tree blown over across the stream bed above the Saturday Cave main entrance. We believe that this tree is visible as a dark line across the stream in Figure 4a. If the line on the thermal image is the tree, then some flow was reaching Entrance 1 when the image was made.

In addition to the images of Vinson Cave and Saturday Cave, the thermography revealed a new spring on the ridge to the west of Frank's Cave. The thermal and visual images are shown in Figure 5. We located the spring on March 12, photographed it, measured its temperature as 14º C, and estimated the flow as about 30 liter/sec.

On this same flight, we flew over Vinson Hollow, which is the one hollow in Horse Cove we had not yet surveyed on foot. We found a warm spring entering and mixing with the cooler surface stream. Because of the appearance of the feature on

Figure 4b. Saturday Cave Entrances 1 and 3.

Figure 4c. Saturday Cave Entrance 2.

the thermal image shown in Figure 6a, we felt that a cave could be associated with the spring. Figure 6b shows the spring flowing (1 liter/sec) from the cave entrance.

Figure 6a also shows solar thermal reflection on the sunny slope. The streaks in the picture are shadows of trees. The upper right of the picture is still in the shadow of the north facing slope. If the sun were a little higher, we might not have noticed this spring. Though springs are visible on south facing slopes, they are much harder to see on the thermography.

Conclusions

The imagery shown here demonstrates the ability of thermography to locate springs and areas of heavy infiltration in karst. Caves with springs discharging from the entrance are also clearly indicated. So far, three new springs and a cave were identified from thermal images. Many other features on the imagery await field work. From the information collected so far, we believe that airborne thermography is a valuable aid for identifying and locating features of hydrologic importance. We believe that had weather conditions been more favorable, we could have flown at much higher altitudes and covered

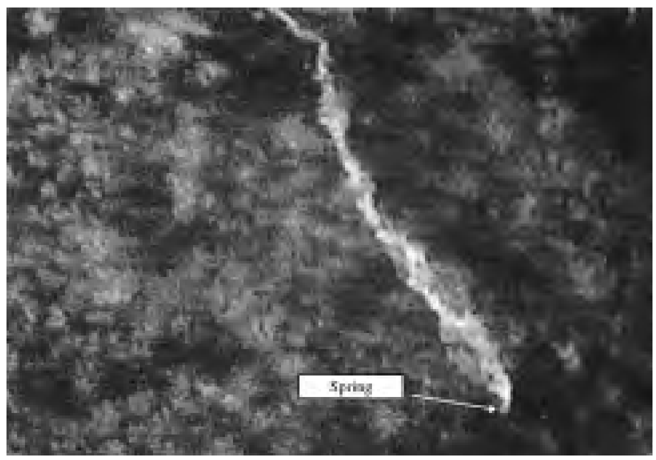

Figure 5a. Shelton Spring thermography.

more area with our scans. We base this conclusion on the size of the image, the resolution and sensitivity of the camera, and on a reduction of image size with the square of the altitude. Springs with flows less than 1 liter/sec were clearly visible

Figure 5b. Shelton Spring.

from altitudes of 500 m AGL.

The data presented clearly show that very small springs (as small as 3 liters/sec) can be identified on the imagery produced by this thermal camera. Caves with springs discharging from the entrances are clearly visible. An area of infiltration in a losing stream was clearly identified. Three new springs and a new cave were found with the thermography.

The best time for thermographic flights in north Alabama is in the winter during cold weather when the leaves are off the trees. The best time of day is in the early morning before sunrise. However, our best flight was in the daytime. Thermography of shaded slopes can reveal many features. Springs can be seen on sunny slopes, though not as clearly.

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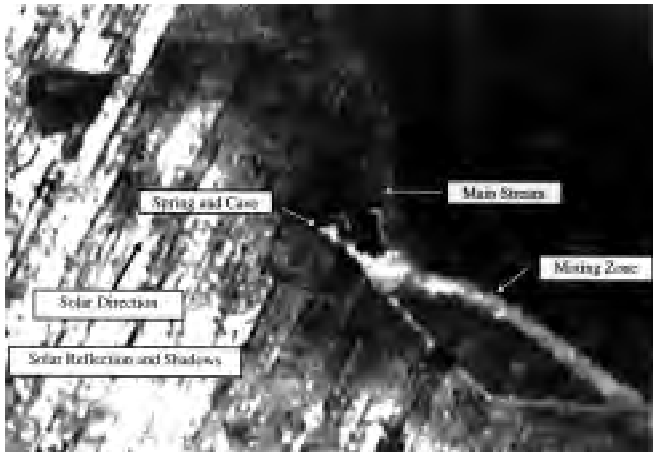

Figure 6a. Vinson Hollow spring and cave.

Figure 6b. Vinson Hollow spring and cave.

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Christiansen, Kenneth and Bellinger, Peter—Cave Arrhopalites New to Science. *Journal of Cave and Karst Studies* 58(3):168-180.

CAVE *ARRHOPALITES*: NEW TO SCIENCE

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Ten new species of the genus Arrhopalites *are described from caves in Oklahoma, Virginia, and Texas. A system for labeling the circumanal setae is presented, following the scheme of Lawrence (1979).*

This is the second of our papers dealing with new species of North American cave Collembola. In this we describe nine new species of the genus *Arrhopalites*.

Species	Region
caedus	Virginia
carolynae	Virginia
commorus	Virginia
jay	Oklahoma
lacuna	Virginia
marshalli	Virginia
pavo	Virginia
sacer	Virginia
silvus	Virginia
texensis	Texas

Most of these species come from Virginia caves as a result of the remarkable collections of David Hubbard. Virginia appears to have a richer cave fauna of this genus than any other comparable size region of the world.

The genus *Arrhopalites* was proposed by Börner 1906 for the Sminthurinae (in his sense) with the anal and genital segments separate, the latter with only one bothriothrix, and no clavate tenent hairs. The type and only species originally included was *Sminthurus caecus* Tullberg 1871, which has only a single eye on each side. More than 90 names have since been proposed for species assigned to this genus. Some species placed here in the first half of the century have 4-8 eyes per side, and as late as Richards (1968) the generic diagnosis did not emphasize eye reduction; however, species with 4+4 eyes are assigned to *Collophora* Richards 1964 (with anal and genital segments fused), and species with more than 4 eyes per side have been transferred elsewhere (Betsch, 1980). Species placed here at present have no more than 2+2 eyes, a triangular trochanteral organ on the hind leg, acuminate tenent hairs, and some spine—like dental setae. European species have been treated by Stach (1956) and Gisin (1960) and Nearctic species by Christiansen (1966) and Christiansen and Bellinger (1981). More recently many species have been described, especially from caves in Europe, and the present work shows

Table 1. Characteristics New Cave Species Nearctic *Arrhopalites*.

							I---------DENTAL CHAETOTAXY---------I													
species	locality	male seen	subsegments antennal seg. IV	Basal swelling Antennal seg. III	eye nummber per side	clear cephalic spines	e2	e3	e4-5	e6	e8-9	both id2 & 3 present	L1	L2-3	L4	Ve1	Ve2-4	Ve5	unguiculus III apical filament	1) female subanal appendage formula
caedus	Vrginia	-	6	-	1	-	+	s	+	+	-	+	S	S	-	+	+	-	-	10D
carolynae	Virginia	+	5-6	-	2♀,1-2♂	+-♀±♂	+	S	+	+	-	-	S	S	-	+	+	-	+(-)	5D-E
commorus	Virginia	+	(5)6-7	++	1	-	+	s	+	+	-	-	s	+	+	+	+	-	+-	10C
jay	Oklahoma	+	6	-	2	weak	+	S	+	+	-	+	S	S	-	+	+	-	+	2E
lacuna	Virginia	+	6♀,7♂	-	1	-	+	+♀,S♂	+	+	-	-	S	S	-	+	+	-	+-	5C-D
marshalli	Virginia	-	5	-	2	+	+	s (+)	+	+	-	-	S	+	-	+	+	-	+	5D
pavo	Virgina	+	5	-	1	-	+	S	+	+	-	+	S	S♀s♂	-	+	+	-	+	4-5C
sacer	Virginia	-	7	-	1	-	+	+	+	+	-	+	+	s (+)	-	+	+	-	-±	1C
silvus	Virginia	+	(6)-7	weak	1	-	+	+	+	+	-	-	S	S	-	+	+	-	-	5C
texensis	Texas	+?	6	-	1	-,+	+	S	+	+	-	+	S	Ss	-	+	+	-	+♀	10D

S = strongly spine like , s = weakly spine like. +- = both conditions found, ± = weakly developed. 1) See Christiansen 1966, plate 19 for explanation of formulae(assuming all start as a simple sraight cylindrical rod), letter levels represent extremity of modification as shown by second stage modifications shown in level B and . and 5th stage modifications shown by letter E.

Table 2. Chaetotaxy of female lesser abdomen.

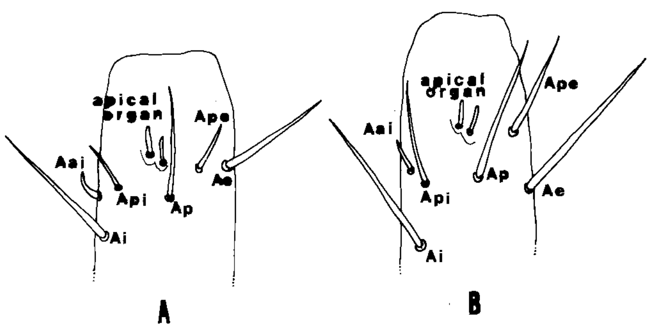
species	DORSAL VALVE SETAE A1	B2	B3	C1	C2	C3	C4	D2	D3	D4	E4	F3	F4	Lateral valve setae C5	C6
A. caedus	+	+	+	+	S,+	S.WL	S.WL	+	+	+	+	+	+	S,WL	S,WL
A. carolynae	+	+	+	+	S,+	+,WL	+,WL	s*	+	+	s*	s*	s*	+,WL	+,WL
A. commorus	sp	+	+	+	S(+)	S(+)	S	+	+	+,-	+	+	+	(S)L	(S)L
A. jay	+	+	+	F	WL	WL	WL	+	+	+	+	+	+	S,WL	S,WL
A. lacuna	+	+	+	+	S	(S)L	(S)L	+	+	-(+)	+	+	+	(S)L	(S)L
A. marshalli	+	+	+	+	L	L	L	+	+	+	+	+	+	L	L
A. pavo	+	+	+	+	S	S	S.WL	+	+	+	+	+	+	S	S
A. sacer	+	+	+	+	+	S	L	+	+	+	+	+	+	S	S
A. silvus	+	+	+	+	S	S(L)	S(L)	+	+	+	+	+	+	S,L	S,L
A. texensis	+	+	+	F	s(L)	WL,L	WL,L	+	+	+	+	+	+	WL,L	WL,L

( ) = exceptional conditions. sp= spine like, + = normal smooth acuminate , S = swollen basally, L = clearly lamellate, WL = weakly lamellate, F = forked. s* = setae in these positions much longer than normal and slightly swollen.

the genus is also well represented and diverse in the United States.

Males are rare in collections and show little interspecific variation in chaetotaxy. They are generally so similar that specific identification is difficult unless they are associated with females. In addition they often show considerable difference from the putative conspecific female specimens.

In our work with the genus we use features previously used to identify species of the genus (Table 1). We have changed the use of the presence or absence of seta Id3 to both Id2 & Id3 present since it is usually impossible to determine whether the missing seta is in fact Id2 or Id3. We have also used the setae of the apex of the third antennal segment following the system developed by Nayrolles (1991). This shows some variations useful in taxonomic separation (Figure 1 A&B) of species. While there is much variation between species the patterns generally are similar to some aspects of one or the other of the forms shown in this figure. We have also examined and use features of the sixth abdominal chaetotaxy in the female (Table 2). Several systems have been developed for categorizing the chaetotaxy of this segment in Sminthuridae (Yosii & Lee, 1963; Yosii, 1969; Lawrence, 1979; Betsch & Waller, 1994; and Bretfeld, 1990, 1994). Unfortunately no two of these systems are really compatible and each requires abandoning all others. The system we found most readily applicable to *Arrhopalites* was that of Lawrence and we have followed this in our work. Figures 2 and 3 show our interpretation of these setae as seen in adult females. There is considerable intraspecific variation in these setae but some features appear to be generally intraspecifically constant and variable between species. Among these is the presence of a fork in the unpaired seta C1, the relative size of the D2, F3, and F4 setae compared to the C setae and their shape, the shape and size of seta A1, the positions of setae C8-C10, the relative sizes of setae E10 & E11, the relative shapes and sizes of setae B11 and C11, and the presence or absence of seta C10. Seta C10 is usually absent but is sometimes small and associated with D10; however in many cases no seta occurs in the position of the normal D10 (in a direct line with D8 and D9) but a large seta occurs much anterior to this. In these cases we interpret this to be seta D10.



Figures 1A & 1B. Semidiagrammatic illustrations of two typical 3rd antennal segment apical setae types.

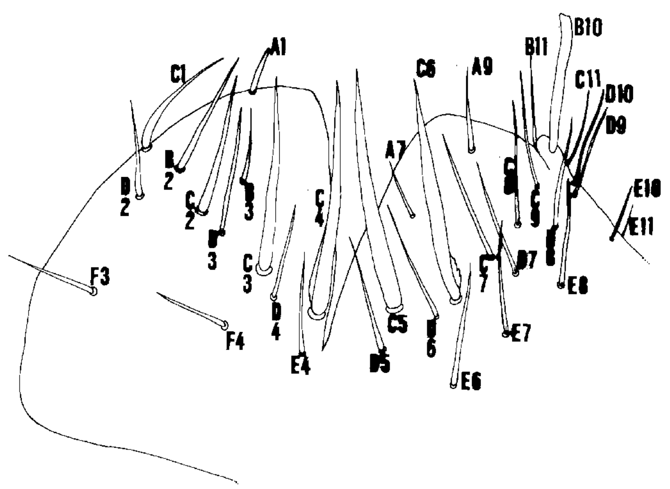


Figure 2. Semidiagrammatic illustration of lateral view of female sixth abdominal chaetotaxy using lettering system after Lawrence (1979).

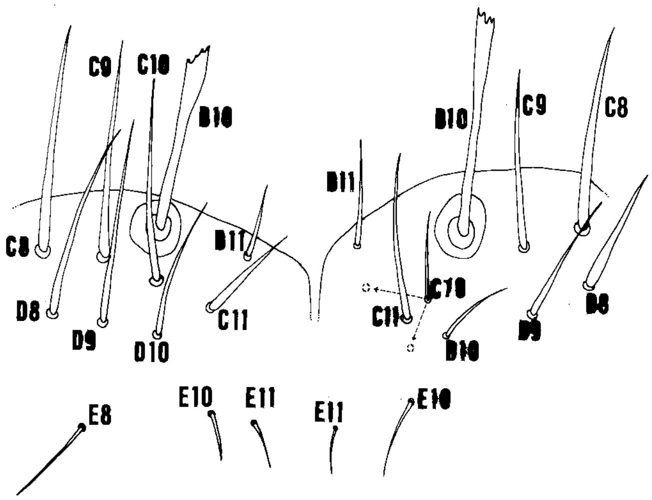


Figure 3. Semidiagrammatic illustration of ventral view of female sixth abdominal chaetotaxy of dorsal valve using lettering system after Lawrence (1979).

The shape of seta B10 has long been known to be of critical importance in the taxonomy of the genus. The setae in males appear to be relatively invariant (Figure 4) and of little taxonomic value.

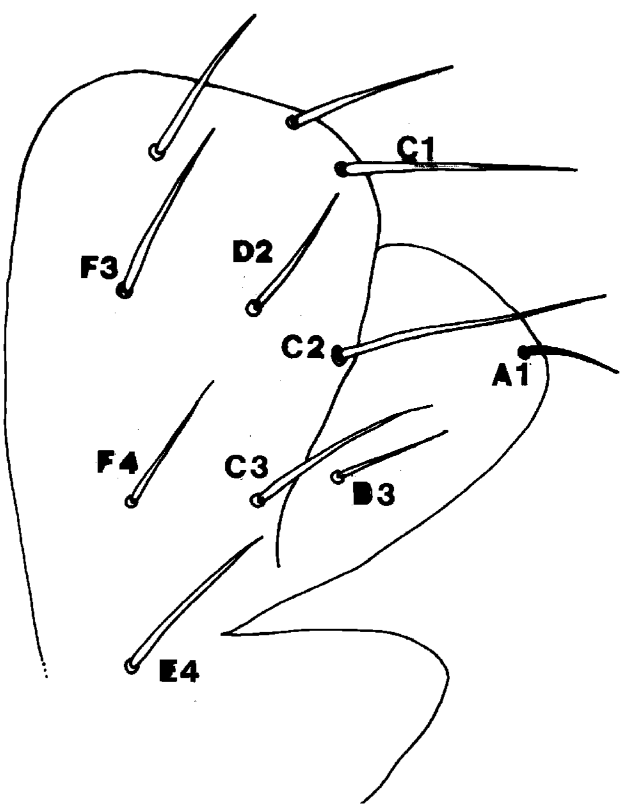


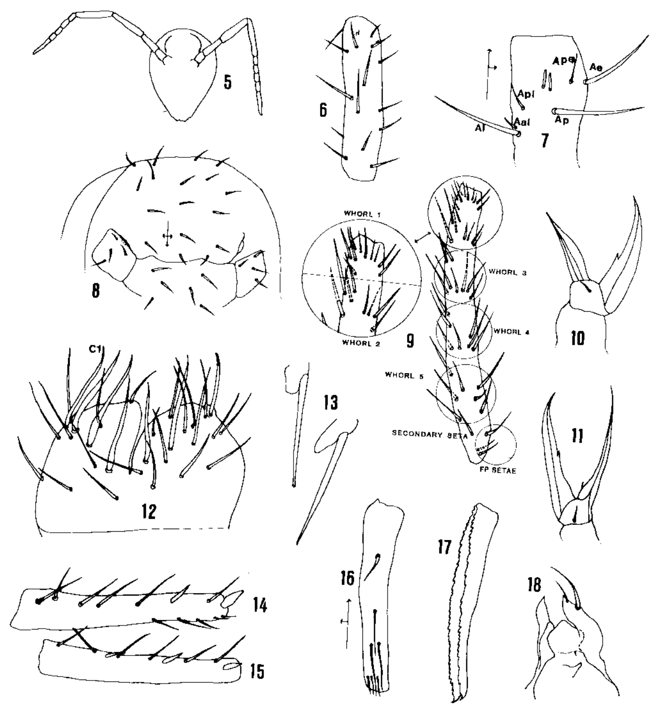
Figure 4. Semidiagrammatic illustration of lateral view of male sixth abdominal chaetotaxy of dorsal valve using lettering system after Lawrence (1979).

New systems have been used to designate the setae of the head; however we see no reason to abandon the system developed by the senior author in 1966 and continue to follow that here. Nayrolles (1988) has developed a system for studying the tibiotarsal chaetotaxy. We have found this system difficult to apply and of only slight taxonomic value in separating species; however we describe (and sometimes illustrate) the posterior tibiotarsal chaetotaxy for all our new species.

The members of this species are best examined when mounted laterally in a slightly dorsal position. This generally allows one to see all the features with some ease. The head is best seen when viewed from the dorsal side.

Arrhopalites caedus sp. nov. (Figs. 5-18)

Description : Eyes 1+1. Color white without trace of pigment. Maximum length 1.5 mm. Antennae 1.35 to 1.8 times as long as cephalic diagonal. Ratios of antennal segments 1-4 as 1/ 1.75-2/ 3-3.5/ 7-8.75. Fourth antennal segment with 6 subsegments and first subsegment 1.55-1.65 times as long as last. Longest setae of segment about 2 & 1/2 times as long as diameter of segment. Third antennal segment without clear basal swelling but slightly thicker on basal half than on distal. Apical organ of third antennal segment of two apically pointed elliptical rods in separate shallow grooves, the outer rod distal to the inner one. Apical seta Aai curved, short, and blunt, about half as long as setae Api and Ape which are straight to slightly curved and acuminate. Seta Ae on a level with Ape, acuminate, slightly shorter and more basally swollen than setae Ap and Ai. Interantennal setae all slender, short, acuminate, and not spinelike. Longest setae (IL3) a little more than half as long as diameter of first antennal segment. Hind tibiotarsal setae all acuminate and smooth, none strikingly differentiated except fine setae of whorl 1. Three FP setae present as well as one secondary seta above whorl 5. Whorls 4 & 5 with 7 setae, whorls 2 & 3 with 8 and whorl 1 with 10. The i setae of whorls 3 & 4 paired. All ungues without trace of tunica. Mid and hind ungues with strong and fore with weak inner tooth. Fore unguis 1.15 to 1.3 times as long as hind. All unguiculi with well developed apical filaments. Fore and mid unguiculi with well developed corner tooth, hind without one. Hind unguiculus subequal to and fore 1-1.1 as long as unguis. Tenaculum typical of genus with posterior unpaired lobe slightly longer than anterior bisetaceous unpaired lobe. Dens 1.25 to 1.5 times as long as mucro. Manubrium with 6+6 slender acuminate smooth setae. Mucro with both edges heavily serrate over whole length and without apical swelling. Female dorsal sixth abdominal setae as shown in table 2. Seta F3 slightly shorter than seta D2. C setae not clearly flanged but in side view a line can be seen possibly representing a minute flange. Seta A1 slender and sometimes curved. Setae D8-D10 slender, acuminate and in a line with seta 9 much longer than other two. Seta C10 absent. Setae C11 and B11 subequal, slender , curved and relatively short. Seta E8 present, E10 and E11 subequal and longer than normal. Female subanal appendage tapered, truncate and either straight or slightly curved apically. Males not



Figures 5-18 all of type specimens of *A. caedus*. 5. Outline of head and antennae. 6. Third antennal segment. 7. Expanded detail of apex of segment, another specimen. 8. Detail of median portion of dorsum of head showing chaetotaxy. 9. Hind tibiotarsal chaetotaxy. 10. Hind foot complex. 11. Fore foot complex. 12. Female sixth abdominal chaetotaxy, lateral view. 13. Female subanal appendages. 14. Outer face of dens. 15. Inner face, same specimen. 16. Ventral surface of dens. 17. Mucro, side view. 18. Tenaculum.

seen.

Holotype: female and 4 female paratypes, Catawba Murder Hole, Botetcourt Co., Virginia, 9 September 1994 D. Hubbard coll., (locality no. 7757).

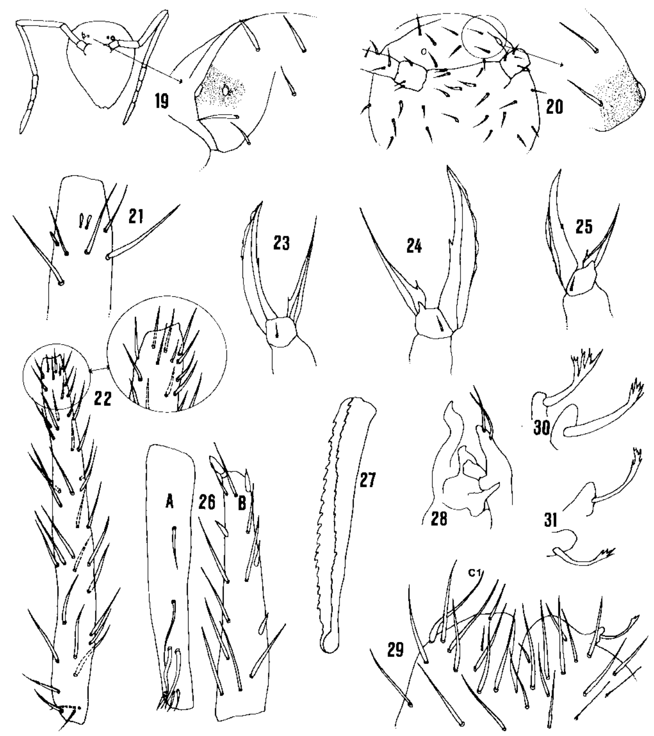
Other locality: Virginia, Little Starr Chapel Cave, Bath Co. water surface, 10 June 1995, Hubbard coll. (locality no. 7841).

Derivatio nominis: from the Latin caedes = killing, after the type locality.

Remarks: This species resembles *A. hirtus* Christiansen 1966 but can be readily separated on the basis of the setae e6 and the shape of the female subanal appendage. It also differs in having a simple C1 seta whereas this is forked in *A. hirtus*. It also resembles *A. pygmaeus* but can be readily separated by the form of the female subanal appendage. There appears to be some variation in the numbers of setae in the various whorls on the hind tibiotarsus.

Arrhopalites carolynae sp. nov. (Figs. 19-29)

Description: Eyes 1+1 to 2+2 in male and 2+2 in female with inner eye smaller than outer and without clear cornea. Color reddish with abundant granules of reddish pigment over head and in two broad longitudinal bands over the dorso-lateral surfaces of the greater abdomen to white without trace of pigment. On the head the pigment, when present, is darkest where eye patches would typically be. Maximum length 1.5 mm. Antennae 1.92 to 2.4 times as long as cephalic diagonal. Ratios of antennal segments 1-4 as 1/ 1.7-2.5/ 3.7-5.0/ 9-11. Longest setae of segment 2.8-3.7 times as long as diameter of segment. Third antennal segment uniform in width to very slightly expanded basally. Apical organ of third antennal segment with two short elliptical rods in common or separate sockets, usually angled out from segment. Apical seta Aai curved to straight, peg like but tapered and from 1/3 to 1/2 as long as setae Api and Ape which are slender, acuminate, and thin walled. Seta Ae and Ap are acuminate, straight to slightly curved, and on the same level. Seta Ai is somewhat longer



Figures 19-29 of *A. carolynae*. 19. Head and detail of female specimen showing integumentary granulations, from Butler Cave, Bath Co. 20. Dorsum and detail of head of male paratype showing eye. 21. Apex of third antennal segment, type specimen. 22. Hind tibiotarsus, specimen from Butler Cave, Bath Co. 23. Fore foot complex, female type specimen. 24. Mid-foot complex, same specimen. 25. Fore foot complex, same specimen. 26. Ventral (a) and dorsal (B) view of dens, female type specimen. 27. Mucro, same specimen. 28. Tenaculum, same specimen. 29. Sixth abdominal chaetotaxy, later view, same specimen (setae beyond D8 and E8 not visible). 30. Female subanal appendage, type specimen. 31. Same, specimen from ButlerCave, Bath Co.

than these and weakly curved to straight. Seta Ae slightly longer and more basally swollen than other two. Fourth antennal segment with first subsegment 1.5-2.3 times as long as last. Female interantennal setae ranging from having A2 A3 L1 L2 IL2 & IL3 all distinctly spine like to having only posterior IL and M setae as well as seta A1 thickened basally but not spine-like. In the male these setae are shorter and somewhat spine-like. The longest seta in the male is about half as long as the diameter of the antennal base. In the female the longest seta (IL3) is distinctly shorter to slightly longer than the basal antennal diameter. Hind tibiotarsal setae in female all smooth and none clearly distinguished except for fine setae in whorl 1. Three FP setae as well as one secondary seta above whorl 5. Whorl 5 with 7 setae and whorls 2-4 with 7-8; whorl 1 with 9-10. Seta i of whorls 2-4 paired. All ungues with inner teeth. Female ungues usually with tunica, clear in mid and hind unguis and weak on the first. Ungual tunica lacking in male. Fore unguis 1-1.2 times as long as hind. All unguiculi with clear corner tooth. Hind and mid unguiculi with short and fore with long apical filaments. Fore unguiculus 0.95-1.35 and hind 0.75-1.4 times as long as corresponding unguis. Tenaculum typical of genus with posterior unpaired lobe much longer than anterior bisetaceous unpaired lobe in females and equal to slightly longer in males. Dens 1.5 to 1.95 times as long as mucro. Manubrium with 6+6 dorsal setae, distolateral 3+3 to 4+4 thickened basally and much longer than inner apical 2+2. Mucro heavily toothed along both margins in most specimens but occasionally weakly serrate or smooth along basal 1/3 to 2/3 of inner margin. Mucro slightly to strongly apically swollen. Female sixth abdominal segment with D, F, & E setae somewhat longer and thicker than normal. Male with typical number of setae but all setae except C1, A1, & B3 much thicker and longer than normal. Setae D8-D10 similar in size and shape, slender, acuminate, and in a row. Seta C10 absent. Setae C11 and B11 similar in size and shape, slender and curved. Seta E8 present, E11 and E10 subequal or with E10 slightly larger. Female subanal appendage stout, curved and apically palmate and serrate.

Holotype: female and three female and one male paratypes, Wildcat Saltpetre Cave, Wise Co. Virginia, 24 January 1995, D. Hubbard coll. (locality no. 7790).

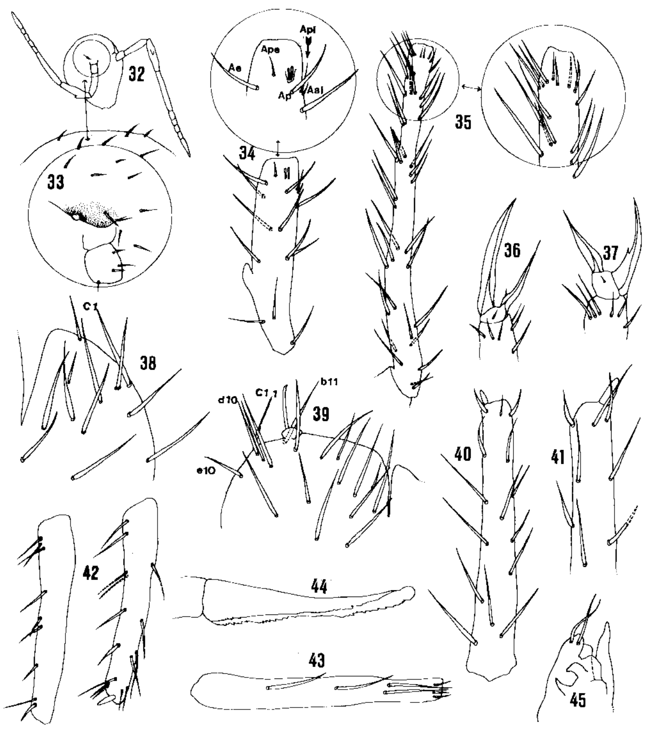
Other localities: Virginia, Staunton Quarry Cave, Augusta Co. 6 April 1995, D. Hubbard Coll. (locality no. 7816); Butler Cave, Bath Co., pool surfaces 1 September 1994 , D. Hubbard Coll. (locality no. 7760); Spangler Cave, Lee Co. 29 March 1995. D. Hubbard coll. (locality no. 7815). Little Starr Chapel Cave, Bath Co. on water surface, 10 June 1995, Hubbard coll. (locality no. 7841); Marshalls Cave, Highland Co. water surface, 27 August 1995, Hubbard coll. (locality no. 7863); Water Sinks Cave, Highland Co., pools 3 September 1995, D. Hubbard Coll (locality no. 7875).

Derivatio nominis: named for the wife of the junior author, without whom he would not have lasted to pursue Collembola so long.

Remarks: This is a remarkably variable species. The first populations we saw were from Bath and Wise Counties and these were so different that we considered them as separate species; however, additional specimens from Lee and Augusta Counties have shown sufficient intermediacy that we now consider them as a single taxon. The Bath County specimens are the most unusual, being the only ones lacking a clear apical filament on the hind unguis, lacking a tunica, and having 2+2 eyes in the male. It should be noted that only single males, one each from Bath, Lee, and Wise Counties, have so far been seen, so it is possible that intrapopulation variation occurs. The Bath and Augusta Counties specimens have 5 subsegments on the 4th antennal segment whereas the others have 6. The Wise County specimens are the only ones with brilliant coloration. The 2+2 eyes in the female as well as the subanal appendages and uncommon 6th abdominal chaetotaxy serve to separate this species from most others. The species is very close to *A. marshalli* n.sp. and they may be part of the same extremely variable taxon.

Arrhopalites commorus sp. nov. (Figs. 32-45)

Description: Eyes 1+1, unpigmented. Color white without trace of pigment. Maximum length 1.5 mm. Antennae 1.73 to 2.08 times cephalic diagonal in females and about 4 times in male. Ratios of antennal segments 1-4 about 1 : 2: 3-3.5; 8-10. Fourth antennal segment with (5)6-7 subsegments and ratio of first to last subsegment 1.5-1.9. Longest setae 2.5-2.8 times as long as diameter of segment in females and 3.5-4.2 times as long in males. Third antennal segment with basal papilla extremely pronounced and apical organ of two elongate elliptical rods in a shallow groove. Apical seta Aai cylindrical and blunt, about 1/2 as long as seta Api which is acuminate, thin walled, and slightly basally expanded. Seta Ape is similar to Api. Setae Ae, Ap, and Ai are similar in size and shape, acuminate, and curved. Seta Ae is on a level with Ap. Cephalic dorsal setae all slender and acuminate, longest (IL2 & IL3) about 1/2 diameter of first antennal segment. Female hind tibiotarsal setae all smooth and acuminate. 3 FP setae present. Setae i of whorls 3 and 4 are paired on all legs. Setae Pi of whorls II-IV are shorter and more spiniform that the other setae. Ungues without trace of tunica. Fore unguis without and hind unguis with or without a small inner tooth. Fore unguis 1.1-1.3 times length of hind unguis. Fore unguiculus with clear corner tooth and terminal filament. Hind unguiculus without both or with small apical filament. Both fore and hind ungues distinctly longer than corresponding unguiculi. Tenaculum typical of genus with posterior unpaired lobe much longer than anterior bisetaceous unpaired lobe. Dens 1.6 to 1.8 times length of mucro. Manubrium with 4+4 acuminate smooth dorsal setae. Mucro with both margins finely serrate and a slight apical swelling. Female sixth abdominal dorsal valve with seta D4 present or absent. Seta A1 straight and slightly spine-like. D2 & B2 setae similar to C setae in length. Seta D8 present or absent, when present in a straight line with D7, D9 & D10. Seta B11 is straight, somewhat thickened, and slightly longer



Figures 32-45 all of type specimens of *A. commorus*. All specimens females unless otherwise noted. 32. Outline of head. 33. Detail of right eye and antennal base, showing integumentary granulations. 34. Third antennal segment with blow-up of apex. 35. Hind tibiotarsus with blow-up of apex. 36. Fore foot complex. 37. Hind foot complex. 38. Dorsal valve, sixth abdominal segment. 39. Ventral valve, another specimen (setae D11 not seen). 40. Right dens of male specimen seen from above. 41. Blow-up of apex of same specimen, left dens. 42. Dentes of female, left external face, right internal face. Dotted lines represent broken setae seen on other specimens. 43. Ventral surface of dens. 44. Mucro. 45. Tenaculum.

than the slender acuminate C11 but C11 is sometimes not visible from side and may be absent. Seta E8 present and seta E10 clearly longer than E11. Male typical of genus. Female subanal appendage subcylindrical, slightly tapered, straight or slightly curved with a flattened finely ciliate apex.

Holotype: female and four female and two male paratypes, Stay High Cave, Giles Co., Virginia, 6 August 1994, D. Hubbard Coll. (locality no. 7754).

Additional records: Virginia: Burton Cave, Lee Co., 29 May 1994, D. Hubbard coll. (locality no. 7710). Little Kennedy & Big Kennedy Caves, Wise Co., 17 April 1995, D. Hubbard coll. (locality nos. 7817 & 7818).

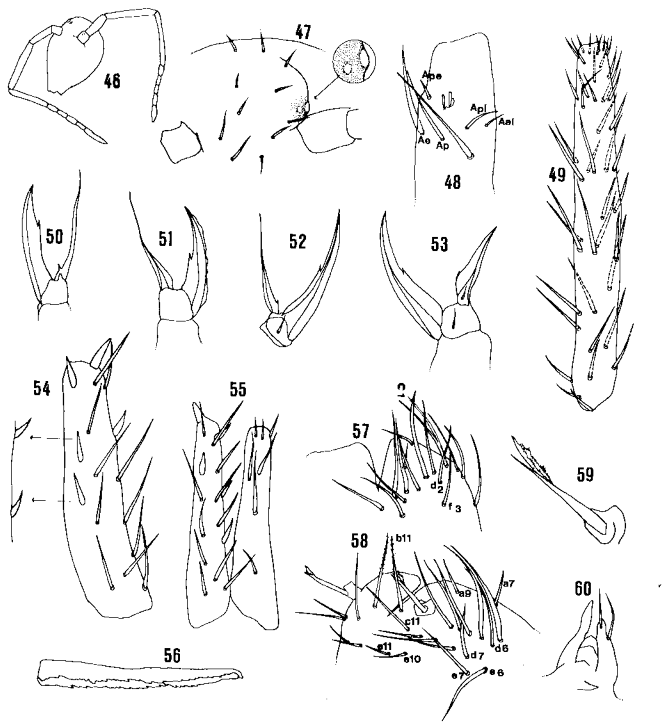
Derivatio nominis: from the Latin commoror to stay, after the type locality cave.

Remarks: This unusual species has a dental seta positioned so that it could be considered either L4 or an Id4. Since there is no case of the existence of an Id4 we interpret it as the former. The species is similar to *A. clarus* Christiansen 1966 in many respects but can be easily distinguished on the basis of the large 3rd antennal segment swelling as well as the absence of a forked C1 seta. The two males examined appeared to have a much larger antenna—cephalic diagonal ratio that the females but were otherwise similar, except for the normally sexually dimorphic features. The males are also unusual in being only slightly smaller than the females. The species also shows considerable variation. The single specimen from Lee Co. has 5 antennal subsegments while those from Wise and Giles counties have 6 to 7 subsegments. The two females from the type series had sixth abdominal segment C8 seta absent while those from other localities had it present.

Arrhopalites jay sp. nov. (Figs. 46-60)

Description: Eyes 2+2 with the inner eyes much smaller than the outer and without pronounced cornea. Color white without trace of pigment.

Maximum length 1.6 mm. Antennae 2.25 to 2.5 times cephalic diagonal. Ratios of antennal segments 1-4 about 1:2: 4.4 : 9-10. Fourth antennal segment with 6 subsegments and the ratio of the first to the last subsegment about 3:1. Longest setae of segment 3.25 to 4 times as long as diameter of segment. Third segment without basal papilla and with apical organ of two ovoid clubs in a shallow groove, the outer below the inner. Apical seta Aai short, thick, curved and apically acuminate, about 1/3 as long as seta Api and Ape which are strongly curved and acuminate. Setae Ae, Ap, and Ai similar, acuminate and slightly curved. Setae Ae and Ap on the same level. Most interantennal cephalic setae weakly spine-like. Longest (Seta A1) 3/4 to 3/5 as long as diameter of first antennal segment. Female hind tibiotarsal setae all acuminate and smooth, none clearly differentiated except for extremely thin setae in whorl 1. Three FP setae present as well as two secondary setae above whorl 5. Setae i of whorls II , III, & IV paired. Only 6 setae in whorl IV. All ungues without trace of tunica and with a small to minute inner tooth. Fore unguis 1.1 to 1.2 times length of hind. Fore unguiculus with and hind unguiculus without corner tooth. Fore unguiculus with prominent apical filament. Hind unguiculus with such in female but without in male. Ratio of fore unguiculus to unguis 1.1.-1.2. Ratio in hind foot about 1.25 in female and 0.8 in male. Tenaculum typical of genus with posterior unpaired lobe much longer than anterior bisetaceous unpaired lobe. Dens about 1.45 times as long as mucro in female and 1.7 in male. Manubrium with 6+6 dorsal and lateral setae, with 1-3 of these much heavier and larger than others. Mucro without apical swelling and with both edges strongly serrate. Female sixth abdominal dorsal setae as shown in table 2. Setae B2 ,D2 & F3 about 2/3 as long as C2. Other A , B, D, & F setae much shorter. Setae D8-D10 slender, acuminate and in a straight row. Seta E8 present and E10 slightly longer or subequal to E11. Seta D10 a little more than 1/2 as long as D9. Seta C10 present or absent and slightly shorter than seta D10. Setae B11 and C11 acuminate and straight to slightly curved. Seta B11



Figures 46-60 of *A. jay*. Outline of head, type specimen. 47. Detail of head specimen from Cherokee Co. showing integumentary granulations. 48. Apex of third antennal segment, type specimen. 49. Hind tibiotarsus, type specimen. 50. Fore foot complex, type specimen. 51. Hind foot complex, same specimen. 52. Fore foot complex, specimen from Cherokee Co. 53. Hind foot complex, same specimen. 54. Dorsal face of right dens, same specimen. 55. Dorsal (left) and ventral (right) face of dens, type specimen. 56. Mucro, type specimen. 57. Dorsal valve of sixth abdominal segment, type specimen. 58. Ventral valves of sixth abdominal segment, specimen from Cherokee Co. 59. Blow-up of female subanal appendage, same specimen. 60. Tenaculum, same specimen.

very slightly weakly ciliate. Male as shown in figure 4. Female subanal appendage deeply branched with outer branch smooth and acuminate and inner branch unilaterally ciliate or serrate.

Holotype: female and 1 female and 1 male paratype, Peach tree Cave, 5 miles south of Jay, Delaware Co., Oklahoma, 5 October 1991 (locality no. 7486).

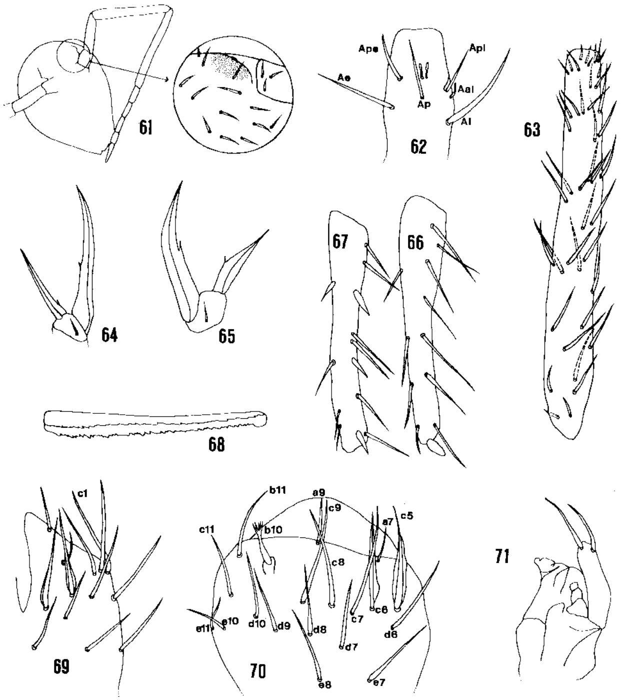
Other locality: Oklahoma: Dressler Cave, 4 miles N. Fort Gibson, Cherokee Co., 26 September 1991 (locality no. 7484).

Derivatio nominis: Named after the town nearest the type locality cave.

Remarks: The unusual female subanal appendage serves to distinguish this species from all other North American forms. The forked subanal appendage places it in a group with *A. hirtus* Christiansen 1966 and *A. texensis* n.sp. The inner eyes may not be eyes at all since they have no evidence of a thickened cornea or pigment; however, the shape, size, and position of these smooth areas all suggest eye vestiges. The eyes are quite different from the only known U.S. surface species with 2+2 eyes, *Arrhopalites bellingeri* Christiansen 1966. We thus have to hypothesize either that this species, as well as the *A. carolynae* group, have evolved from some now extinct surface species, or that both have secondarily acquired this plesiomorphic feature. While neither hypothesis is particularly attractive, the former appears to be more acceptable. This species displays an unusual degree of sexual dimorphism, in the presence of a tunica and an unguicular filament on the posterior foot only in the female. Unfortunately only one male specimen was seen so verification of this difference must await further collections.

Arrhopalites lacuna sp. nov. (Figs. 61-71)

Description: Eyes 1+1. Color varying from white to reddish with pigment granules densely scattered with two bands over dorsolateral surface of greater abdomen and dorsum of head. Maximum length 1.5 mm in female and 1 mm in male. Antennae 2.0 to 2.6 times as long as cephalic diagonal. Ratios of antennal segments: 1: 2: 4-5:10-13. Fourth antennal segment with 6 subsegments in female and 7 in male. Ratio first to last subsegment 2.1-2.5 in females and 1.5 in males. Longest setae 3.0 to 3.8 times as long as diameter of segment. Third antennal segment without basal swelling and with apical organ of two elliptical rods projecting from a shallow pit. Apical seta Aai straight, slightly tapered but truncate and about 1/3 as long as setae Api and Ape which are acuminate and straight to slightly curved and slightly swollen basally. Setae Ae & Ap on same level. Seta Ae slightly shorter than Ap and both clearly shorter than Ai. Dorsal cephalic IL setae plus L1 and posterior M setae slightly thickened basally but not clearly spinelike. Longest setae (usually L1) 4/5 as long as diameter of first antennal segment. Female hind tibiotarsal setae all acuminate and smooth, none clearly differentiated except for extremely thin setae in whorl 1. Setae i of whorls 2-4 paired. 3 FP setae as well as two secondary setae above whorl 5. All ungues without trace of tunica and with clear inner teeth. Fore unguis slightly longer than hind. All unguiculi with clear corner tooth and short apical filaments. Fore unguis 1.2-1.3 X unguiculus; hind 1.3 times unguiculus. Tenaculum typical of genus. Posterior unpaired lobe about as long as setaceous unpaired lobe in females but distinctly longer in the single male seen. Dens 1.5 to 1.8 times as long as mucro. Manubrium with 6+6 dorsal and lateral setae, all similar. Seta e3 on dens is basally more or less expanded in females but not a spine. In males it is clearly a spine. Mucro with both edges clearly serrate and with a slight apical swelling. Female sixth abdominal dorsal setae as shown in Table 2. Setae C3 and C4 vary greatly in the size of the lateral flange; however, it is never serrate. Seta F3 is about 3/4 as long as D2. Setae D8-D10 slender, acuminate, and similar in length. C9 unusually close to and anterior to C10. Setae B11 and C11 similar, curved to straight, slender and acuminate. B11 slightly longer than C11. Seta E8 present with E10 and E11 subequal to each other. One specimen has seta E8 missing. Female subanal appendage apically palmate. Male setae typical in one specimen



Figures 61-71 of female type specimens of *A. lacuna*. 61. Outline of head with details of setae, integumentary granulations of eyes near base of left antenna. 62. Apex of third antennal segment. 63. Hind tibiotarsus, seen from anterior view. 64. Fore foot complex. 65. Hind foot complex. 66. inner face of dens. 67. Outer face of dens, same specimen. 68. Mucro, same specimen. 69. Dorsal valve, sixth abdominal segment seen from side. 70. Left side, ventral valve of different specimen. 71. Tenaculum.

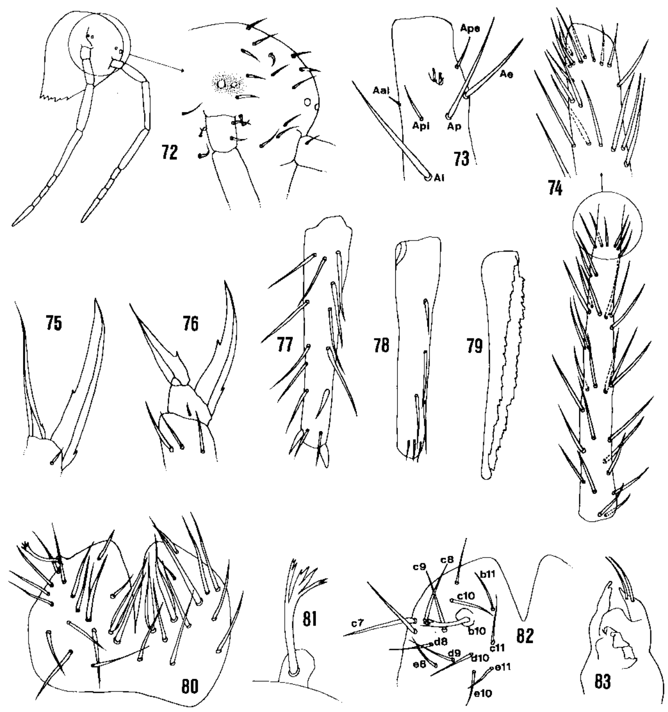
but with seta C2 truncate in the other.

Holotype: female and 14 female and 2 male paratypes, Paxton's Cave, Alleghany Co. Virginia, on pools, 9 & 30 July, 1994, D. Hubbard coll. (locality numbers 7740 & 7753).

Derivatio nominis: from the Latin lacuna-cavern.

Remarks: This species shows a striking sexual dimorphism in the number of antennal subsegments and the fact that the male seta e3 differs strikingly from the female. Only two males were seen and one of these has the unique condition of having the C2 setae truncate. It would be interesting to discover whether this is a unique specimen or a truly polymorphic condition. This species resembles *A. clarus* Christiansen in a number of respects but can be easily separated on the basis of the subanal appendage and the dental chaetotaxy.

Arrhopalites marshalli sp. nov. (Figs. 72-83)
Description: Eyes 2+2 with inner eye much smaller than outer. Color white without trace of pigment. Maximum length 1.7 mm. Antennae (all ratios in parentheses below appear in one unusually large specimen) 1.9-2.3 (2.5) times as long as cephalic diagonal. Ratios of antennal segments as 1/1.8-1.95/3.2-3.7/7.8-8.6 , (1/2.1/4.2/12). Fourth antennal segment with first subsegment 1.6-1.7 (2.0) times as long as last. Longest setae of segment about 3 times as long as diameter of segment. Third antennal segment with seta Aa1 blunt and cylindrical and slightly less than half as long as seta Api; seta Apo short, acuminate, and more anterior than normal in genus. Interantennal setae IL1 L2 & 3 and often M4 and A3 large and spinelike; longest setae about 2/3 as long as diameter of first antennal segment. Hind tibiotarsal setae all smooth and acuminate and none clearly differentiated except for fine setae of whorl 1; three FP setae as well as one secondary seta above whorl 5; whorls 4 & 5 with 7 setae , whorls 2 & 3 with 8, and whorl 1 with 9-10 setae; the i setae of whorls 2-4 are paired. All ungues without tunica and with very small to minute inner tooth; fore unguis slightly longer to slightly shorter than hind and 1-1.25 length of unguiculus; hind unguis 1.1-1.38 times as long as corresponding unguiculus. Tenaculum typical of genus with posterior lobe slightly longer than bisetaceous anterior unpaired lobe. Manubrium with 6+6 setae; posterior lateral



Figures 72-83 of female type specimens of *A. marshalli* except where otherwise noted. 72. Outline of head with detail of central chaetotaxy and eyes showing integumentary granulations around left eyes. 73. Apex of third antennal segment. 74. Hind tibiotarsus with blow-up of apex of apex. 75. Fore foot complex. 76. Hind foot complex, same specimen. 77. Dorsum of right dens. 78. Venter of same. 79. Mucro. 80. Lateral view of circumanal setae. 81. Subanal appendage, another specimen. 82. Ventral valve sixth abdominal setae of specimen form Canyon to Nowhere Cave, Scott Co., Virginia. 83. Tenaculum.

3+3 distinctly thicker and longer than remainder. Mucro clearly toothed along both margins and without apical swelling. Dens 1.5-1.85 times as long as mucro. Abdominal segment 6 with Setae C4-C6 generally clearly lamellate. C7-C9 slender and acuminate. Seta C10 absent or present; when present more anterior and lateral than normal. Setae C11 & B11 slender, acuminate, and similar. Seta E10 longer than E11. Female subanal appendage apically palmate and serially divided. Males not seen.

Holotype: female and six female paratypes, Wininger Cave, Scott Co. Virginia, 22 May 1995 D. Hubbard coll. (locality no. 7839).

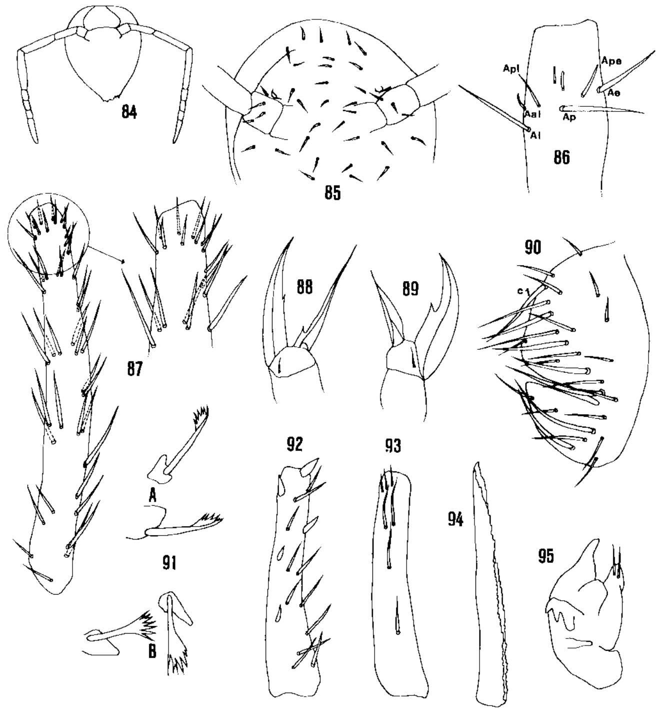
Other locality: Virginia, Canyon to nowhere Cave, Scott Co. 18 April, 1995 D. Hubbard coll. (locality no. 7819).

Derivatio nominis: named in honor of John Marshall whose assistance to us over many years has been invaluable.

Remarks: This species is easily distinguished from all other Nearctic species by the combination of 2+2 eyes and a lack of spinelike dental setae L2 L3. The type locality cave also houses specimens of *Arrhopalites pavo*.

Arrhopalites pavo sp. nov. (Figs. 84-95)

Description: Eyes 1+1. Color white without trace of pigment or with scattering of reddish pigment granules over head and dorsum of body. Maximum length 1.2 mm. Antennae 1.75 to 1.6 times as long as cephalic diagonal in females and about 1.85 in males. Antennal segment ratios as 1/ 2.0 -2.5/ 3 -4 / 9 -13 in females and about 1/-1.9/3/7.5-8.5 in males. Fourth antennal segment with 5 subsegments. First subsegment 1.4 to 1.7 times as long as last. Longest setae 2.1 to 2.4 times as long as diameter of segment. Third antennal segment apical organ of two rods, on surface of segment or in very shallow separate pits. Seta Aai curved, short and blunt, about half as long as seta Api which is slender, straight, and acuminate. Seta Ape similar to Api. Seta Ae on level with seta Ape, slightly heavier and more spine like than setae Ap or Ai. All these three setae acuminate and gradually tapered. Interantennal setae small, slender, and acuminate. Longest setae (L3) about half as long as diameter of first antennal segment. Hind tibiotarsal setae all smooth and acuminate, none strikingly differentiated except for thin setae in whorl 1. Three FP setae as well as one secondary seta above whorl 5. Whorls 4 & 5 with 7 setae, whorl 3 with 8, whorl 2 with 9, and whorl 1 with 9-10 setae. Whorls 2-4 with paired i setae. All ungues without tunica and with strong internal tooth. Fore unguis 1.1-1.2 times as long as hind. Fore and mid unguiculi with and hind without corner tooth. All unguiculi with clear apical filaments. Fore and mid unguiculus 1.2 to 1.3 and hind 1.0 to 1.2 times as long as corresponding unguis. Dens 1.2 to 1.4 times as long as mucro. Manubrium with 6+6 dorsal setae and only the inner basal seta much smaller than others. Female sixth abdominal setae as shown in table 2. Seta A1 straight but not clearly spinelike. Setae D2, F3, and F4 short, slender, and subequal in length. Setae C2-C6 swollen and sometimes with a small, unilateral lamella. Seta D8 absent, D7-D10 slender straight and in a row.



Figures 84-95 of female type specimens of *A. pavo*. 84. Outline of head and antennae. 85. Detail of dorsal cephalic chaetotaxy and eyes. 86. Apical third antennal chaetotaxy. 87. Hind tibiotarsus seen from front. 88. Fore foot complex. 89. Hind foot complex. 90. Sixth abdominal chaetotaxy seen from side. 91 A&B. Subanal appendages of two different specimens. 92. Dorsal chaetotaxy of left dens. 93. Ventral chaetotaxy of same. 94. Mucro seen from side. 95. Tenaculum.

Seta C10 absent. Setae B11 and C11 slender, straight to slightly curved and subequal. Seta E8 present, E10 slightly longer than E11. Female subanal appendage short, stout, and straight, apically deeply serrate, usually unilaterally.

Holotype: female and four female paratypes, Turkey Hill Cave, Rockbridge Co., Virginia, 22 October, 1994, on wood near pools, David Hubbard coll. (locality no. 7763).

Other locality: Wininger Cave, Scott Co., Virginia, 22 May 1995 D. Hubbard coll. (locality no. 7839)

Derivatio nominis: from the Spanish pavo = turkey, after the type locality cave.

Remarks: Two males were seen from Wininger Cave and as this is the type locality of *A. marshalli* n.sp. we at first suspected that they were the males of this species but they clearly belong to *pavo* which also occurs in this cave. In spite of the great difference in location the females from the two localities are very similar. The unguiculi are slightly longer in the Scott County specimens than those from the type locality. This species is very close to the problematic *A. benitus* (Folsom, 1896) and for a time we considered them as synonyms; however, all specimens of *A. benitus* we have seen have some spinelike cephalic setae while these are totally absent in *A. pavo*. In addition *A. benitus* is usually found in surface localities and is frequently pigmented while *A. pavo* is an entirely cave form. The only cave specimens that we saw identifiable as *A. benitus* had the multiple forked subanal appendage characteristic of surface specimens of *A. benitus* and a different sixth abdominal chaetotaxy from that seen in *A. pavo*. It may be that they are local variations of the same species but we feel it best to consider them separate on the basis of present information.

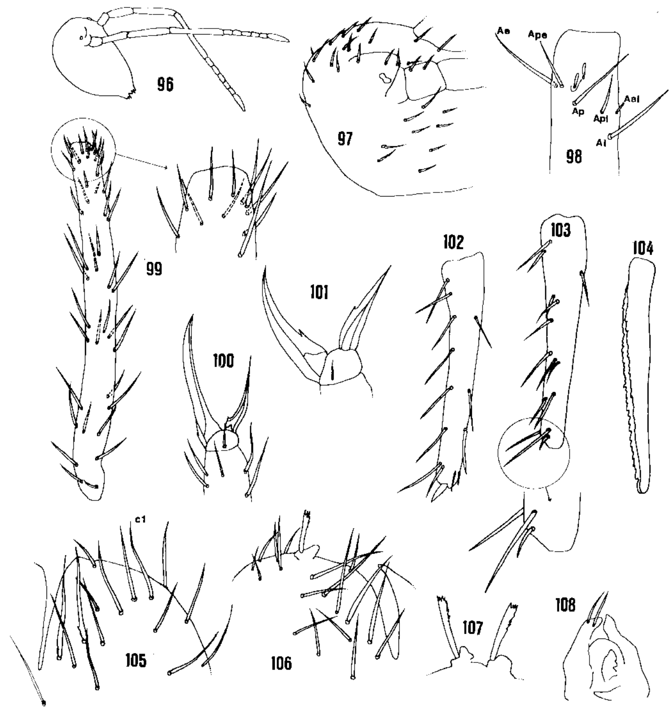
Arrhopalites sacer sp. nov. (Figs. 96-108)

Description: Eyes 1+1. Color white without trace of pigment or with scattering of reddish pigment granules on dorsum of head and abdomen. Maximum length 1.2 mm. Antennae (in adults) slightly more than twice as long as cephalic diagonal. Ratios of adult antennal segments 1-4 as 1/ 2.1-2.4/3.8-4.2/ 10-12. Fourth antennal segment with 7 subsegments and first subsegment 2.2-2.4 times as long as last; longest setae of segment about 2 times as long as diameter of segment. Third antennal segment without basal swelling. Apical organ of third antennal segment of type A (Figure 1) except that setae of apical organ slightly swollen. Hind tibiotarsal setae all acuminate and smooth, none strikingly differentiated except fine setae of whorl 1; three FP setae present as well as one secondary seta above whorl 5; whorls 4 & 5 with 7 setae, whorls 2 & 3 with 8, and whorl 1 with 9; the i setae of whorls 3 & 4 paired. All ungues without trace of tunica. Mid and hind ungues with strong and fore without inner tooth. Fore unguis 1.23 to 1.25 times as long as hind. Fore unguiculus with very small apical filament and mid and hind unguiculi without or with extremely short filaments. Fore and mid unguiculi with small corner tooth, hind without one. Hind unguiculus 0.82 and fore 0.70-0.76 times as long corresponding unguis. Tenaculum typical of genus with posterior unpaired lobe slightly longer than anterior bisetaceous unpaired lobe. Dens 1.5 to 1.7 times as long as mucro. Manubrium with 5+5 slender acuminate smooth setae, inner anterior pair distinctly smaller than others. Mucro with both edges serrate over whole length or with inner lamella clearly serrate only along basal 1/3 to 1/2, and without apical swelling. Female dorsal sixth abdominal setae as shown in Table 2. Seta F3 subequal to seta D2. C setae C3-C6 only slightly swollen, C4 with small serrate lamella basally. Seta A1 slender, short, and curved. Setae D8-D10 slender, acuminate and in a line. Seta C10 absent. Seta E8 present, E10 and E11 subequal and short. Female subanal appendage straight, stout, truncate, and serrate along one distal margin and apically. Males not seen.

Holotype: female and 1 female paratype, Little Starr Chapel Cave, Bath Co., Virginia, 10 June 1995 D. Hubbard coll., (locality no. 7841).

Other locality: Virginia, Butler Cave, Bath Co., 24 September 1994, Hubbard coll. (locality no. 7760).

Derivatio nominis: from the Latin = consecrated, after the type locality.

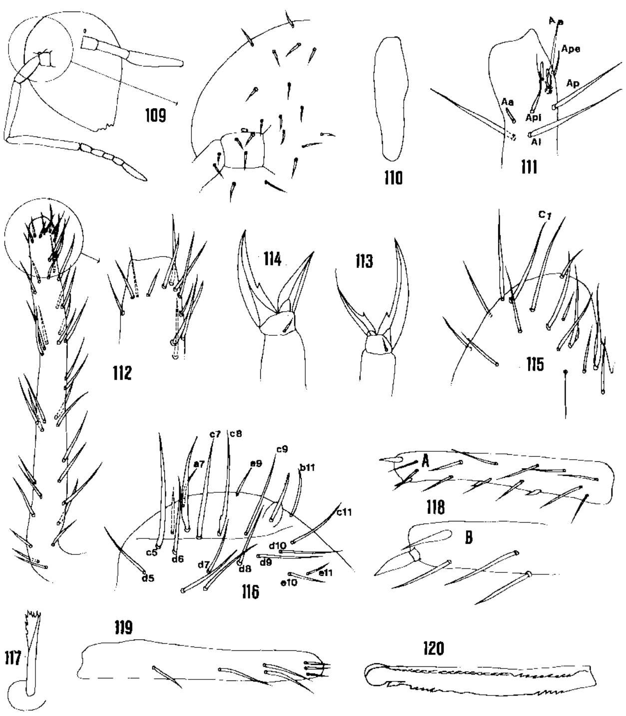


Figures 96-108 of type female specimens of *A. sacer*. 96. Outline of head and antennae. 97. Detail of head and eye of right side, same specimen. 98. Apex of third antennal segment, same specimen. 99. Hind tibiotarsus, same specimen. 100. Fore foot complex, same specimen. 101. hind foot complex, same specimen. 102. Outer face of right dens, same specimen. 103. Inner face of same with blow-up of apex. 104. Mucro, same specimen. 105. Dorsal valve, sixth abdominal segment, side view. 106. Ventral valve, same specimen. 107. Ventral appendages. 108. Tenaculum.

Remarks: This species is similar to *A. commorus* n.sp. but may be easily distinguished by the absence of a third antennal segment basal swelling as well as the slightly more spinelike L2 L3 setae. This species is also extremely close to *A. silvus* n. sp. and may prove to be part of the same geographically variable taxon; however the different female sixth abdominal chaetotaxy as well as dental chaetotaxy difference lead us to consider them as separate species for the present. The single immature paratype differs from the two adult specimens seen in a number of ratios but is otherwise very similar. The type locality also hosts specimens of *A. caedus* and *A. carolynae*. nn.spp.

Arrhopalites silvus sp. nov. (Figs. 109-120)

Description: Eyes 1+1. Color white without trace of pigment. Maximum length 1.3 mm. Antennae 1.95-2.15 times cephalic diagonal. Ratios of antennal segments 1-4 about 1: 2-2.5: 3.5-4: 9-10. Fourth antennal segment with 6-7 subsegments with the first subsegment being 1.7 to 2.2. times as long



Figures 109-120 all of female type specimens of *A. silvus*. 109. Head with enlargement of detail of right eye region. 110. Outline of third antennal segment. 111. Apex of third antennal segment. 112. Hind tibiotarsus seen from front. 113. Fore foot complex. 114. Hind foot complex. 115. Dorsal valve, sixth abdominal segment seen from side. 116. Ventral valve, left side, seen from below and an angle. 117. Female subanal appendage. 118. A, dorsal surface of dens, left side, B, detail of apex of right side. 119. Ventral surface of dens. 120. Mucro seen from above.

as last. Females with longest seta 2.2-2.5 times and single male 1.9 times as long as diameter of segment. Third segment with weak but clear basal swelling over basal 1.3 to 1/2 of segment. Apical organ of third segment of two elliptical rods in shallow pit. Apical seta Aai short, straight, blunt, and peglike, about 1/3 as long as seta Api which is straight and acuminate. Seta Ape similar to Api but slightly longer. Seta Ae on level with apical organ and seta Ape, or slightly posterior to these. Setae Ape, Ap and Ai all straight, acuminate, and not swollen basally. Seta Ae slightly shorter than Ap which is shorter than Ai. No spinelike interantennal setae. Longest setae (A1, IL3 or M5) are 0.5 to 0.6 as long as diameter of first antennal segment in females and 0.75 as long in single male seen. Hind female tibiotarsal setae with normal unusually slender setae in whorl 1. Some of i setae are thicker and slightly more expanded basally than remainder. 3 FP setae present as well as one secondary seta above whorl 5. Whorls 2-5 each with 7 setae. Setae i of whorls 2-4 usually paired. All ungues without trace of tunica. Hind and mid unguis with strong and fore unguis with very small inner tooth. Fore unguis 1.15 to 1.5 times as long as hind. Fore unguiculus with clear but short apical filament. Mid and hind unguiculi with no or very short filament (<0.08 length of rest of unguiculus). Ratio of fore unguis to unguiculus 1.25-1.6; hind 1.25-1.5. Tenaculum typical of genus with posterior unpaired lobe much longer than anterior bisetaceous unpaired lobe. Dens 1.35 to 1.95 times as long as mucro. Mucro serrate for at least part of length on both margins, serrate portion varying from basal 1/3 to whole length. Mucro with small apical swelling, striking when seen from above. Manubrium with 6+6 similar acuminate smooth setae. Female dorsal sixth abdominal setae as shown in Table 2. Lamellae of C setae, when present, very small. Setae F3 1/2 to 3/4 as long as D2 setae. Setae D8-D10 slender acuminate, similar and in straight line. Setae B11 and C11 slender, acuminate, straight to slightly curved with C11 slightly to distinctly longer than B11. Seta E8 present and E10 distinctly longer than E11. Seta C8 sometimes thickened and basally expanded. Subanal appendage short, stout and straight with short serrations on apical 1/3 to 1/4 of dorsal edge and on apex. Male chaetotaxy typical of genus.

Holotype: female and four female paratypes, Woods-Terry Cave, Highland Co.,Virginia, 22 July 1994, from water surface, David Hubbard coll., (locality no. 7741).

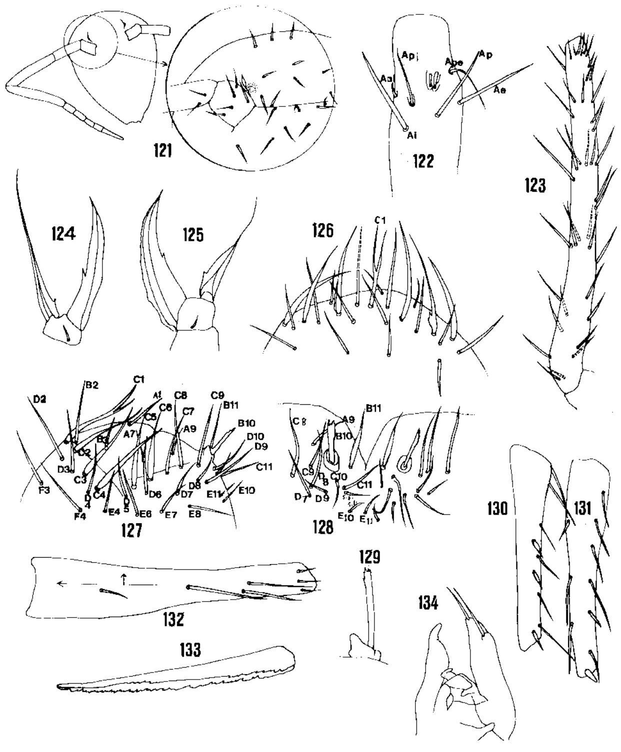
Other locality: Virginia, Hiner Cave, Highland Co., 29 May 1994, D. Hubbard coll. (locality no. 7709).

Derivatio nominis: from Latin Silvae-woods, after the name of type locality.

Remarks: This species resembles *A. hirtus* Christiansen 1966 in a number of respects but can be readily distinguished on basis of a third antennal segment basal swelling and lack of spinelike e3 dental seta as well as the shape of the female subanal appendage. One of the type series females has a very abnormal dorsal lesser abdomen chaetotaxy: C3 seta on the left side is bifurcate and on the right trifurcate. In addition, most of the C setae have short serrate basal flanges. The specimen otherwise resembles the others. One of the type specimen females has 7 antennal segments, as does the single male. The male and a single female were collected from the Hiner Cave along with a number of female (and one male) specimens of *A. pygmaeus* (Wankel), 1860.

Arrhopalites texensis sp. nov. (Figs. 121-134)

Description: Eyes 1+1. Color (in mounted specimens) white without trace of pigment. Maximum length 2.2 mm. Antennae 2 - 2.5 times as long as cephalic diagonal. Ratios of antennal segments 1-4 as 1/ 1.7-2/ 3.3-4.3/ 8-10. Longest setae in females 3-3.3. times as long as diameter of segment. Single questionable male specimen with seta 3.9 times diameter of segment. Third antenna segment without basal swelling and with apical organ of two moderately long elliptical pointed pegs in shallow separate grooves, one slightly posterior to other. Apical seta Aai short, curved, and blunt, about 1/3 as long as seta Api which is slender, acuminate, and similar to seta Ape. Setae Ae, Ap, and Ai are similar, straight to slightly curved and acuminate. Setae Ae & Ap are on same level.



Figures 121-134 of female specimens of *A. texensis*. 121. Head and right antenna, with enlargement of right antennal base chaetotaxy, type specimen. 122. Apex of third antennal segment, same specimen. 123. Hind tibiotarsus, specimen from TWAS Cave, Williamson Co. 124. Fore and 125. hind foot complexes, same specimen. 126. Dorsal sixth abdominal chaetotaxy, Wurzbach Bat Cave. 127. Lateral view sixth abdominal chaetotaxy, specimen from TWAS Cave, Williamson Co. 128. Ventral sixth abdominal chaetotaxy, specimen from Wurzbach Bat Cave, Bexar Co. showing supernumerary setae. 129. Female subanal appendage, specimen from TWAS Cave, Williamson Co. 130. Inner and 131. outer face of dens, same specimen. 132. Ventral dental chaetotaxy, type specimen. 133. Mucro, type specimen. 134. Tenaculum, TWAS Cave, Williamson Co.

Fourth antennal segment with 6 subsegments and with first subsegment 2.3-2.8 as long as last. Interantennal setae with some weakly spine like forms; spinelike nature is most pronounced in setae IL 1-3 and L1. Longest setae (A1) about half as long as basal diameter of antennae. Hind tibiotarsal setae acuminate and smooth, none strikingly differentiated except slender setae in whorl 1. 3 FP setae and one supplementary seta above whorl 5. Whorls 2 & 5 with 7 setae and whorls 3 & 4 with 7 or 8. Whorl 1 with 9 setae. Setae i of whorls 2-4 paired. Hind and mid ungues with well developed tunica. Fore unguis with or without such. All ungues with clear inner tooth. Fore unguis slightly longer than hind. Unguiculi with clear apical filaments, varying greatly in length on hind unguiculus but always long on others. Fore and mid unguiculus with well developed corner tooth and hind with or without same. Fore unguiculus 1.1 to 1.3 and hind 1.0 to 1.3 times as long as corresponding unguis. Tenaculum typical of genus with posterior unpaired lobe much longer than anterior bisetaceous unpaired lobe in all save one specimen of type series where it is subequal. Dens 1.3 to 1.75 times as long as mucro. Manubrium with 6+6 dorsal setae, distal 4+4 much longer than basal 2+2. Mucro with both edges heavily serrate along entire length and without apical swelling. Dental setae L2 & L3 spinelike but small and with short apical filaments. Sixth abdominal segment with C1 seta clearly forked but not swollen. Setae C2 -C6 variable but generally lamellate. Setae D6-D10 all slender, acuminate, and similar in size. Seta B11 thickened and straight to very slightly curved. Seta E8 present and E10 distinctly longer than E11. Subanal appendage thick, straight, and rodlike with fine serrations on inner edge near the apex and at the truncate apex.

Holotype: female and five female paratypes, Haby Salamander Cave, Bandera Co. Texas, 9 September and 31 October 1984, Scott Harden Coll.
(locality nos. 6940 & 6927).

Other localities: (all from Texas) T.W.A.S. Cave, Williamson Co. 16 May 1989, Reddell & Elliott Colls. (locality no. 7138); Whirlpool Cave, Travis Co., 22 September 1988, Grimm Coll. (locality no. 7189); Wurzbach Bat Cave, Bexar Co. 25 June 1993, Reddell Coll. (locality No. 7649).

Derivatio nominis: Named after the only state where it has been found.

Remarks: This species appears to be widespread in Texas caves; however, it is rarely abundant. The forked C1 seta and female subanal appendage and the 8 fourth antennal subsegments as well as the long unguicular filaments readily separate this from other Nearctic species. It also has the unusual feature of having a B11 seta on the 6th abdominal segment much thicker than the C 11 seta. The single specimen from Bexar county had a number of supplementary setae on the venter of the 6th abdominal segment (Figure 128) and may represent a different species. Unfortunately, no males were seen except for a single male specimen from Venom Cave, Williamson Co., which was unassociated with females. It generally shares the characteristics of the species except for a very short apical filament on the third ungues and much weaker ungual tunica.

Acknowledgments

This study was made possible largely by the collections made over the years by several speleologists. We would particularly like to thank James Reddell and, most particularly, David Hubbard who collected all of the many new Virginia species. Roy Rich helped with much of this work and John Wenderoth helped in the preparation of the illustrations. Their work was supported by funds from Grinnell College. Type specimens will be deposited at the Texas Memorial Museum and the Museum of Comparative Zoology at Harvard.

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Cokendolpher, James C. and Polyak, Victor J.—Biology of the Caves at Sinkhole Flat, Eddy County, New Mexico. *Journal of Cave and Karst Studies 58*(3):181-192.

BIOLOGY OF THE CAVES AT SINKHOLE FLAT, EDDY COUNTY, NEW MEXICO

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An annotated faunal list is provided to the animals observed or collected in gypsum caves of Sinkhole Flat. Records from the literature of animals from these caves also are listed. More than 70 species are recognized and many are new to science or could not be identified because the taxonomy of that particular group is in need of taxonomic revision.

Sinkhole Flat, as the name suggests, is a region of relatively few features in southeastern New Mexico (Figure 1). There are a few arroyos and sinkholes. This study area is in the northern Chihuahuan Desert and plants are typical for this desert region which lies at about 1,000 meters elevation. The vegetation consists predominately of grasses, *Opuntia, Yucca, Larrea,* and *Acacia*. The caves at Sinkhole Flat have developed in gypsum and gypsiferous sandstone beds. Periodically, flooding during heavy rainfalls washes sand, gravel, mud, and organic debris into these caves. The larger caves apparently remain wet year-round, providing an oasis from the arid surface environment. The topography and vegetation typical of Sinkhole Flat are shown in Figures 2-3.

Until now, the gypsum caves at Sinkhole Flat have received little attention by cavers or biologists. There are only two accounts that have been published (Reddell, 1965; Barr and Reddell, 1967) and both of those reports were based upon a single trip made by James Reddell and William Russell in December 1964. Records from other caves in the region (Barr and Reddell, 1967; Elliott, 1978; Welbourn, 1976, 1978) suggest that there might be a much richer fauna at Sinkhole Flat than the 12 species documented by Barr and Reddell (1967). The flora and microbiology of caves in southeastern New Mexico have been essentially ignored until recently (Cunningham et al., 1995). Thorough studies of cave biology require extensive training, considerable time (both field and laboratory), and specialized equipment. We did not collect fungal or microbiological samples.

It is not just caves at Sinkhole Flat, but gypsum caves in general in New Mexico that have been little studied. Other than anecdotal remarks found in trip reports and mention of vertebrates, few notices of cave biology of gypsum caves have appeared. With the growing concerns about biodiversity and potential loss of faunas and floras, it is hoped that individuals who have unpublished records from New Mexico caves will make them available for others, thus reducing duplicated effort. Future studies should be directed at the gypsum caves. While these caves are generally not as attractive and respected in terms of conservation as the carbonate caves, they are refugia for unrecorded life forms.

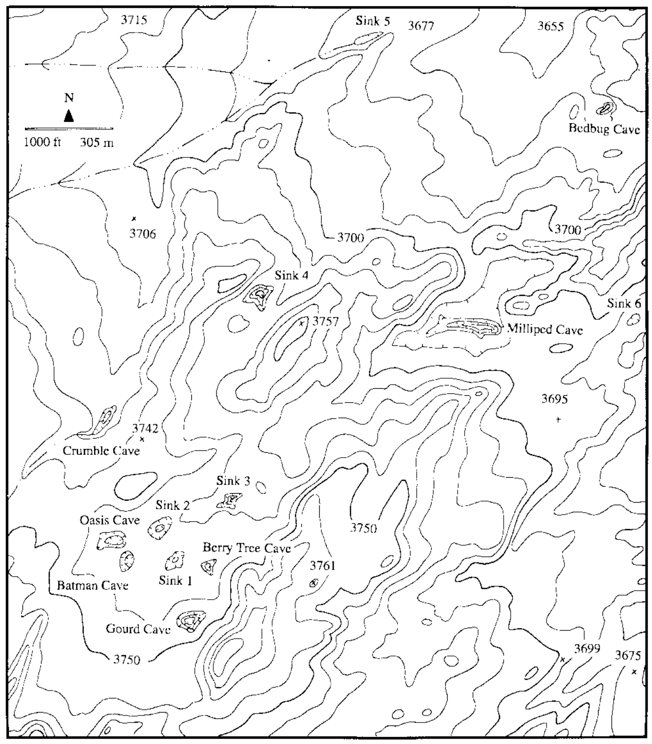

Figure 1. Location map of the drainages and sinks of Sinkhole Flat, New Mexico. The roads and other identifying structures have been excluded. Precise cave locations can be obtained from the Bureau of Land Management, Roswell, New Mexico. Elevations are in feet.

MATERIALS AND METHODS

CAVES EXAMINED

Reddell (1965) reported that there were about 15 caves at Sinkhole Flat. He did not provide a map and the precise local-

Figure 2. Victor Polyak in the upper portion of the sinkhole entrance to Bedbug Cave, showing desert vegetation typical for this area. Above.

Figure 3. The entrance of Oasis Cave is at the bottom of a sinkhole with about 5 meters of gypsum bedrock exposed from the entrance to the surface. Note the thin bed of dolomite protruding from the bluff above the cave entrance. A small intermittent stream drains into the cave. Right.

ities of the caves found can not be verified. Three of those caves examined were named in the paper by Barr and Reddell (1967): Bobcat Sink, Milliped Cave, and Sinkhole Flat Cave No. 1. Recent communications with James Reddell and Dr. Thomas C. Barr, Jr. revealed that currently neither has details on the locations of the caves. Because of the uncertainty of the precise location of their caves, Milliped Cave of Barr and Reddell (1967) will be referred to in this report as Milliped Cave-1967. In this way, records can be kept separate from the Milliped Cave named by the BLM, until the information is available to show that they are the same cave.

The majority of the land at Sinkhole Flat is public property and is administered by the US Bureau of Land Management (BLM). The collections forming this report were obtained during a contracted investigation (No. 1422G910-C2-0008) of the region for the BLM by the Lubbock Area Grotto, Lubbock, Texas. Cave exploration and specimen collections were under supervision of the BLM.

Biological material was collected in six caves: Batman Cave (BLM-NM-060-122) [the southeastern section of this cave is referred to as Whirlpool Sink (BLM-NM-060-121)], Berry Tree Cave (BLM-NM-060-125), Crumble Cave (BLM-NM-060-126), Gourd Cave (BLM-NM-060-124), Milliped Cave (informally called Barbed Wire Cave) (BLM-NM-060-123), and Oasis Cave (BLM-NM-060-120). The twilight zone of one additional cave (Bedbug Cave) on BLM property also was investigated. The cave appeared very unstable, therefore the interior was not examined. Because of the question regarding the identities of the caves, we have provided a map (Figure 1) of the region and have labeled each of the caves and sinks. Sink 1 is on BLM property and is informally called "No-Where Cave," because the cave entrance was too small for human entry. Sinks 2 through 6 were not investigated because they are on private property. We cannot state for certain that cave entrances are present because we did not examine these sinks. Also, while walking between caves we saw several small sinks without entrances that were not on the topographic maps. Precise cave locations can be obtained from the BLM, Roswell, New Mexico.

METHODS

Collection trips were made to caves at Sinkhole Flat on 6 June 1992 and 23 January 1993. Hand collections were taken during each trip. Most organisms were placed alive in 15 ml vials for transport back to Lubbock where some were photographed and observed for parasites. Notable piles of organic debris and accessible floors, walls, and ceilings were searched; some organic debris was returned to Lubbock and placed in Berlese funnels for collection of microarthropods. Pools were examined closely, but no macroscopic aquatic invertebrates were noted. Because of time constraints, baited pitfall traps were not used.

SPECIMEN DEPOSITION

Some specimens were retained in the collections of the consulting taxonomists. Other examples are in the collection of Cokendolpher, the Texas Memorial Museum, the University of Texas at Austin, and the Arthropod Museum, New Mexico State University, Las Cruces.

Results

Unique Faunas

There were no animals in the caves that are currently listed on state or federal endangered species lists. The owls are protected under federal law (Migratory Bird Treaty Act, Title16, United States Code, Section 703; and Title 50, Code of Federal Regulations, Part 10).

The only troglobites located in the caves during our study also occur in other Eddy County caves. It is possible some of the unidentified/undescribed taxa are unique to caves at Sinkhole Flat, but the current state of their taxonomies, or lack of specialists, prevents positive designations. Several of the mites and the nematode are known only from the caves at Sinkhole Flat. While this may indicate that they are restricted to the immediate region, it is more likely that this group of animals has been little sampled or studied in southeastern New Mexico.

ANNOTATED FAUNAL LIST
(Table 1)

PHYLUM NEMATODA
CLASS ADENOPHOREA
Order Mermithida
Family Mermithidae

Genus and species. A rove beetle (*Eustilicus condei*) was found dead within Crumble Cave about 46 meters from the entrance. It was under a rock and had been killed by a mermithid nematode. The emerging juvenile mermithid had in turn died and was attacked by a fungus. This is only the second known case of a rove beetle mermithid parasite and is probably undescribed. The other staphylinid mermithid was described from England. Mermithids cannot be identified accurately to genus from the juvenile stages. Living material is needed so that it can be reared to adulthood. We have also examined a juvenile mermithid from a camel cricket (*Ceuthophilus carlsbadensis*) collected in another gypsum cave (Carcass Cave, near Mesa, DeBaca County, New Mexico).

PHYLUM ANNELIDA
CLASS CLITELLATA
Order Haplotaxida
Family Enchytraeidae

Worms were encountered in the back of Milliped Cave under rocks. Most were immature, but one sample consisted of a mature worm identified as a member of either *Henlea* or *Fridericia*.

PHYLUM ARTHROPODA
CLASS ARACHNIDA
Order Araneae
Family Linyphiidae

Eperigone antraea (Crosby). Barr and Reddell (1967) noted that this small darkly colored spider showed no special morphological modifications to suggest that it was an obligate cavernicole. They listed it as a troglophile. This species was originally described from Carlsbad Cavern and has since been recorded from numerous localities in Arizona, Colorado, Texas, and Mexico. It is frequently collected in caves (Millidge, 1987) but is uncommon in caves at Sinkhole Flat. Three females were collected under rocks: two in the twilight zone of Bedbug Cave and one in the dark zone at the pit of Batman Cave.

Eperigone eschatologica (Crosby). Barr and Reddell (1967) reported this spider from Milliped Cave-1967. They stated that it was found beneath stones and suggested that it was a troglophile. Millidge (1987) records this species from numerous localities in Mexico and most of the southern U.S.A. We did not collect it during our study.

Family Dictynidae

Cicurina varians (Gertsch and Mulaik). We found this spider under rocks in the dark zones of Batman, Berry Tree, Crumble, and Oasis caves. All of the specimens obtained that were adults were smaller than adults of this species from other localities in southeastern New Mexico and central Texas. The spermathecae match those of typical *C. varians*. No males were collected at Sinkhole Flat.

Family Theridiidae

Achaearanea canionis (Chamberlin and Gertsch). Bedbug and Crumble caves are home to this comb-footed spider. We found it in small webs placed in the twilight zones of the caves. This is apparently the first record of this species from New Mexico. Levi (1955) recorded the spider from non-cave localities in California, Utah, and Arizona.

Family Nesticidae

Eidmannella pallida (Emerton). This small, irregular web-building spider was found in the dark zones of Gourd and Milliped caves. It is commonly encountered in caves of southeastern New Mexico and probably occurs in all of the larger caves at Sinkhole Flat. Elsewhere, outside of caves it has been recorded from protected sites on or in the ground. Gertsch (1984) demonstrated that this spider occurs throughout the West Indies, Central, and North America.

Family Pholcidae

Physocyclus enaulus (Crosby). Although confused with a daddy-long-legs (Opiliones) by some, this long-legged arachnid is a true spider. It is common in the entrances and twilight zones of Batman, Berry Tree, and Oasis caves. Females were collected with egg-sacs during June in Batman and Oasis

Table 1. CAVE FAUNA OF SINKHOLE FLAT

Taxa	PRESENT STUDY							BARR & REDDELL, 1967		
	Batman	Bedbug	Berry Tree	Crumble	Gourd	Milliped	Oasis	Milliped (1967)	Sinkhole Flat 1	Bobcat
Achaearanea canionis		*		*						
Agonum arizonensis							*			
Aleocharinae								*		
Amydria arizonella	*	*	*	*						
Anapleus sp.							*			
Aphodius aemulus						*				
Bakerdania quadrata							*			
Belonuchus sp.							*			
Bembidion sp.						*				
Bethylidae				*						
Bimichaelia sp.							*			
Bubo virginianus						*				
Caligonella sp.							*			
Cambala reddelli	*			*			*	*		
Ceuthophilus carlsbadensis	*		*	*	*	*	*	*		*
Ceuthophilus conicaudus	*		*	*	*		*	*		
Ceuthothrombium cavaticum	*			*			*			
Cicurina varians	*		*	*			*			
Cricetidae			*	*						
Crotalus atrox	*						*			
Dendrolaelaps sp.							*			
Dithinozercon sp.							*			
Eidmannella pallida					*	*				
Enchytraeidae						*				
Entomobrya guthriei							*			
Entomobrya sp.							*			
Eperigone antraea	*	*								
Eperigone eschatologica								*		
Epidamaeus sp.							*			
Eustilicus condei				*		*				
Galumna sp.							*			
Gemmazetes sp.							*			
Geolaelaps sp.	*									
Gymnolaelaps sp.							*			
Haematosiphon inodorus		*								
Hister sp.						*				
Histiostoma sp.				*						
Ixodes conepati		*	*	*		*		*		
Leiobunum townsendi							*			
Lithobiidae				*						
Lynx rufus										*
Macrocheles sp. 1	*			*						
Macrocheles sp. 2							*			
Mermithidae				*						
Mithostylus setosus							*			
Myotis velifer	*			*						
Nothrus sp.							*			
Onthophagus brevifrons						*				
Oppiella sp.							*			
Orus rubens	*							*		
Philonthus sp.	*	*	*			*	*			
Phthitia obunca							*			
Physocyclus enaulus	*		*				*			
Pilogalumna sp.							*			
Psyllipsocus ramburii	*		*	*						
Rhadine longicollis	*			*		*	*	*		
Rhadine sp.								*		
Sancassani sp.	*									
Scaphisoma sp.						*				
Schwieba sp.				*						
Sciaridae	*									
Scutacarus sp.							*			
Selenophorus sp.						*				
Speodesmus tuganbius	*			*		*	*	*		
Stratiolaelaps sp. 1							*			
Stratiolaelaps sp. 2							*			
Tachys proximus									*	
Trox carinatus						*				
Tydeidae	*									
Tyrophagus sp.							*			
Tyto alba		*								
Uropodidae	*									
Zygoribatula sp.							*			

caves. Its webs are often communal and are found in crevices on walls and in domes. This is a common spider in eastern Arizona, New Mexico, and the western half of Texas. It is encountered in caves, tunnels, old houses, animal burrows, and other protected sites.

Order Opiliones

Family Sclerosomatidae

Leiobunum townsendi (Weed). A single specimen was collected from a crack in the ceiling in the twilight zone of Oasis Cave. This is the long-legged opilionid of western North American caves. It also occurs outside of caves in moist protected places.

Order Acari

Acariformes

Suborder Prostigmata

Family Bimichaelidae

Bimichaelia sp. This unidentified species is relatively common outside of caves in soil and litter and does not appear to be cave-adapted. We obtained it in organic debris (mostly twigs) on the mud floor in the dark zone of Oasis Cave during June.

Family Caligonellidae

Caligonella sp. A single sample of this mite was obtained from organic debris (mostly twigs) on the mud floor in the dark of Oasis Cave during early June. This mite is probably an undescribed species, but does not appear to be cave-adapted. Additional specimens will have to be obtained for identification.

Family Neothrombiidae

Ceuthothrombium cavaticum (Robaux, Webb, and Campbell). Mites of this species were recovered from camel crickets (*Ceuthophilus carlsbadensis*) collected in both sections of Batman, Crumble, and Oasis caves. This mite probably completes its life cycle in the caves. Nymphs and adults are free living, whereas the larvae are parasitic on crickets. Robaux et al. (1977) reported this mite from the same host from Lake Cave, Carlsbad Caverns National Park. It is otherwise known from camel crickets from central Texas.

Family Pygmephoridae

Bakerdania quadrata (Ewing) [= *sellnicki* Krczal]. A single female of this species was collected from organic debris found on the mud floor of Oasis Cave during June. The mite was from the dark zone of the cave.

Family Scutacaridae

Scutacarus sp. This species was collected from organic debris found on the mud floor of Oasis Cave during June. A single female was collected from the dark zone of the cave. This is apparently the only known locality for this species and is probably undescribed.

Family Tydeidae

Genus and species. Berlese funnel extraction of bat guano revealed the presence of this mite in Batman Cave. It was found in the dark about 30 meters from the entrance.

Suborder Oribatida

Family Damaeidae

Epidamaeus sp. Mites of this species were obtained in the dark zone of Oasis Cave during June. It was in organic debris (mostly twigs) on the mud floor.

Family Galumnidae

Galumna sp. These oribatid mites were obtained in the dark zone of Oasis Cave during June. It was in organic debris (mostly twigs) on the mud floor.

Pilogalumna sp. Specimens of this species were obtained in the dark zone of Oasis Cave during June. It was in organic debris (mostly twigs) on the mud floor.

Family Oppiidae

Oppiella sp. This species was obtained in the dark zone of Oasis Cave during June. It was in organic debris (mostly twigs) on the mud floor. This taxon appears closely related to *O. nova* (Oudemans), a widely-ranging species found throughout the world.

Family Oributulidae

Zygoribatula sp. We obtained this species in the dark zone of Oasis Cave during June. It was in organic debris (mostly twigs) on the mud floor. This species is a member of the *fusca* species group.

Family Nothridae

Nothrus sp. This species is near *N. silvicus* Jacot, which is known only from Indiana. It was obtained in the dark zone of Oasis Cave during June and was found in organic debris (mostly twigs) on the mud floor.

Family Thyrisomidae

Gemmazetes sp. The dark zone of Oasis Cave is home to this mite. It was found in organic debris (mostly twigs) on the mud floor during June. This mite is related to *G. cavaticus* Kunst, which was described from bat guano in Europe.

Suborder Astigmata

Family Acaridae

Schwiebea sp. *Cambala reddelli* millipeds maintained in the laboratory were infested with these mites. Because the millipeds were collected from several caves at Sinkhole Flat, it can not be determined for certain from which specific cave this acarid originated. This species of milliped is very abundant in and around the edges of pools in Crumble Cave, therefore it is likely that the mites originated there. In captivity, the mites flourished and became so numerous that they killed the millipeds. This is an undescribed mite belonging to a group of species that inhabit very wet (including fully aquatic) habitats. Sinkhole Flat is apparently the only known locality for this species. The culture was also infested with a few deutonymphs of *Histiostoma* mites.

Tyrophagus sp. Males are needed for species identification in this genus. We have only females. The species is probably *similis* or *molitor*, both of which are litter inhabitants. Our collections were obtained during June in the dark and were from organic debris (twigs mostly) on the mud floor of Oasis Cave.

Sancassania sp. One series of deutonymphs (phoretic/resistant stage) was obtained from a Berlese funnel extraction of bat guano from Batman Cave during January. The sample was from the dark zone about 30 meters from the entrance. Species identification in this genus is extremely difficult due to the large variations in body size coupled with polymorphisms. There is a new species of this genus known from all life stages from Carlsbad Cavern. It is uncertain if it is the same as the species at Sinkhole Flat, because only one life stage of the latter is known. We have also collected deutonymphs of a *Sancassania* sp. in bat guano from a gypsum cave in northwestern Texas (River Styx Cave).

Family Histiostomatidae (= Anoetidae)

Histiostoma sp. *Cambala reddelli* millipeds maintained in the laboratory were infested with a few deutonymphs of this mite. Because the millipeds were collected from several caves at Sinkhole Flat, it can not be determined for certain from which specific cave these mites originated. This is a very large genus, with numerous North American species. This one likely represents an undescribed species.

Parasitiformes

Suborder Mesostigmata

Family Digamasellidae

Dendrolaelaps sp. This mite was collected from the dark zone of Oasis Cave during June. It was taken from a Berlese funnel extraction of organic debris (mostly twigs) found on the mud floor of the cave. This probably undescribed species is a member of the *sellnicki* species group.

Family Dithinozerconidae

Dithinozercon sp. This apparently undescribed mite was taken from organic debris (mostly twigs) on the mud floor of Oasis Cave and was identified as an undescribed species near *halberti* Berlese. Johnston (1961) reported an undescribed species of *Dithinozercon* from New Mexico (no specific locality mentioned). It is uncertain if it is the same species as that collected from Oasis Cave because Johnston did not provide a description of his specimens.

Family Laelapidae

Geolaelaps sp. Specimens of this species were obtained from bat guano found about 30 meters from the entrance to Batman Cave in the dark. The sample was obtained in January.

Gymnolaelaps sp. A mite of this apparently undescribed species was collected from organic debris (mostly twigs) found on the mud floor of Oasis Cave during June. This sample was from the dark portion of the cave. This is the only locality known for this species.

Stratiolaelaps sp. 1. Mites of this apparently undescribed species were collected in the dark, in an organic mat lodged in a crack on the wall about 2 meters off the floor in Oasis Cave. This sample was obtained during June and this is the only locality known for this species.

Stratiolaelaps sp. 2. This apparently undescribed species of mite was collected from organic debris (mostly twigs) found on the mud floor of Oasis Cave. This sample was obtained in the dark during June. This is the only locality known for this species.

Family Macrochelidae

Macrocheles sp. 1. Specimens collected from bat guano in Batman and Crumble caves during January were identified as an undescribed species near *M. mesochthonius* Krantz and Whitaker. This latter mite is known from the midwestern USA to the northwestern mountain states where it is found associated with ground squirrels, mice, and opossums (Krantz and Whitaker, 1988). The mite from Batman and Crumble caves is known with certainty only from those caves, but a similar (possibly the same species) mite has been collected from bat guano in River Styx Cave in northwestern Texas. The Texas locality also is from a gypsum cave.

Macrocheles sp. 2. This mite was collected from organic debris (mostly twigs) on the mud floor of Oasis Cave and identified as an undescribed species of the *muscaedomesticae* species group, close to *M. muscaedomesticae* (Scopoli). As the name implies, this latter species is known (phoretic association) from house flies. It is cosmopolitan in distribution and also is known from associations with other flies, coprophagous

Figure 4. This *Ixodes conepati* tick was found in Bedbug Cave. Numerous other specimens were recovered from cavers exiting other caves. This species of tick is primarily parasitic on skunks and other small mammals. It is not known to carry any human diseases.

beetles, and varied vertebrate taxa (Krantz and Whitaker, 1988). The undescribed species of mite is known only from Oasis Cave.

Family Uropodidae

Genus and species. A single series of mites of this species were collected from a Berlese sample of bat guano from Batman Cave. The sample was obtained in the dark about 30 meters from the entrance to the cave during January.

Suborder Metastigmata
Family Ixodidae

Ixodes (*Pholeoixodes*) *conepati* Cooley and Kohls in Cooley (Figure 4). Barr and Reddell (1967) reported that this tick was parasitic on skunks and other mammals and suggested that it was an accidental visitor to the caves. Kohls and Clifford (1966) reported this species from Milliped Cave-1967. We found it in the twilight zones and on exiting cavers from Bedbug, Berry Tree, Crumble, and Milliped caves. We also have a female and nymph collected from cavers exiting Carcass Cave, near Mesa, DeBaca County, New Mexico during February. This tick has been recorded from Eddy County in New Mexico and from numerous counties in Texas (Kohls and Clifford, 1966; Keirans and Clifford, 1974). Also we have seen it in Carcass Cave (see above) during February. This species was described originally from a cave in Comal County, Texas (Cooley and Kohls, 1943).

CLASS CHILOPODA
Order Lithobiida
Family Lithobiidae

Genus and species. (Figure 5). A single specimen was collected under a rock about 12 meters inside of Crumble Cave. This area of the cave is just past the twilight zone. Members of this family are in need of taxonomic revision.

CLASS DIPLOPODA
Order Polydesmida
Family Polydesmidae

Speodesmus tuganbius (Chamberlin) (Figure 6). Chamberlin (1952) originally described this species from Carlsbad Cavern. Barr and Reddell (1967) reported that this species (as *Speorthus tuganbius*) was extremely abundant along silt banks throughout the length of Milliped Cave-1967. This species is known from numerous caves in southeastern New Mexico and extreme western Texas (Shear, 1974; Barr and Reddell, 1967). We found this small white milliped relatively abundant in Batman, Crumble, Milliped, and Oasis caves. This cave-adapted milliped easily desiccates and is most often obtained from dark, muddy areas in the caves. One specimen was found under a rock in the twilight zone. We have seen numerous specimens collected in two other gypsum caves from near Mesa, New Mexico (Carcass Cave, DeBaca County and Flat Rock Cave, Chavez County).

Figure 5. Lithobiid centipedes are common surface inhabitants. This specimen was in the dark zone of Crumble Cave. Because the taxonomy of this group is in need of revision, we are unable to determine if the species is described. It does not show any remarkable cave adaptations and is probably an accidental visitor to the cave.

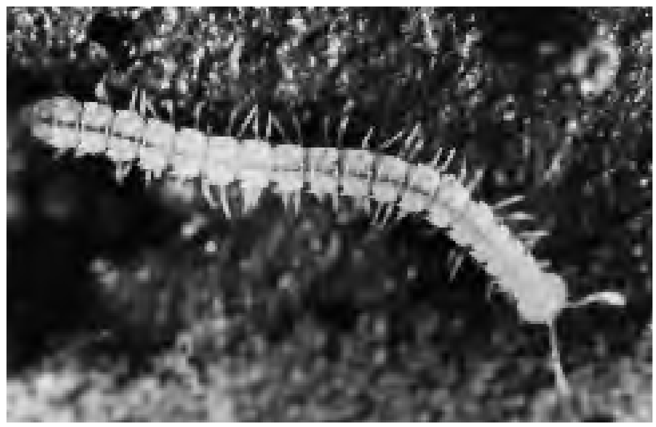

Figure 6. The small white milliped *Speodesmus tuganbius* is probably the most cave-adapted animal at Sinkhole Flat.

Order Spirostreptida
Family Cambalidae

Cambala reddelli (Causey). This milliped was reported by Barr and Reddell (1967) from Milliped Cave-1967 where it was found on organic debris on silt banks. It is common in the larger caves at Sinkhole Flat that retain muddy areas, especially Crumble Cave where the millipeds were on the mud banks and walking in the pools (completely submerged). All specimens were taken in the dark zone from both sections of Batman, Crumble, and Oasis caves. It is surprising that we did not obtain specimens in Milliped Cave. This species is known also from western Texas and a few other localities in New Mexico. Some millipeds from Sinkhole Flat caves that were maintained in a laboratory culture were killed by an outbreak of phoretic deutonymphs of acarid mites. The mites were so numerous that the millipeds could not move or feed. In captivity, the millipeds burrowed in the wet to damp soil and were seldom on the surface. Entrances to their burrows are about a millimeter in diameter and lack surrounding piles of soil.

Burrow entrances are unremarkable and probably have been overlooked by other biologists. It is unknown what portion of the population in a cave is actually seen walking on the surface of the muds/soil.

CLASS PARAINSECTA
Order Collembola
Family Entomobryidae

Entomobrya (Entomobrya) sp. *Entomobrya* is a large complex genus in need of taxonomic revision and consequently this species cannot be identified at this time. The specimens were obtained from a pile of debris (mostly twigs) on a muddy floor in the back of Oasis Cave.

*Entomobrya (Entomobryoides) guthriei (*Mills). Springtails were collected in the back of Oasis Cave in a mat of organic material lodged in a crack about two meters off the floor. This species is found throughout most of the western U.S.A. and is known from a few scattered localities in the eastern half.

CLASS INSECTA
Order Psocoptera
Family Psyllipsocidae

Psyllipsocus ramburii (Sélys-Longschamps). Numerous specimens of this species were collected from 9-30 meters inside Batman, Berry Tree, and Crumble caves during January. Specimens were most numerous on bat guano and in small piles of organic debris that were washed into the caves and carried in by rats. All were from areas of total darkness. None were seen on the collection trip during June. Barr and Reddell (1967) reported that it was a troglophile. Unlike most troglophiles this animal feeds on rather dry organic matter in the caves. Mockford (1993) reported that this species has been found in caves, cellars, shaded rock outcrops, and occasionally on stored collections of insects. This is a widespread species occurring throughout Europe, USA, and many other parts of the world where human commerce has introduced it.
Order Orthoptera

Family Rhaphidophoridae

Ceuthophilus carlsbadensis Caudell (Figure 7). Barr and Reddell (1967) reported this camel cricket from Bobcat Sink and Milliped Cave-1967. They indicated that it also was taken outside of the entrance to Bobcat Sink in December and considered it a trogloxene or facultative troglophile. We collected this species from Batman (including Whirlpool Sink section), Berry Tree, Crumble, Gourd, Milliped, and Oasis caves. Specimens were obtained during this study from throughout the caves. Individuals were generally found in the dark zones and did not clump in small groups like the following species. This cricket is known from caves in Eddy County, New Mexico and Culberson, Brewster, and Jeff Davis counties in Texas. We have seen a specimen of this species parasitized by a mermithid nematode that was collected in another gypsum cave (Carcass Cave, near Mesa, DeBaca County, New Mexico).

Figure 7. This darkly colored cricket (*Ceuthophilus carlsbadensis*) is a common resident of many of the caves at Sinkhole Flat. This cricket is generally seen as it roams around the floor of the cave.

Figure 8. This cricket (*Ceuthophilus conicaudus*) is lightly colored and generally will be found in clumps of similar crickets. It is especially common in small domes where it will be found hanging up-side-down.

Ceuthophilus conicaudus Hubbell (Figure 8). This camel cricket is considered to be a trogloxene. It was reported by Barr and Reddell (1967) from Milliped Cave-1967. They stated that this cricket leaves caves in considerable numbers during the summer nights. It is most often found clumped in domes near the entrance, but can be found throughout the caves. We collected this species from Batman (including Whirlpool Sink section), Berry Tree, Crumble, Gourd, and Oasis caves. This cricket has essentially the same range as the preceding species in New Mexico and Texas.

Order Diptera
Family Sphaeroceridae

Phthitia obunca (Marshall). A single fly of this small species was taken 2 meters from the entrance of Oasis Cave in the twilight zone. It was on the floor during June. This species is otherwise known from surface habitats in California to New Mexico and Utah. The only previous New Mexico record was from S. Baldy Peak in Soccoro County (Marshall and Smith, 1992).

Family Sciaridae

Bradysia sp. Two dark-winged fungus gnats were obtained in the Whirlpool section of Batman Cave. They were found on the wall in the dark zone. Members of this genus cannot be identified at present as the genus is in need of taxonomic revision.

Order Hymenoptera
Family Bethylidae

Genus and species. An unidentified wasp was collected about 30 meters from the entrance to Crumble Cave in the dark zone. It was recovered from a Berlese sample of crumbled wood. The specimen was probably an accidental visitor to the cave. Members of this family parasitize beetles and microlepidoptera.

Order Hemiptera
Family Cimicidae

Haematosiphon inodorus (Duges). Members of this bedbug were found in the entrance and twilight zones of Bedbug Cave in June. Skeletons of owls as well as obvious roosts were evident in the cave entrances. Bedbugs were on the floor and walls. This species is reported elsewhere as feeding on owls, eagles, and the California Condor as well as chickens. It is recorded from Oklahoma and Texas west to California in the USA (Usinger, 1966).

Order Coleoptera
Family Staphylinidae

Orus (Leucorus) rubens (Casey). Herman (1965) reported this troglophile from organic debris in Milliped Cave-1967. It is otherwise known from caves in central Texas. We collected a single female presumably of this species (males are needed for positive identification) under a rock in the pit of Batman Cave.

Belonuchus sp. We collected two specimens of this species in Oasis Cave and one specimen in Batman Cave. This is the first report of this genus from a cave in southeastern New Mexico. One of the specimens from Oasis Cave was on a rock next to a pool in the dark zone, whereas the second was in the twilight zone on the cave floor. The specimen from Batman Cave was on bat guano in the dark zone.

Philonthus sp. (Figure 9). This troglophilic rove beetle was reported from gypsum caves in southeastern New Mexico and western Texas by Barr and Reddell (1967). It also is known

Figure 9. This rove beetle *Philonthus sp.* was obtained in Berry Tree Cave. It is easily distinguished from the other rove beetles in the caves by having the abdomen entirely black.

from caves in central Texas. We found it to be relatively common in Milliped Cave. It was also observed in the Whirlpool section of Batman, Berry Tree, Oasis, and Bedbug caves. Samples from caves at Sinkhole Flat were taken at various sites from the twilight zones near the entrances to dark sections about 90 meters from the entrance. We are aware of another collection in a gypsum cave from Chavez County, New Mexico (Flat Rock Cave, near Mesa).

Eustilicus condei (Jarrige). Barr and Reddell (1967) recorded this troglophile as *Stilicolina condei* from Milliped Cave-1967 and Sinkhole Flat Cave No. 1. It is recorded from caves throughout Texas. A specimen of this beetle was found dead about 45 meters from the entrance in Crumble Cave in January. It was under a rock and had been killed by a mermithid nematode. This species of beetle was also found in the back of Milliped Cave near a pile of twigs which had washed into the cave.

Subfamily Aleocharinae

Genus and species. Barr and Reddell (1967) reported a species of this subfamily from Milliped Cave-1967; it was not collected in the present study. The taxonomy of this subfamily is in need of study. Until that time, a definitive identification can not be made.

Family Curculionidae

Mitostylus setosus (Sharp). The specimen of this weevil was collected in the back of Oasis Cave.

Family Carabidae

Agonum arizonensis (Horn). This species was collected in the dark zone among rocks found on the floor of Oasis Cave.

Bembidion sp. Ground beetles were found under rocks on the mud floor in the dark zone of Milliped Cave. They were collected on both visits to the cave. This species is a member of the *grapel* species group.

Rhadine longicollis (Benedict). Examples of this troglophilic beetle were recorded from Milliped Cave-1967 by Barr and Reddell (1967). We collected it in Milliped Cave, Crumble Cave, Oasis Cave, and the Whirlpool Sink section of Batman Cave. It is primarily found in the dark zone, but it was collected throughout the cave including the twilight and entrance zones. This beetle is known only from caves (both gypsum and limestone) near Carlsbad and Artesia in New Mexico and in Culberson County, Texas.

Rhadine sp. Barr and Reddell (1967) stated that they had an apparently undescribed troglophilic species from Milliped Cave-1967. It was reported to have been found running along a silt bank. This beetle is otherwise known only from Beetle Cave which is a gypsum cave about 8 km east of Artesia, New Mexico. Barr stated in a recent letter that the new species belongs in the *dissecta* species group.

Selenophorus sp. We found this ground beetle on the mud floor in the dark zone of Milliped Cave. There are many species of *Selenophorus* in North America and the state of the taxonomy of the group does not permit a specific identification at this point.

Tachys proximus (Say). This troglophile was reported by Barr and Reddell (1967) from organic material in Sinkhole Flat Cave No. 1. It is reported to be a common beetle in caves of central Texas and northern Coahuila, Mexico. It was not collected during the present study.

Family Histeridae

Hister sp. A single specimen of this beetle was collected on a rock in the dark zone near the twilight zone in Milliped Cave. Adults of other *Hister* sp. are recorded from carrion, in fungi, and in mammal burrows (Arnett, 1971).

Anapleus sp. This clown beetle was in a pile of debris (twigs mostly) on the mud floor in the dark zone of Oasis Cave.

Family Scaphidiidae

Scaphisoma sp. This shining fungus beetle was taken from the ceiling in the twilight zone of Milliped Cave. This genus contains numerous species and an authoritative identification is not possible at this time. Other members of this family are recorded to live in fungus, rotten wood, dead leaves, and under the bark of logs (Arnett, 1971).

Family Scarabaeidae

Aphodius aemulus (Horn). Examples of this beetle species were collected under a rock and on a mud floor in Milliped Cave. Other members of this genus are known to live in burrows of gophers and prairie dogs (Arnett, 1971).

Onthophagus brevifrons (Horn). This scarab beetle was taken at the twilight/dark junction on the wall of Milliped Cave.

Trox carinatus Loomis. A single scarab beetle of this species was taken at the twilight/dark junction on the wall of Milliped Cave. It is otherwise known only from Texas. Other members of this genus are known from vulture and owl nests (Arnett, 1971).

Figure 10. The guano moth (*Amydria arizonella*) was seen fluttering in the dark of several of the caves in Sinkhole Flat. This specimen was photographed in Batman Cave.

Order Lepidoptera
Family Tineidae

Amydria arizonella Dietz (Figure 10). This troglophilic guano moth was collected in Batman, Bedbug, Berry Tree, and Crumble caves. It was found only in the dark portions and was often seen flying near guano piles. Davis (1972) reported that this was one of the most common species of moths to be found in USA caves and was especially abundant in Bat Cave at Carlsbad Cavern. It ranges over much of the southern portion of the country and has often been taken from surface habitats. Davis (1972) suggested that it is a facultative troglophile, living in nests of various mammals when not occurring in caves.

PHYLUM CHORDATA
CLASS AVES
Order Strigiformes
Family Strigidae

Bubo virginianus (Gmelin), Great Horned Owl. Although a nest was not observed, four young birds were seen exiting the cliff near the upper entrance to Milliped Cave. This owl is known throughout most of the USA.

Family Tytonidae

Tyto alba (Scopoli), Barn Owl. Owls roost in the entrance to Bedbug Cave and several skeletons of this bird were noted in the entrance zone of the cave. This species has been observed in caves in Culberson County, Texas.

CLASS MAMMALIA
Order Rodentia
Family Cricetidae

Genus and species. We observed nests of rodents in Berry Tree and Crumble Caves but never saw the animals so that a

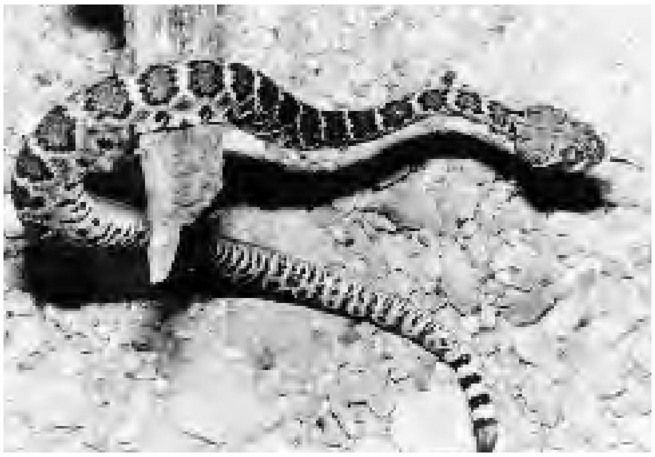

Figure 11. The Western Diamondback Rattlesnake (*Crotalus atrox*) has been observed in several of the Sinkhole Flat caves. This young specimen was photographed inside of Batman Cave during January. Even though it was winter, the animal was able to move and strike.

specific identification could not be made. The rodents in Crumble Cave were particularly adept at carrying cactus thorns into the cave, a fact which was painfully discovered by almost everyone crawling through that cave.

Order Carnivora
Family Felidae

Lynx rufus (Schreber), Bobcat. Barr and Reddell (1967) named one of the caves they visited at Sinkhole Flat as Bobcat Sink. They did not state why this was done, but a recent conversation with James Reddell revealed that a bobcat was seen in the cave. We did not see any bobcats during our visits. A bobcat has also been observed in Wildcat Cave (a gypsum cave), Culberson County, Texas (Barr and Reddell, 1967).

Order Chiroptera
Family Vespertilionidae

Myotis velifer (Allen), Cave Myotis. On 6 June, a bat nursery in Batman Cave was disturbed. The party quickly exited the cave as bats ladened with young were flying into the investigators. Returning that evening, an estimated (very rough estimate) 10,000 bats exited the cave. Batman Cave connects with Whirlpool Sink. The odor of bat guano is strong at the entrance to Whirlpool Sink, but no bats were observed exiting the sink. Bats apparently do not overwinter in any of the caves. Large piles of guano were discovered in Crumble Cave during January, indicating that it, too, houses a large bat nursery. This cave was not visited in June. Other bats may be present in the cave, but we did not want to disturb the nursery.

CLASS REPTILIA
Order Squamata
Family Viperidae

Crotalus atrox (Baird and Girard, Western Diamondback Rattlesnake (Figure 11)). The only snakes observed in the caves at Sinkhole Flat were rattlesnakes. They were seen in the entrances of Batman Cave (January) and Oasis Cave (June). The Western Diamondback Rattlesnake occurs from Arkansas to California and adjacent regions in Mexico.

Discussion

The ages of these caves are unknown, however, they probably formed during the Pleistocene Epoch (glaciation) and the Holocene Epoch (post glaciation). Little has been reported regarding the age of gypsum caves in the southwestern United States. Minimum ages might be determined from sediments and speleothems, but such studies are lacking.

Some of the caves of Sinkhole Flat could be as young as the Holocene. Similar-sized gypsum caves along the western edge of the ~5,000 years old (Salyards, 1991) Little Black Peak basalt flows in central New Mexico have probably formed during the Holocene. The surface archeology indicates that human occupation of the area immediately surrounding the caves at Sinkhole Flat goes back about 7,000 years (Polyak and Cokendolpher, 1996). This only indicates that the Sinkhole Flat cave area was present at that time, assuming that the archeological evidence is linked directly to the caves. The gypsum caves of Sinkhole Flat formed relatively fast and are probably short-lived. They form along or within surface drainage systems and probably migrate with the denundation of the region wherever the soluble Permian gypsum units crop out. olde As one cave collapses or fills with sediment, another forms nearby. The cave complex, therefore, probably is older than the individual caves.

Continual introduction of surface invertebrates by periodic flooding and by larger animals possibly hinders the development of troglobitic species in these caves. The large number of species of mites noted in this study reflects the lack of published detailed studies, the periodic flooding events that wash soils and organic debris into the caves, and possibly isolation due to climatic change.

Results of this study suggest three areas that should be topics for future studies: (1) The summer bat colonies at Batman and Crumble caves should be investigated to determine if more than one species is present. (2) Extensive Berlese funnel samples and baited pitfall traps should be taken in the larger caves to look for small, rare taxa not encountered in this study (e.g., Milliped, Batman, Crumble, and Oasis caves). (3) More material of some of the taxa collected in this study should be obtained, especially the worms, mermithid nematode, and mites.

Acknowledgments

We thank the following people who helped with the collections: D. Dennison, J. Dossett, R. Harbuck, V. Hildreth, C. Holsey, B. Johnson, B. Lee, A. MacDowell, G. Reese, B. Shannon, and T. So. We are grateful for their work under less than enjoyable conditions and for their companionship in the remote camps of Sinkhole Flat.

Verifications or identifications could not have been made without the aid of numerous specialists to whom we are grateful. Additionally, J. Reddell kindly provided advice and information on cave faunas of the region and commented on an early draft of the manuscript. The taxonomists who aided this project are: Y. Bousquat (ground beetles); K.A. Christianson (springtails); K.A. Coates (worms); T.J. Cohn (camel crickets); D.R. Davis (moths); R. J. Gagné (sciarid flies); L. Herman (rove beetles); A.T. Howden (weevils), H.F. Howden (scarab beetles); P. Hunter (laelapid mites); G.W. Krantz Oregon (macrochelid and laelapid mites); E.E. Lindquist (digamasellid, pygmephorid, scutacarid mites); E. Mockford (psocids); A.L. Norrbom, (sphaerocerid flies); R.A. Norton (general mites and oribatid mites); B.M. O'Connor (acarid and histiostoimatid mites); R.G. Robbins (ticks); L. Strange (wasp); G.O. Poinar, Jr. (nematodes); W.A. Shear (millipeds); L. Subias (oppiid mites); S.B. Peck, (assorted beetles); C. Welbourn (caligonellid and bimichaelid mites). Generally only one or a few examples of each species were mailed for verification or identification. Fred Stangl kindly verified the bat identification from photographs made at Batman Cave.

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COMMENT ON EXTREMELY LOW FREQUENCY RADIO EMISSIONS IN BAT CAVES

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After reading the article Extremely Low Frequency Radio Emissions in Bat Caves (Koemel, 1996) I felt compelled to write to highlight several problems and questions that this article raised in my mind. These center primarily around the methods used for the data observation and the conclusions that this article purports as well as why the article was not challenged more vigorously before publication.

DISCUSSION OF THE METHODS USED

In a scientific data collection process one of the objectives is to distinguish the data being collected from noise that is inherent in the system collecting the data. No efforts were really made in this article to establish the noise floor of the system being used. There are several simple experiments that could be performed to establish what signals are data and what is the noise level of the system. For instance, if the recording apparatus were operated in an electrically shielded room such as a metal screen room used for EMI and RFI testing, then a baseline could be established for the recording system.

To perhaps demonstrate the low frequency radio emissions of bats even better than the data presented in the article, a bat could be introduced into the screen room test. This would maximize the signal to noise ratio possible for this recording system and help further characterize the emissions that have been observed.

Another concern with the methods used is the process of tape recording the data logging sessions. Using a wide band receiver is certainly a good idea for this type of investigation. However, the signal seems to be bandwidth limited to the device hooked to the output of the receiver. Either 18kHz when the earphones are used, or by the tape recorder when it is used. High fidelity tape recorders could perhaps get to 15kHz or so, but most portable recorders that I have seen (and most likely used for the field work) would not have a bandwidth much beyond 5-6kHz. Nothing in the article discusses the type of recorder or tape that was being used even though they probably are the devices limiting system bandwidth. Again, a screen room test with and without the tape recorder would help establish what it might add to the system noise figure.

Even though the graphs presented in the article make up half the printed space, they represent a total of less than one half second of data. In some cases there is clear evidence of signal information, but in several cases I am not convinced that the signal presented is not a transient from an unknown source. A correlation study of many signals of the same suspected source would perhaps be in order, or an observer recording bat flights and correlating these to a longer-term signal recording might prove informative.

All these suggestions are not to say that I don't think bats emit low frequency radio emissions, in fact I think they probably do. My concern is that by making several more simple observations and presenting data in a different way the case for these emissions could be made much stronger.

DISCUSSION OF CONCLUSIONS

Which brings me to the other topic that I would like to discuss. The title of the article and all of the information presented concern low frequency radio emissions, then when Mr. Koemel reaches his conclusion section he makes four conclusions that I have a hard time relating to the rest of the article in any way. On top of that he fails to address the low frequency radio emissions from bats which I was led to believe was the point of the article in the first place.

First, concluding that bats can detect atmospheric weather conditions from inside a cave is a far stretch from the data presented. Granted, the apparatus used to collect data may be able to detect weather conditions and bats indeed may be able to detect weather conditions, but nowhere is the behavior of bats in different weather conditions discussed in this article except for this conclusion statement.

Second, bats may be affected by 60Hz ground return currents in caves. Again, this may very well be the case, but how does any of the body of this article support this conclusion? I have to repeat, nowhere is the behavior of bats under different conditions presented in this article.

Third, how is the use of the VLF emissions for predation and location of young arrived at by the author? Were the emissions that were observed always just before the bat captured an insect or in the presence of young bats? At best, I think that Mr. Koemel could conclude that bats emit VLF radio signals, but the purpose of these emissions I believe is still more speculation than conclusion and should be stated that way.

Fourth, concluding that bats can locate a cave entrance in the dark because they can orient themselves to the earth's magnetic field is again not supported in this article. I think that Mr. Koemel's observation that bats spiral in different directions in different hemispheres is very interesting and worth further investigation. However, water spirals down a drain in different directions in different hemispheres because of gravity, friction, and the rotation of the earth, not magnetic field. Maybe other forces are at work on bats too. The leap is then made to conclude that this magnetic orientation talent helps bats with cave entrance location. I again didn't find any discussion of bat navigation in the article or how the ability of bats to locate entrances was observed by Mr. Koemel.

SUMMARY

There are two areas of improvement that I would like to suggest. First is the referee process for the *Journal of Caves and Karst Studies* and second is the methodology and conclusions presented by Mr. Koemel. It is my opinion that the referees that reviewed this article should have caught this article in the "quality" filter before it was published to maintain the high standards that the *Journal* is trying to achieve. With the appropriate presentation of the information that Mr. Koemel has collected I think there is a very fascinating conclusion lurking in the article. However, the conclusions that Mr. Koemel presented detract greatly from the message contained in the methods and results of the article.

REPLY TO COMMENT ON EXTREMELY LOW FREQUENCY RADIO EMISSIONS IN BAT CAVES

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First, I want to thank Mr. Withrow for having enough interest to read my paper and consider the observations. In essence, my paper says, "Please consider these things in your research."

Obviously, Withrow did not build a copy of my wideband radio receiver as fully described in Koemel and Callahan (1994). If he had, he would know its noise floor is at zero (dead silent). In 1983, I corresponded with W.R. Intosh (Mr. Computer) concerning this instrument. This instrument was thoroughly tested before 1994. The observed frequencies are well within the limits of the cassette tape recorders mentioned by Withrow.

I want bat researchers to introduce a bat into a Faraday cage (screen room) to study this phenomenon further. Bats might produce radio frequencies far above the observed frequencies. The Wright brothers were the first to fly, but they did not fly coast to coast, or break the sound barrier on their first flights!

The oscilloscope prints in this paper represent recordings containing many 2000 to 3500 Hz radio pulses from each of several caves. The figures are not graphs, but actual oscilloscope displays from a digital computer oscilloscope. They contain more information than can be printed in words in the same space. For example, figure 4 (Koemel, 1996) shows a decaying 2000 Hz pulse from an unknown source in a moonlit sky. All the signals from the earth were electrically shielded out. The 2000 Hz pulse is shown from 0-10 ms. The rest of the display shows background noise from 15-50 ms. Figure 5 shows radio emissions near the ceiling of Mason Bat Cave with no evidence of 60 Hz. This cave is very small with a very prolific bat population. This contrasts greatly with figure 7 which shows a strong 60 Hz emission near the ceiling of Lair Cave. Lair Cave is of similar size, but has a sparse diminishing bat population. Please compare the presence of 60 Hz in caves with diminished bat populations and diseases. Figure 8 shows a 2500 Hz pulse between 15 and 20 ms. The rest of the display shows background noise. Figure 9 shows a 2000 Hz pulse between 45 and 50 ms. The rest of the display shows background noise. Figure 1 shows static spikes from rain clouds near Mason Bat Cave. This shows the radio pulses produced by bats are different from atmospheric discharges. The observations made in the entrance to Carlsbad Cavern were made before and during the bat flight. The 2000 Hz pulses were not present before the bat flight.

Page 35, paragraph 7 (Koemel, 1996) contains the preliminary data about radio pulses produced by flying bats. Please do more research that relates to this data. I showed that different weather conditions produce different ELF radio spectra. These ELF signals can be observed inside the cave. Ask any bat researcher how he bats know when to fly or when not to fly out from the cave when atmospheric conditions inside the cave are very different from atmospheric conditions outside. Bat flights are totally unpredictable in relation to sunset or time. The conclusion will be obvious.

It is not gravity and friction that causes hurricanes to rotate counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere. Ben Franklin demonstrated that a flow of electrons will move air.

Let's search for a magnetic anomaly. Manta rays and honey bees use magnetic field lines as references when they return to their nest. Why not bats? If one moves a beehive three meters after some of the worker bees go out to forage, the honey bees follow an invisible, unscented reference while returning to the beehive. They return to the original hive site. They have difficulty finding the new hive site even though it is only 3 meters away and clearly visible with the scent of the queen bee inside.

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CAVE SCIENCE NEWS

NEW LIFE SCIENCES EDITOR APPOINTED

The *Journal of Cave and Karst Studies* welcomes Dr. David Ashley as our new Associate Editor for Life Sciences. Ashley is a Professor of Biology at Missouri Western State College in St. Joseph, Missouri and holds a Ph.D. in Life Sciences from the University of Nebraska in Lincoln. He is a Regional Vice President for Beta Beta Beta, the National Biology Honor Society, and a fellow in the Missouri Academy of Science.

Ashley serves on the Board of Directors and the Research Council of the Missouri Speleological Survey, Inc. He pursues an interest in cave ecology and has published papers about webworms, snails, coliform, and general ecology in Missouri caves. In addition to various speleological publications, his papers have been published in *Journal of Parasitology, Ohio Journal of Science, The Science Teacher, Journal of the American Veterinary Association,* and *American Journal of Veterinary Research.*

MEDVILLE JOINS JOURNAL STAFF

The *Journal of Cave and Karst Studies* is pleased to announced that Douglas M. Medville has joined the Editorial Board as Associate Editor for Exploration. Medville is well-known in cave exploration circles and received the Lew Bicking Award in 1971. The Lew Bicking Award is given for outstanding lifetime achievement in cave exploration. The NSS also presented Medville with an Outstanding Service Award in 1993.

Medville recently retired from a 26-year career with The MITRE Corporation in McLean, Virginia as a manager and industrial engineer. He now devotes nearly full-time caving-related projects in Virginia, Colorado, and Hawaii.

During his professional career, Medville frequently wrote and editted technical reports and articles as well as presented conference papers. He has also been principle author for three articles in the *Journal's* predecessor, the *NSS Bulletin*. His most recent contribution was "Structural and stratigraphic influence on the development of solution conduits in the Upper Elk River Valley, West Virginia", co-authored with Bill Storage.

GSA FEATURES TWO CAVE-RELATED SESSIONS

The annual meeting of the Geological Society of America held in Denver, Colorado in late October featured two sessions involving caves. The Archaeological Geology Division hosted a symposium on "Geoarchaeology of Caves and Cave Sediments." The fifteen minute presentaions covered a broad range of topics and cave types including Maya utilization of resources in extensive caves in Central America to mechanisms of rockfall in shallow sandstone shelters in the midwestern US.

A paper presented by B.A.B. Blackwell described a leg bone of an ancient, juvenile cave bear with four precisely drilled holes. The artifact was closely associated with a hearth and other tools in a Slovenia cave. The paper speculated that the object was a Neanderthal flute and several wire services and National Public Radio picked up the story.

James Dixon presented another paper in the same session announcing a 9700+ years BP age for a human mandible removed from a cave in southeast Alaska. This is the oldest known human remain in northwestern North America, according to Dixon.

Cavers in the audience visibly squirmed at times during a presentation and follow-up discussion by leading cave archaeologist, James Brady, on the Maya use of speleothems. The audience raised questions and discussed the difficulties in carving and making fresh breaks in speleothems.

The Hydrogeology and the Engineering Geology Divisions cosponsored a special symposium on "Evaporite Karst: Origins, Processes." Session Chair Kenneth Johnson and NSS Honorary Member Derek Ford gave introductory, overview talks on evaporite karst in the United States and Canada, respectively.

At least 14 other papers specifically on caves are karst were presented at other session during the four days. In addition, Undersecretary of Agriculture James Lyons cited the White River National Forest cooperation with the Ute Nation in deciding how to manage Hourglass Cave in Colorado as an outstanding example of agency-Native American collaboration during an Environmental Geology session.

As always, the Friends of the Karst gathered on Monday night to informally discuss topics of mutual interest and share libations. The geologists discussed a planned, upcoming issue of the *Journal* on Isla de Mona, Puerto Rico, and the possibility of working on an environmental karst slide show.

UNDERWATER CAVE SCIENCE STUDY GROUP MEETS

In an attempt to improve communication between cave divers, cave scientists, and cave diver/scientists, the Underwater Cave Science Study Group (UCSG) has been formed. With the advent of new technology and new skills, cave divers have been able to penetrate farther and deeper into active cave conduit systems, as in the famous Florida karst springs, or into flooded cave systems, such as Bahamian blue holes. Their discoveries offer new insights into how cave systems form and develop, and the unique biological and chemical environments that exist at depth. The UCSG met in Branford, Florida, May 25, 1996, to begin the initial planning for the organization and its intent to bring cave scientists and cave divers together. Persons interested in more information about the UCSG should contact Chris Elmore, 3916 Linbrook Drive, Columbia, SC 29204 USA, 803-787-2216 (before 9 pm

ET), <chris@otis.cla.cs.edu> Taken from *The KWI Conduit IV* (2), fall 1996.

CLIMATIC CHANGE—THE KARST RECORD CONFERENCE IN NORWAY

The Climatic Change—The Karst Record conference was held in Bergen, Norway, August 1-4, 1996, under the joint sponsorship of the University of Bergen and the Karst Waters Institute. A total of 72 participants from 22 countries presented 48 talks and 24 posters, mostly dealing with interpretation of climatic records from speleothems. Some papers discussed clastic sediments, paleomagnetic analysis of cave deposits and paleokarst, paleontology, and speleothem luminescence.

Regional comparisons were made between the climatic signal determined from cave deposits, and those determined from the deep sea core oxygen isotope record, the ice core record, pollen studies, and other surficial records. A trend emerged in which cave scientists no longer seek to fit their data to the existing climatic data records mentioned above, but instead, argue that the cave record is more accurate and precise than the records determined from surface environements, and it is the other data sets that should be fit to the cave data.

NEW BOOK ON THE DELAWARE BASIN

The Permian Basin Section of the Society for Sedimentary Geology has announced the impending release of their Publication 96-39, *Geology of the Delaware Basin, Guadalupe, Apache, and Glass Mountains; West Texas and New Mexico* by Carol Hill. This comprehensive study covers all aspects of the geology of the Delaware Basin and the surrounding mountains including stratitgraphy, structure, tectonics, petroleum geology, geology of economic minerals, geochemistry, diagenesis, and geochemical clues to the processes of dissolution and cave formation. The book can be ordered from PBS-SEPM, P.O. Box 1595, Midland, Texas 79702.

PROTECTING KARST BIOTA

The Karst Waters Institute is sponsoring a conference on Conservation and Protection of the Biota of Karst to be held February 13-16 in Nashville, Tennessee. The conference will focus on both surface and subsurface karst biota. Sessions of invited papers will include Biodiversity in Karst, Demography and Genetics of Karst Biota, Sampling Subterranean Fauna, Biodiversity Hotspots in Karstlands, and Karstlands Protection. Thomas Hemmerly and Thomas Barr, Jr., will lead field trips to Cedar Glades in Tennessee and Mammoth Cave National Park, respectively. More information can be obtained at http://www.uakron.edu/geology/biota.html or by writing Dr. David Culver at Karst Waters Institute, P.O. Box 490, Charles Town, West Virginia, 25414 or at dculver@american.edu.

CALL FOR PAPERS
KARST-WATER ENVIRONMENT SYMPOSIUM & WORKSHOP
October 30-31, 1997
Roanoke, Virginia, USA

Karst aquifers are a major source of drinking water supplies and stream baseflow in certain regions of North America and other parts of the world. Prevention of groundwater pollution, land use and water source management, and preservation of ecosystems in karst terrane are a major challenge to scientists, regulators, industry, local officials, and land managers. The objective of the symposium is to provide a multidisciplinary forum for scientists, engineers, agency personnel, and others to discuss current and applied research, technical and regulatory issues, case-studies, and solutions to the water source protection and water quality problems in karst terrain.

Abstracts are solicited for presentation and possible inclusion in the symposium proceedings on the following topics:
- karst hydrology (flow characteristics, measurement, monitoring, modeling, surface-subsurface flow interactions, and drainage mechanisms)
- characterization of karst-water quality
- contaminant fate and transport
- land use impacts on karst-water quality (septic systems, spills, landfills, agricultural impacts, etc.)
- water quality impacts on biodiversity
- water source development and management
- water quality protection and land use planning
- monitoring system design
- remediation technology
- federal and state regulations and case studies
- local ordinances, conservation easements, and wellhead protection
- emergency response and contingency planning
- vulnerability of karst terranes

The deadline for a 300-500 word abstract is December 1, 1996. Include the name, title, complete mailing address, telephone number, FAX number, and e-mail address for the corresponding author. Successful abstract authors will be notified by January 1, 1997 and will receive the author guide for the symposium proceedings. The deadline for submission of a complete paper for inclusion in the symposium proceedings is July 1, 1997. Please mail the abstract to:

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LAMOREAUX HONORED BY AGI

Noted hydrologist, Philip E. LaMoreaux, recently received the William B. Heroy, Jr., Award For Distinguished Service by the American Geological Institute. LaMoreaux is the founder of P.E. LaMoreaux and Associates, a firm actively consulting on karst hydrology problems. The award cited LaMoreaux's more than three decades of service to the Institute and his recent work in establishing an active Environmental Geoscience Advisory Committee.

NSS-AGI JOINT PUBLICATION PLANNED

The NSS Board of Governors approved a proposal for a joint karst publication with the American Geological Institute (AGI). The book will be part of a series of the AGI's Environmental Awareness Series primers. The Geology and Geography Section of the NSS will oversee the project with Section's Executive Secretary, Dr. George Veni, acting a co-editor.

The AGI serves 29 member societies and the geoscience community of ~80,000 geologists, geophysicists, and other earth and environmental scientists. Member societies include the National Speleological Society, Association of Petroleum Geologists, American Institute of Hydrology, Association of American State Geologists, Geological Society of America, and International Association of Hydrogeologists. Their home page is <http://agi.umd.edu/agi/agi.html>.

The NSS representative to the AGI and its Environmental Geoscience Advisory Committee is Harvey DuChene of Englewood, Colorado. NSS membership is based on the professional membership within the Geology and Geography Section. The Section pays half of the Society's dues in AGI and the general NSS membership pays the rest.

AGI REVISES GLOSSARY

The American Geological Institute (AGI) is revising their *Glossary of Geology*, a reference that sits on nearly every earth scientist's desk. Editor Julia Jackson has been working with Harvey DuChene and other NSS members to update the karst and speleological terms.

AGI JOINS IUGS

The American Geological Institute (AGI) was recently accepted as an Affiliated Organization of the International Union of Geological Sciences (IUGS). Founded in 1961, the IUGS is one of the largest and most active scientific, non-governmental organizations in the world. The National Speleological Society is an Affiliated Member of the AGI.

"The American Geological Institute adds to a distinguished list of international affiliates covering the world and all areas of the geological sciences," said IUGS President Robin Brett. "Geology by necessity has always been a global science. Now, with vastly increased communications and accessibility, a new era of international cooperation awaits us. AGI has already shown its willingness to be a leader in that cooperation."

LETTER TO THE EDITOR

The special theme issue on Belize (*Journal of Cave and Karst Studies 58*(2)) is a truly notable contribution. However, both the historical overview and the "Bibliography of Belizean Speleology" overlook the important contributions of the NSS' Cascade Grotto and its members *per se*. Along with the cited contributions of the Sligo Grotto, these were particularly important at the beginning of organized speleology in Belize in the early 1970s. Some are documented in the following issues of *The Cascade Caver* (publication of the Cascade Grotto of the NSS, Seattle, WA) not included in "Bibliography of Belizean Caving":

Albert, D. 1971. Belize Speleological Survey Progressing. *Cascade Caver 10*(12): 75, December. Narrative of field work in St. Herman's Cave and others. Terms himself and Barbara MacLeod "the southern extension of the Cascade Grotto.

Halliday, W.R. 1973a. Cascade Grotto Speleoarchaeological Field Trip. *Cascade Caver 12*(5): A3-A6, May. Narrative of field work in Caves Branch and Rio Frio areas.

Halliday, W.R. 1973b. *Cascade Caver 12*(5): 3-4 (pages not numbered), June. Seven photographs (uncredited) of Petroglyph Cave, St. Herman's Cave, Caves Branch, and Blancaneaux Cave.

MacLeod, B. 1972. Belize Speleological Survey Needs Help. *Cascade Caver 11*(4): 25-26, April. Narrative of field work in St. Herman's Cave, Mountain Cow Cave and Caves Branch System.

MacLeod, B. 1973. Progress in Mayan Speleoarchaeology. *Cascade Caver 12*(1):3, January. Narrative of recent field work, without details of caves.

MacLeod, B. 1974a. Belize Speleological Survey Progress. *Cascade Caver 13*(1): A-10, January. Short narrative of mapping and archaeological studies in Bancaneaux Cave.

MacLeod, B. 1974b. Belize-Chiapas Caving/Rafting. *Cascade Caver 13*(5): 4, April. Brief mention of mapping in St. Herman's Cave and Caves Branch System; also first mention of discoveries on Mountain Pine Ridge by John Hudson.

Miller, T.E. 1973. Tom Miller's Extension of the British Honduras Field Trip. *Cascade Caver 12*(12): A-7, December. Contains brief mention of new discoveries in Petroglyph Cave.

Zarwell, W. 1973. Bill Zarwell in British Honduras. *Cascade Caver 12*(12): A-6. Brief mention of field work in Petroglyph Cave, Mountain Cow Cave and Blancaneaux Cave.

Barbara MacLeod is one of two Honorary Members of the Cascade Grotto, and all the writers cited above were members at this crucial period (Cascade Grotto, 1972. Current Grotto Membership. *Cascade Caver 11*(2): 13-14, February).

William R. Halliday, PO Box 1526, Hilo, HI 96721

SELECTED ABSTRACTS FROM THE 1996 NATIONAL SPELEOLOGICAL SOCIETY NATIONAL CONVENTION IN SALIDA, COLORADO

ANTHROPOLOGY AND ARCHEOLOGY SESSION

Session Chair: Jerald Jay Johnson

LEAKY TANK, A GYPKAP (NEW MEXICO) ARCHEOLOGICAL STUDY SITE

Carol L. Belski, 408 Southern Sky, Carlsbad, NM 88220-5338

GypKaP participants are trying to expand the knowledge of our project caving area by studying as many related fields as possible. Archeology is intriguing, partly because the area has been largely omitted in studies. Participants in this project, while mainly interested in finding and documenting caves, are trying to understand the entire caving area through multi-faceted studies. We have found Native American cultural remains throughout the area and are documenting them and attempting to learn who these people were who previously used these areas and who may have occasionally used the caves.

Studies of the artifacts scattered at the Leaky Tank surface site, combined with a lot of research, are coming up with some rather interesting results. I am proposing that this is a Jumano traders site, possibly developing out of Mogollon roots. Jumano peoples were documented as tradesmen, guides, and hunters by the Spanish explorers and missionaries, but have been ignored by most classic archeological studies.

CAVER RECOGNITION OF CULTURAL CONTEXT: DID NATIVE AMERICANS USE THIS CAVE?

David A. Hubbard, Jr., 40 Woodlake Drive, Charlottesville, VA 22901

Caves were used by prehistoric Native Americans for a variety of purposes. The recognition and documentation of these uses is important to the archaeological, Native American, and speleological communities. Yet, the vast majority of the known caves have never been examined by professional archaeologists, let along professionals experienced in cave archaeology, for evidence of cave resource utilization. Many cave archaeological sites were first discovered by cavers. In Virginia, caver- recognized "dark zone" prehistoric sites include: burial, ceremonial (mud glyph and pictograph), hunting (hibernating bear), lithic quarrying, and mineral collection sites. The important contribution of the experienced caver is the recognition of non-natural or unusual modifications to the cave that may evidence the past activities of man, a cultural context!

One of the most important clues to identifying prehistoric caving activities is the presence of charcoal from torches. To date only pine and native cane charcoal has been noted and dated at our Virginia sites. Other lighting material may include the bark of the shagbark hickory, other woody materials, or wick and tallow lamps. Unfortunately, historic pine charcoal cannot be distinguished from prehistoric pine charcoal without testing or other associated evidence. Careful attention to not damaging the charcoal, watching for prehistoric footprints, and looking for traces of what activities were conducted on these ancient cave trips is too much to ask of cavers without professional help. If you find evidence of prehistoric caving activities, retreat and offer your help to a cave experienced archaeologist. See the professional for verification and documentation before you accidentally damage what might be a significant archaeological site.

ARTIFACTS MADE FROM CALCITE AND MARBLE QUARRIED BY NATIVE AMERICANS IN CENTRAL CALIFORNIA 3000 TO 4500 YEARS AGO

Jerald Jay Johnson, Department of Anthropology, California State University, 6000 J Street, Sacramento, CA 95819-6106

Native American miners acquired calcite and marble from caves in the Mother Lode of the Sierra Nevada in central California between 3000 and 4500 years ago. They manufactured these into pipes, charmstones, beads, and pendants, and traded them to the west into the lower Sacramento and San Joaquin valleys and delta where they were probably exchanged for shell beads and ornaments that had been derived from the Pacific coastal region. The trade of artifacts from cave resources into the great valley to the west apparently ended by 2500 years ago with some use of these materials persisting as offerings left in vertical burial caves in the higher foothills until as late as 2000 years ago.

Evidence exists in several caves of past Native American quarrying activity including battered and sometimes shaped hammerstones and broken stalagmites and stalactites. The focus of this presentation, however, is on the artifacts which were produced from the materials acquired during the mining activities of various Native American populations.

Ponderosa Cave, A Possible Prehistoric Calcite Quarry in the Sierra Nevada in Central California 3000 to 4500 Years Ago

Heather McDonald and Matt Leissring, 158 Third Street, Woodland, CA 95695

Ponderosa Cave was mapped by members of the Mother Lode Grotto of the NSS in the winter and spring of 1996. During this activity, the bases of at least four stalagmites were noted that appeared to have been broken off and battered a long time in the past. A few stone artifacts and a possible bone artifact were also noted. Two archaeologists from California State University, Sacramento, who are members of the Mother Lode Grotto visited the site with the authors and noted one large flattened elongated stone which had been battered, a bone artifact, obsidian flake and a shell bead. These artifacts are all of Native American origin and the bead type dates before 3000 years ago. The artifact assemblage, cave characteristics and environment will be compared to several other quarry caves previously identified in the Mother Lode of the Central Sierra Nevada in California.

Fern Cave . . . A Pictographic Recording of the Supernova of 1054 AD?

William Papkel, 5412 Hesper Way, Carmichael, CA 95608

A recent regional held by the Western Region of the NSS at Lava Beds National Monument afforded a first-time visit to Fern Cave. This cave is known to have the best display of pictographs in the monument, and perhaps the most concentrated display on the whole of the Modoc Plateau.

A discussion of the discovery and archaeological investigation of the cave and an interpretation of a particular pictograph in this site will be presented. This will be compared and contrasted with other pictographs in caves and on canyon walls in the southwest. A further discussion of the problems of conservation and preservation of this site will also be given.

BIOLOGY SESSION

Session Chair: Ed Lisowski

Temporal Variations in the Emergence Flights of *Myotis velifer*

Debbie Buecher, 7050 E. Katchina Court, Tucson, AZ 85715

Bats are nocturnal mammals and many North American species spend their days resting/sleeping in caves which provide a stable temperature, humidity and protection from predators. Bats that live in total darkness in a cave or mine depend upon a circadian rhythm to trigger their daily arousal and initial departure (emergence) from the roost area. They can then fine-tune this activity pattern with light testing in the entrance area of the site until the light intensity matches that characteristic of the species for their evening emergence. Many of the insectivorous bat species have an emergence pattern that is parallel with the time of sunset. A maternity roost of *Myotis velifer* in Kansas studied by others in the 1970s and this current study in Arizona both reflect an interesting deviation from this "standard" emergence pattern. *Myotis velifer* appears to emerge sooner in the early spring and autumn than in late spring and summer. Besides this variation in the time of emergence, the character of the outflight also changes through the summer period. An explanation for these emergence pattern variations could be the reproductive condition of the females in the maternity roost. Other factors such as ambient temperature may also play a role. Probably no one element is the trigger for emergence, but a rather a combination of factors.

A Comparison of Aquatic Cave Communities in Horse Cave and L&N Railroad Cave: Are They Converging as Horse Cave Recovers?

Thomas G. Jones & William D. Pearson, Biology Department, University of Louisville, Louisville, Kentucky 40292

The east and south branches of Hidden River were devastated by point source pollution before 1990. L&N Railroad Cave stream has escaped this destruction by being perched 20 meters above the level of Hidden River upstream from the major pollutant inputs. Total nitrogen levels in L&N are high (greater than 3000 mg/L). This suggests continued enrichment of the watershed, probably due to fertilizers and inadequate septic systems. The community structure of the troglobitic and troglophilic aquatic fauna of L&N Cave has remained consistent for three years. Water quality of Hidden River has improved substantially in the last five years. Illegal dumping, washout of toxin-laden sediments, and the time lag recovery of the natural buffering systems probably account for the variations in water quality that continue.

Significant changes have occurred in the community structure of Hidden River. An apparent single cohort of comprised 21 of the 29 fish observed in 1993. No troglobitic fish were observed in the south branch until 1995. The reproducing (?) population of troglophilic crayfish (had poor recruitment in 1994), and the number of individuals observed dropped from 39 in 1994 to three in 1995. High levels of recruitment continue in both troglobitic isopods and crayfish (Recovery of the troglobitic community has been facilitated by movement of adults and recruits from the east branch to the south branch of Hidden River. The resilience of this devastated aquatic cave community provides hope that future successes in cave conservation and reclamation are within our grasp.

On the Roles of Phylogeny and Stochasticity in the Evolution of Perennibranchiate Troglobitic Salamanders

D. Bruce Thompson, National Inst. of Health, 4112 N. 16th Street, Phoenix,AZ 85016 & Thomas R. Jones, Grand Canyon University, Phoenix, AZ 85017

In general, a variety of different traits characterize the morphology and physiology of troglobitic organisms. These include absent or reduced eyes, elongated appendages, loss of pigmentation, decreased metabolic rates, increased longevity, and delayed reproduction. In addition to many of these characteristics, most troglobitic salamanders are also paedomorphic.

The evolution of paedomorphic troglobitic salamanders is often discussed implicitly as a deterministic process in which metamorphosing, epigean ancestral salamanders enter caves, and their descendants subsequently evolve a suit of morphological characters, including paedomorphosis, which provide a selective advantage in the cave environment. Alternatively, we suggest that paedomorphosis in troglobitic salamanders is the result of historical processes and was present in the ancestors of troglobitic salamanders, rather than an adaptation to the cave environment. Furthermore, the frequency of paedomorphosis in troglobitic salamanders may be the result of stochastic entrapment of epigean species that were polymorphic for paedomorphosis. Once trapped in a cave environment additional characteristics evolved that provided additional selective advantage, including some of the more conventional adaptations noted above. Finally, we describe the first instance of paedomorphic, apparently reproducing, cave dwelling tiger salamanders (that may represent an intermediate stage in the evolution of obligately troglobitic salamanders.

CONSERVATION AND MANAGEMENT SESSION

Session Chair: George Huppert

Protecting Caves From Road Construction

William R. Halliday, Hawaii Speleological Survey of the NSS, 6530 Cornwall Court, Nashville, TN 37205

In 1995, a spokesman for the Mayor of Hawaii County, HI, announced plans to collapse segments of Kazumura Cave, Keala Cave, and other world-class lava tube caves in upgrading a subdivision road. Kazumura Cave is the world's longest lava tube cave with a variety of spelean resources and values. Protests on an international scale were necessary to obtain protection for these important caves. On the other hand, a program of active cooperation had already begun with the Hawaii State Highway Department. With the possible exception of the National Park Service, no standards for protection of caves from roads (and vice versa) seem to exist. This is a nationwide problem which should be addressed by the National Speleological Society.

The Southeastern Cave Conservancy

Kenneth Huffines, 356 O'Brian Drive, Stone Mountain, GA 30088, <khuffines@lithonia.com>

The Southeastern Cave Conservancy (SCC) is a relatively new organization designed to acquire and manage caves for scientific study, speleology education, and conservation of caves. It is modeled after other organizations with similar purposes but is specifically concerned with cavers' interests. Although concentrating in Tennessee, Alabama and Georgia, the SCC enjoys a wide membership base throughout the United States. There are still many cavers who are unaware of the SCC and its mission. This presentation will review the Conservancy's purpose and goals, management, education and monitoring programs, properties acquired, and future plans.

Global Cave Conservation Education Via the Medium of the Poster

George N. Huppert, Department of Geography and Earth Science , University of Wisconsin, La Crosse, WI 54601

Messages may be presented to the general public in many different ways. Posters are one of the most common media used to advertise show caves and to influence the public's image of and attitudes toward their protection. This is, most likely, due to the fact that this is one of the cheapest methods to present a message to the greatest number of people.

Cave Entrance Stewardship at Mammoth Cave National Park

Rick Olson, John Fry, & Joe Meiman, Division of Science & Resources Management, Mammoth Cave National Park, Kentucky

In terms of access and security, cave entrances are the door to the bank vault. In terms of physical, biological, and energy exchange, they are primary portals between the surface and underground world. Structures installed in cave entrances must: 1) provide an adequate deterrent to illegal entry, which is to say that extraordinary means beyond hand tools are required to gain access, and 2) they must allow natural exchange rates of air, water, organic matter, and commuting wildlife. These characteristics are vital for conservation of cave adapted communities, cultural resources, and even minerals. Changes in cave temperatures, humidity, water flow, and input of organic material can have consequences equal in severity to illegal entry.

Airflow Bat Gates designed by the American Cave Conservation Association and approved by the US Fish and Wildlife Service have been installed at Long, Lee, Bat, Dixon, and White Lightning caves, plus the Colossal, Proctor, Salts, and Historic entrances to Mammoth Cave. Airlocks have been installed on artificial entrances to Mammoth Cave (including the Frozen Niagara, New, Carmichael, Violet City, Elevator, Doyel Valley, and Austin entrances). We custom fitted gates to Wondering Woods Cave and Bedquilt Entrance to Mammoth Cave and reinforced Crystal Cave's gate.

What's next? The Historic Entrance ecotone in Mammoth Cave is the target of a three year ecological restoration project to begin reactivation of this formerly major bat hibernaculum.

Puerto Rico's Karst, An SOS

Abel Vale, President of Ciudadanos del Karso, Citizens of the Karst, Cond. La Cumbre Gdns., Apt. 209, Rio Piedras, PR 00926-5404

Puerto Rico has a great variety of landforms developed by dissolution of limestone under tropical climatic conditions. The most developed karst area is in the northern and northwestern parts of the island, which are underlain by thick Oligocene and Miocene limestone formations. Using Watson Monroe's words, "Although the areas of karst terrans are not large compared to other countries, they have aroused the interest of karst specialists, especially from Europe, because of the excellent examples of cone and tower karst, well developed cuestas and many features not known elsewhere." Our most spectacular caves are within the northern Puerto Rico karst area, including the world's longest known traversable underground river (16.9 km) to date. The region contains about 50% of the privately owned forests, which are the habitat of many endangered species of flora and fauna, and it is the most important area of recharge to our largest aquifer and to several wetlands.

The rapidly growing population in other portions of Puerto Rico has brought massive residential, commercial, and industrial expansion to the northern portion of the karst lands. The nature of this construction frequently involves extensive deforestation, landform obliteration, and water diversion and contamination.

ELECTRONICS AND COMMUNICATIONS

Session Chair: Frank Reid

Improving the Accuracy of Cave Radio Locations

Bob Buecher, 7050 E. Katchina Court, Tucson, AZ 85715

A cave radio was used to provide independent verification of target locations inside Kartchner Caverns prior to tunnel construction. A "Single Blind" technique allowed a separate determination of the accuracy of the cave radio locations. Points were located to an accuracy of ±8 in (±20 cm) at depths of 170 ft (52 m). This high degree of accuracy was confirmed by comparison to a precise theodolite survey of the cave. Additional tests were done to demonstrate the accuracy of depth determination with the cave radio.

GEOLOGY AND GEOGRAPHY SESSIONS

Session Chair: George Veni

Comparison of Physical and Chemical Discharge to Determine the Relationship of Two Springs at Woodlawn Memorial Park, Nashville, Tennessee

Eric Anderson, 648 Des Moines Dr., Hermitage, TN 37076 <anderson@telalink.net>

Springs in karst terranes can be either a single discharge point or a distributary system. In this study two springs discharging from the same hillside were studied to determine if they drain the same or separate basins.

Sampling strategies were implemented to accurately record the chemical and physical qualities of both springs in relationship to a rain event. Discharge volume, pH, conductivity, and temperature were monitored at approximately 12-hour intervals before, during, and after a rain event. A V-notch weir and a bucket and stop-watch method were employed to measure the discharge volume of the springs. Other qualities of the springs were monitored with a pH meter, a conductivity meter, and a thermometer.

The data were plotted on graphs for comparison. Results in discharge volume, conductivity, pH, and temperature indicated that the two springs had different quantitative and qualitative responses to the same rain event.

The chemical and physical response of the two springs to a rain event indicated that they drain different groundwater basins.

Spring Creek Dye Tracing: Greenbrier County, West Virginia

George Dasher, West Virginia Association for Cave Studies, MaxWelton, WV 24957 & Doug Boyer, US Dept. of Agriculture, Agricultural Research Station, Beckley, WV

Spring Creek, West Virginia, is ~24 mi (~39 km) long and flows south from the south flank of Droop Mountain to the Greenbrier River. Large springs rise along the creek and include cave streams from some of West Virginia's longest caves. The Buckeye Basin overlies the underground Culverson stream, and is located between that basin and Spring Creek. Both the Culverson and Buckeye basins, their caves and the Buckeye resurgence, are in the Union Limestone. The four Culverson resurgences are in the Patton Limestone, which is below the Union Limestone and the 20 ft thick Taggard Shale. It is not known where or how the subterranean Culverson Creek crosses through this shale.

Beginning in 1994, 17 dye traces were completed in the Buckeye Basin, nine in the Culverson Basin, and seven to Spring Creek. In the Buckeye Basin, Fuells Fruit Cave resurgences in the adjacent valley of Turner Hollow to the northwest; the Turner Pit #2 water appears at Apple Spring; the

Baber Pit and Sissler Sink water resurge at Callisons Pond Cave, and all three of these waters reappear at Rubble Spring on Spring Creek. All of the upper Buckeye Basin insurgences breach the Taggard Shale and resurge at the four Culverson springs. The southernmost sink in the Buckeye Basin, the Reynolds Swallowhole, flows into the Boggs Bluehole, the uppermost of The Hole resurgences.

In the Culverson Basin, Plastic Bag Cave System and the two AWOL insurgences resurge at Picnic Cave, Poorfarm Cave resurges at the Scout Camp North Spring, and Stove Cave resurges at Briar Patch Spring. On Spring Creek, two streams in the Boarhole and the entrance stream of The Portal reappear at Cannon Hole, the resurgence for Friars Hole. This estavelle is located on Spring Creek between the Culverson and Buckeye resurgences, just upstream of the Spring Creek Cenotes.

Scanning Electron Microscopy of Fine-grained Sediment From Movile Cave, Southern Dobrogea, Romania

Annette Summers Engel, Department of Geology, University of Cincinnati, Cincinnati, OH 45221-0013

Since its discovery in 1986, Movile Cave, Romania, has been of interest to scientists. The main foci for investigations have been the chemoautotrophically based ecosystem and the troglomorphic terrestrial and aquatic organisms. This is the first detailed examination of scanning electron microscopy images highlighting Movile Cave sediment.

Sediment samples were collected from passage walls, ledge accumulations, and from pits dug into the cave floor. Sediment was analyzed by SEM (with EDAX) and X-ray diffraction (XRD). Based on the mineralogy of the sediment, two populations of cave sediment exist—allochthonous and autochthonous. The first has clay minerals of mostly mixed-layer silicates, specifically illite-smectite, kaolinite-smectite, and lesser chlorite-smectite. Additionally, 0.5-4.0 mm grains of goethite, quartz, muscovite, and minor concentrations of mafic minerals are also associated with these accumulations. SEM images of bulk sediment and grain mounts show these detrital minerals are abundant (roughly 85%) in clay and fine-grained sediment. The second type of sediment resembles the carbonate bedrock. Dolomite, with trace amounts of illite (and possibly kaolinite), is in the <2.0 µm sediment fraction. Calcite rarely occurs in the sediment, but is the major component of bicarbonate crusts and calcite laminae within the bedrock. XRD analyses of powdered bedrock and sediment prove that the major constituents of the autochthonous sediment are dolomitic ooids. SEM images reveal tiny (0.5-2.0 µm) zoned dolomite rhombs on the outer surfaces of ooids. Some dolomite crystal faces have an abundance of adhering, spherical single and chained bacteria. The average diameter of the chained spheres is 1.0 µm, with a connecting filament of approximately 1.0 µm of length. Bacteria chains, up to 20 µm long, rest in dents and depressions on dolomite crystal faces.

Stratigraphy and Sedimentology of GypKaP Caves

Jeffrey Forbes, 625 Monroe SE, Albuquerque, NM 87108 and Ray Nance, 2421 Avenue A, Carlsbad, NM 88220

Thousands of solution caves have developed in sequences of evaporites and carbonates of the Permian San Andres Formation that crop out between Vaughn and Roswell, New Mexico. These "gypsum caves" afford an extraordinary opportunity to examine the evaporite rocks. As part of the ongoing Gypsum Karst Project (GypKaP), we have conducted geologic studies in several gypsum caves since 1992. Thus far, stratigraphic sections have been measured in 13 caves scattered over a 1000 square mile area.

Gypsum textures exposed in the caves include massive, nodular, and laminar types. While cavers generally refer to them as "gypsum caves", gypsum is by no means the only rock type exposed in the caves. Some cave passages are developed in thick dolostone units intercalated with or overlain by gypsum beds.

As a result of the contrast in solubility and hardness between gypsum and dolostone, the stratigraphic sequence in a particular cave exerts a profound effect on cave geometry and passage cross-section. Many passages have gypsum walls and a dolostone or limestone floor. Many passages are confined to a single stratigraphic unit for hundreds of feet prior to breaching of the resistant carbonate floor at a vertical shaft or climbdown. Dolostone beds in gypsum caves occupy a similar position with respect to cave development as the chert beds in limestone caves of the eastern US. Although many of the cave passages flood completely during major storm events, the stairstep profile of most of the caves is indicative of speleogenesis that has occurred predominantly within the vadose zone.

A New Technique for Dating Allogenic Cave Sediments Using Cosmogenic Nuclides

Darryl E. Granger, Department of Geology and Geophysics, University of California, Berkeley, CA 94720-4767, <darryl@moray.berkeley.edu>

The concentrations of and in allogenic quartz cave sediment can be used to date sediment deposition over a time span of 0.2 to 4 Ma. Near the ground surface, radioactive (half-life=0.7 Ma) and (half-life=1.5 Ma) are produced in quartz at a ratio of 6:1 by nuclear reactions with secondary cosmic ray neutrons and muons. These cosmic rays are absorbed by rock, so and production in caves is negligible. In quartz sediment which was once exposed at the ground surface but is now buried in a cave, radioactive decay decreases the ratio of to over time. The ratio of to can therefore be used to date sediment burial.

I have used this technique to date river gravels preserved in five caves above the New River, Virginia. Over time, the river has incised through bedrock, so that caves which once opened onto the riverbed and received gravel sediment are now in cliffs high above the river. Sediment emplacement times range from 0.3±0.09 Ma to 1.52±0.18 Ma, and show that the river has incised at a rate of 20-30 meters/Ma.

Genesis of Hydraulic Conduits in Karst Aquifers: A Two Dimensional Modeling Approach

R. Blair Hanna & Hari Rajaram, Department of Civil, Environmental and Architectural Engineering, Campus Box 428, University of Colorado, Boulder, Colorado 80309

Geochemical modeling of the development of conduits and caves in karst systems is an area of active research. One of the goals of geochemical modeling is to estimate the time scales required for the development of hydraulic pathways. Such modeling efforts thus offer a useful tool for exploring different hypotheses on cave development.

Several previous studies have examined the enlargement of conduits in one-dimensional flows. It is our impression that natural fracture planes which lead to the development of conduits are better viewed as two dimensional flow systems. In two-dimensional flows, there is an opportunity for instabilities and preferential flow paths to develop, which can accelerate conduit growth significantly.

A two-dimensional computer modeling approach is used to describe flow, calcite dissolution, transport and wall retreat within an idealized fissure of a karst aquifer. Industry standard groundwater models MODFLOW and MT3D are used to describe the flow and transport within the fissure.

Contaminant Case Studies in Virginia Karst

David A. Hubbard, Jr., PO Box 3667, Charlottesville, VA 22903

Natural processes active in karst result in three types of natural hazards: subsidence, sinkhole flooding, and groundwater pollution. Traditionally, subsidence has been the natural hazard of greatest concern to karstland residents. With continued development and population growth in karstlands, local residents are becoming aware of the high susceptibility of karst groundwater to pollution. Cavers have long been aware that the caves under-draining sinkholes, sinking streams, and other surface water access points, are conduits along which travel is possible for long distances through the subsurface. Liquid contaminants or the leachates of solid wastes typically follow the same solutional conduit pathways as surface water and precipitation in recharging the karstland aquifers. Subsurface flow is through solutionally enlarged fractures and partings in the folded and faulted Valley and Ridge province carbonate rocks. These conduits comprise both storage and flow path components of the karstland aquifers in these otherwise tight rocks. Contaminants that have fouled the Commonwealth of Virginia's karst include spills or leaks of petroleum products, herbicides, sheep and cattle dip, solvents, fertilizers, sewage, milk, and the leachate of improperly disposed waste materials. Remediation of contaminated groundwater is costly and rarely completely effective. The best long term management tools for karstland groundwater resources are: 1) the education of the karstland residents about the nature of karst and the proper handling and disposal of potential pollutants; and 2) protecting the recharge areas through quality control of recharge inputs including the storm-water drainage systems.

Enlargement of Lava Tubes by Downcutting and Breakdown

Stephan Kempe, Am Schloß Stockau 2, D-64807, Dieburg, GERMANY

Pahoehoe lava forms extensive tubes, through which lava is conveyed over large distances. Throughout the active time of such a tube, many processes act to alter its initial tubular appearance. Comparative studies in several major tube systems on Hawaii (Keala Cave, total length 8.60 km; Keauhou Trail System, length of all segments >2.5 km; Clague's Cave, total length ca. 2 km; Charcoal System, total length of all segments ca. 2 km; and Earthquake System, total length 338 m) illustrate the importance of these processes. All of the mentioned tubes show evidence of active downcutting. This downcutting appears to be largely associated with the backcutting of lava falls and is most probably purely mechanical. Several lava falls may move upslope simultaneously, creating tall, canyon-like passages. Very often voluminous plunge pool rooms develop below lava falls. The downcutting is often associated with the undercutting of sidewalls, resulting in a meandering of the passage and causing breakdown to occur.

A Condensation-Evaporation Model for the Origin of Some Types of Speleothems

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Some hollow gypsum speleothems, studied in Kugitangtou caves, may form by permanent evaporation-condensation processes. This mechanism demonstrates high heat and mass transportation efficiency. A physical model and the prominent factors of these processes as well as kinetics of the growth and a stability of these aggregates are discussed. Peculiarities in morphology and structure of some types of crusts and newly described speleothems "hornet nests" may be explained by an evapo-condensation water feeding model.

It is proposed that growth of "hollow gypsum stalagmites", a rare speleothem, is initiated by a cavity of any origin in gypsum deposits, and is controlled by cave air temperature along a vertical gradient. They grow in conditions balanced between seeping and evapo-condensation water feeding, which renders them highly stable. Seasonal changes in the humidity and temperature gradients in caves appears to affect the morphology of these aggregates.

Although attractive, this model has internal contradictions and is an incomplete explanation of this speleothem type.

Gypsum Speleothems of Glacial Origin

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Seasonal permafrost affects the development of gypsum speleothems in caves of the Pinega area, northwestern Russia, including two previously undescribed types of deposits.

One type, called gypsum "ezh" (porcupine) grows in dense clay sediments within a high supersaturation environment. Originally growing in the direction away from the freezing front, they later enlarge almost symmetrically. Their shape and peculiarities are dependent on various factors and provide interesting comparisons with gypsum "roses" from arid regions. A second type, a very rare gypsum speleothem, appears to be produced from concretions of gypsum "powder" accumulated in cavities within a powerful underground glacier. Recrystallization of the gypsum is controlled by fluctuating local temperature and seasonal permafrost in an environment of low supersaturation.

A Possible Influence of the Earth's Rotation on Speleogenesis

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The morphologies of sub-latitudinal (east-west oriented) and sub- longitudinal (north-south oriented) cave stream channels in sub- polar regions of northwestern Russia show differences in cross-section. This effect has been observed in both gypsum and limestone caves. Sub latitudinal passages are commonly almost symmetrical. Sub-longitudinal passages often have a consistent pattern of clearly visible asymmetry.

On the basis of these observations, it is hypothesized that the Earth's rotation (Coriolis force) influences cave morphology. Different mechanisms influencing channel development depend on surficial and underground streams, and local conditions for speleogenesis.

Filamentary Gypsum Crystals From the Cupp-Coutunn Cave

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Various types of gypsum filamentary crystals and their aggregates are widespread in the caves of the Cupp-Coutunn system. These speleothems include flowers, beards, wool, hair, needles on and inside clay, and satin spar veins in clay.

After examination of their structure, substratal peculiarities, and other features of the environment, simple calculations show that the usual model explaining their growth from a solution seeping through porous substrates doesn't work. Impossible pressures are needed and fibers' diameter/length relation dispersion shows the absence of uni-directional seeping.

The only mechanism, suitable for the observed properties, is a short-cycle (seasonal) substratal wetting-drying cycle caused by condensation evaporation. In several cases, there is direct evidence as growth proceeds on isolated pieces of pure carbonate substrates. The only local sulfate source here is the gas from the air, driven into the substrate pores by condensing water.

Some unusual aggregates (quasi-epitaxial gypsum overgrowths on the ends of calcite-aragonite quill anthodites) preserve their original orientation as gypsum hair.

Gypsum needles start as filamentary crystals extruding from clays. They pass through the zones of split growth and skeleton growth. Competition between the pores causes high oversaturation. Crystallization pressure blocks most of the pores, squeezing the solution into the surviving ones and creating strong oversaturation barriers.

New Levels in the Minor Mineral Bodies Hierarchy

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Common classification systems for minor mineral bodies include 1st order populations (crystals, grains), 2nd order populations (skeleton crystals, split crystals, dendrites), aggregates, and upper level minor mineral bodies (for example, veins). This is adequate for "usual" mineralogy. However, caves, with their peculiar environments, display several well-recognized hierarchical levels above aggregates.

Further, needed classifications include: a) multi-aggregates—syngenetic, regular intergrowths of different aggregates (thus, demonstrating that the paragenesis conception may be used with aggregates); b) crusts—unions of all the crystallization products generated during an interval of simultaneous crystallization (extension of the "weathering crusts" conception); c) ensembles—unions of crusts, resulting from prolonged, monotonous crystallization stages.

Unique aggregate and multi-aggregate interrelated activities also results from peculiarities of cave environments. In the usual case, the mass transportation symmetry (and the derived aggregates' texture symmetry) is exclusively controlled by the physics of the crystallization environment. In the interactive case (i.e. helictites), the crystallization environment symmetry is "controlled back" by the growth's peculiarities. So, in this case we must speak not only about the aggregate's structure and texture, but also about their new property—"behavior".

Stable cave environments may also generate upper levels of mineral populations (single-phase generated mineral bodies, started from a single embryo, and having a complete structure). In Cupp-Coutunn Cave, there are 3rd order gypsum individuals (split skeleton screw crystals).

Subaqueous Helictites, Virgin Cave, New Mexico

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Subaqueous helictites have been discovered in a small pool in Virgin Cave, Lincoln National Forest, New Mexico. Previously, the only known occurrences have been within Lechuguilla Cave, Carlsbad Caverns National Park. The helictites extend into a shallow, water-filled pool from a narrow (<1 cm) leading margin of thin, translucent shelfstone. Although the most centered helictite extends to a length of 4 cm and has a diameter of nearly 0.5 cm, most helictites are about a centimeter in length and less than a millimeter in diameter. Submerged, unbroken cave rafts, which are only rarely associated with these unusual speleothems, occur at the bottom of the pool. A gypsum block, approximately 0.5 m in diameter, is situated on wet flowstone which slopes toward the pool. Also, on the slope leading directly to the pool, there are remnant "tufts" of another gypsum block which has not been completely dissolved. The presence of this remnant gypsum supports the theory that subaqueous helictites precipitate in response to the common-ion effect.

The Relationship of Structure and Stratigraphy to Cave Formation in the Fourmile Draw Member, San Andres Formation, Eastern New Mexico

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The gypsum caves on the eastern plains of New Mexico provide a unique window through which to view the structure and stratigraphy of the Fourmile Draw Member of the Permian San Andres Formation. Since 1992, the stratigraphy of a number of gypsum caves has been studied by members of the Gypsum Karst Project (GypKaP) of the NSS. The strata exposed in the caves consists primarily of gypsum, dolostone, and clastic beds deposited along a broad continental ocean shelf during Permian time. When deposits such as these are exposed at the surface they are typically highly weathered. However, in the caves studied, periodic flooding has provided relatively fresh surfaces with extensive lateral exposure, enabling our study to be more comprehensive than one would usually expect in evaporites.

Correlation of beds exposed in different caves has enabling us to infer the regional geologic structure. A number of oil, gas, and water wells have been drilled in the area, and correlation of the logs from these wells has helped in the analysis of the deeper beds not reached by the caves. The larger, more vertically developed caves appear to be forming along structural highs. Analysis of well logs and the stratigraphy exposed in the caves indicates the possible presence of several anticlines in the study area, and that the larger caves are developed near the crests of these folds.

Comparison of Joint, Sinkhole, Photo-lineament, and Cave Segment Orientations for Predicting Contaminant Transport Direction in the Central Basin of Tennessee

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Orientation measurements were made of 979 joints, 260 photo- lineaments, 318 sinkholes, and 247 straight cave segments within the upper Ordovician carbonates of Cannon and Rutherford counties, which are located on the southern flank of the Nashville Dome, Tennessee. Large caves of particular interest for the study were Snail Shell, Espey, Robinson Ridge, and Pleasant Ridge caves. Together, these caves contain over 22 mi (35 km) of passage. Three dominant cave passage orientations were observed with scatter around the following average trends: N55°W, N40°E, and N5°W. Most passages are developed along the N55°W trend and the least along N5°W. Very similar joint orientations were observed in the shaly beds. In the more massive carbonate rock units, the N5°W trend was generally absent. The sinkhole and photo-lineament orientations matched the N55°W and the N40°E trends well, but again the N5°W trend was nearly absent. Although there is some scatter of the data, with this information contaminant transport direction from a spill or leak can better be predicted using sinkhole, joint, and/or photo-lineament orientations where cave data do not exist.

Crystallization of Calcite and Aragonite

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Controversy persists over what controls calcite vs. aragonite precipitation and the morphology of calcite crystals. In caves, averaged measurements of pool chemistry correlate poorly with mineralogy and crystal shapes. However, increases in pH with depth are common in certain cave pools, especially during rapid infiltration, which indicate steep gradients and rapid degassing. Pools with the highest degassing rates contain calcite needles. Those with moderate degassing rates contain blade-shaped calcite, commonly in V-shaped twins. Low degassing rates produce shingled calcite rhombs, and pools with rather static contain unshingled calcite rhombs. Lab experiments are being conducted to clarify these relationships and to determine the influence of dissolved solids on mineralogy and crystal morphology is bubbled through distilled water to achieve PCO_2 levels up to 1 atm, and reagent-grade calcite is dissolved in the solutions to just below saturation. Some bottles are spiked with salts of Ca, Mg, Na, Cl, and samples are allowed to lose at various rates, while pH, ionic composition, and saturation indices for calcite, aragonite, and vaterite are determined with time. Similar studies are performed with spring water. Preliminary results show that degassing rates of roughly >0.01 atm/day produce both aragonite and calcite, accompanied by vaterite when degassing is most rapid, whereas slower rates produce only calcite, independent of the presence of other ions. In Mg-rich water, low-Mg calcite forms on the bottom, while calcite rafts are high in Mg but revert with time to low-Mg calcite. High-sulfate solutions produce very low-Mg calcite.

Dolomite Cave Rafts: Evidence of Dolomitization in Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico

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A sample of cave rafts from the floor at the Rusticles in Lechuguilla Cave consists of dolomite. Petrographic examination of the sample reveals a pseudospar crystal fabric which does not conform to the crystal arrangement common in cave rafts, and therefore suggests replacement of calcite by dolomite. A relict texture of rhombohedral crystal terminations, observed in a thin section of the sample, provides convincing evidence that the rafts originally formed as calcite and were later replaced by dolomite.

The Rusticles area exhibits iron-rich stalactites (the Rusticles), small potholes (partially filled with goethite-rich sediment) formed by corrosion drip waters, and abundant dolomite crusts and aragonite frostwork. The diagenetic history of the cave rafts yields information about the evolution of the pool water chemistry in the vicinity of the Rusticles. Study of the cave rafts may also explain the origin of the iron rich stalactites.

Geochemistry of Lechuguilla Cave Pool Water

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Like other caves in the Guadalupe Mountains of New Mexico, Lechuguilla is believed to have been formed by sulfuric acid dissolution of limestone bedrock. This history is responsible for many of the spectacular sulfate speleothems for which the cave is known, and for distinctive patterns in water chemistry. Since the main cave's discovery in 1986, over 100 water samples from pools throughout much of its known extent have been collected and analyzed for major and trace element chemistry, and in some cases, isotopes including deuterium, and tritium.

Analysis results provide insight into geochemical processes occurring within the cave. Major ion chemistry is controlled by the carbonate bedrock that hosts the cave, but is modified by in- cave processes, including evaporation, condensation, and dissolution and precipitation of secondary cave minerals, including calcite, aragonite, and gypsum. In particular, dissolution of magnesium-containing calcite or dolomite bedrock followed by precipitation of secondary calcite or aragonite within the cave has resulted in increased magnesium: calcium ratios in solution; most Lechuguilla pool waters have a Mg:Ca molar ratio greater than 1. Local groundwater, most of which presumably did not undergo cave processes during recharge, has a Mg:Ca ratio around 0.6.

Two of the more unusual speleothems found in the cave probably owe their origin to common-ion effect precipitation. As previously demonstrated, the subaqueous helictites in Pellucidar and elsewhere reflect carbonate precipitation caused by the addition of gypsum to a solution already saturated with calcite. The exact opposite process may explain the selenite precipitation taking place in the Dilithium Pool, where water saturated with gypsum encounters carbonates and other minerals.

Tritium in Lechuguilla Pool Water: Implications for Recharge Processes

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Numerous isolated pools of various size are found throughout Lechuguilla Cave, fed only by water seeping through the overlying limestone. The pools thus permit direct sampling of locally perched vadose zone water beneath the arid Chihuahuan desert of southeastern New Mexico. Over 20 pool water samples have been collected for low-level tritium analysis. For comparison, a sample of local groundwater was also collected from a nearby well.

Nuclear weapons testing in the 1950s and 1960s released large amounts of tritium into the atmosphere, which was then slowly removed by precipitation. The "bomb-pulse" tritium profile obtained by measuring tritium concentrations at different depths in the cave provides insight into the character and rate of recharge processes in the region.

Our results show that elevated tritium levels are confined to pools within the upper 900 ft of Lechuguilla Cave. Maximum tritium concentrations are an order of magnitude lower than predicted using a piston-flow recharge model. The data can be

fit far better using a well-mixed reservoir model for the vadose-zone. Using this model, the data indicate a mean recharge velocity of roughly one ft/yr, which is reasonable considering estimates of local precipitation, evapotranspiration, and vadose-zone moisture content.

The observed variability in tritium concentrations within the cave hints at the complexity of recharge processes occurring. Variations in surface topography and drainage, preferential pathways along fractures in the overlying bedrock, hydrodynamic dispersion in the vadose zone, and vapor phase advection and diffusion both within and above the cave may all play significant roles in producing the observed tritium profile.

A Geologic Reconnaissance of the Cerro Blanco Karst, Chiapas, Mexico

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The Cerro Blanco karst is situated in north-central Chiapas, Mexico, within the Sierra Madre del Sur, and includes roughly the area northeast from the town of Pueblo Nuevo Jolistahuacan within the Arroyo Seco and Río Colorado drainage basins. Recent exploration has discovered the first major cave systems known in the mountains of Mexico not formed in Cretaceous limestone. The caves are developed in the Oligocene Mompuyil Formation, a marine platform limestone composed largely of calcarenites and terrigenous clastics. The Simojovel Formation, a suite of littoral sand, silt, and some interbedded limestone, is described as conformably overlying the Mompuyil, but the contact is clearly karstified in some areas. The occurrence of gypsum speleothems in several caves indicates the presence of pyrite or other sulfate- yielding minerals within the clastics. Quartz-rich sands, eroded from the Simojovel, cover the floors of many cave passages. However, surface erosion due to recent deforestation has filled and nearly-filled some passages with soil deposits over 10 m deep.

Three major cave systems are known: Cueva del Arroyo Grande (10.2 km long, 292 m deep), Sima Soconusco (8.7 km long, 510 m deep), and Cueva del Aire Fresco (8.6 km long, 280 m deep). Arroyo Grande is a fossil phreatic maze formed under a low hydraulic gradient that existed prior to the incision of the modern valleys. Soconusco and Aire Fresco formed more recently in response to that incision, and Aire Fresco probably pirated flow from Arroyo Grande. Soconusco is a system of hydrologically active vadose shafts and passages formed along the retreating margin of the Simojovel Formation. They feed into the large base level conduits of Aire Fresco, which is collapsed at its downgradient end and forms a roughly 200-m-long valley. This yet-to-be-connected group of caves discharges with an estimated baseflow of 1 m3/s through rubble at the lower end of the valley. Most passages in the area are stratigraphically and structurally controlled: perched on sandstone beds and running down the 14-19° dip. The geometry of the base level passages, and their volume of peak flow discharge (as suggested by sediment deposition and flow features) and baseflow discharge indicate that most of the cave system has yet to be found.

SPECIAL SYMPOSIUM ON GEOLOGY OF THE GUADALUPE MOUNTAINS

Session Chairs: Harvey R. DuChene & Donald G. Davis

Extraordinary Features of Lechuguilla Cave, New Mexico

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Lechuguilla Cave is remarkable for a characteristic suite of geologic features: some of them virtually unique to this cave, others previously known but much better-developed and/or more abundant here than elsewhere. These features, which fall into several classes listed below, will be illustrated and concisely explained.

SPELEOGENS: Acid lake basins, Subterranean karren fields

SPELEOGENETIC DEPOSITS: Gypsum “glaciers”, Sulfur masses

ATMOSPHERIC SPELEOFACTS: Corrosion residue, Rimmed vents, Horizontal corrosion/evaporation lines

SPELEOTHEMS OF UNORTHODOX ORIGIN: Biothems: Rusticles, Pool finger complex;

COMMON-ION-EFFECT SPELEOTHEMS: Common-ion-effect stalactites, Subaqueous helictites; Evaporative speleothems: “Chandelier” stalactites and stalagmites, Giant gypsum hairs, Hydromagnesite fronds, Folia, Raft accumulations and cones, “Silticles”, Splash rings

Permian (Guadalupian) Stratigraphy of the Guadalupe Mountains

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The limestone, dolomite and sandstone beds of the Guadalupe Mountains are part of the Permian (Guadalupian)-age Capitan Reef Complex of New Mexico and west Texas. The Capitan Reef Complex is divided into three major depositional areas: 1) reef, 2) lagoon, (also called “backreef”), and 3) basin. The rocks in each area have distinct stratigraphic characteristics. In the reef, clean, highly fossiliferous limestones and dolomites predominate. On the landward side, lagoonal sediments consist mostly of limestone and dolomite and a few interbedded layers of sandstone. Carbonate rocks become progressively more evaporitic and less fossiliferous toward land. On the seaward side, there is a steep debris slope composed of material that eroded off the reef. Near the base of this slope, reef debris interfingers with dark gray, poorly fossiliferous limestones and fine-grained sandstones of the Delaware basin.

There are two reefs in the Guadalupe Mountains, the older Goat Seep Formation and the younger Capitan Formation. The Artesia Group includes five formations composed mostly of backreef sediments. From oldest to youngest, they are the Grayburg, Queen, Seven Rivers, Yates and Tansill. The Queen and the younger part of the Grayburg formations are equivalent to the Goat Seep Formation. The Seven Rivers, Yates and Tansill are equivalent to the Capitan Formation. In the Delaware basin, the Cherry Canyon Formation is equivalent to the Goat Seep, and the Bell Canyon Formation is equivalent to the Capitan.

Most caves in the Guadalupe Mountains are located in the Capitan, Yates and Seven Rivers Formations. Understanding the stratigraphy of the Permian rocks of the Guadalupes helps cavers understand the origin of known caves as well providing clues to the location of undiscovered caves.

The Lechuguilla Cave Mineralogical and Geological Inventory Project

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In 1992, at the start of the Lechuguilla Cave Mineralogical and Geological Inventory Project (LMIP), a method for the capture and recovery of geologic information was needed. It was suggested that a series of relational databases using software for the Personal Computer (PC) would be a good solution for the problem. With the help of cavers familiar with Lechuguilla, a series of databases covering 146 parameters in the cave was developed. The databases are 1) aragonite speleothems, 2) calcite speleothems, 3) sulfate speleothems, 4) miscellaneous minerals, 5) water, 6) Pleistocene and Permian paleontology, 7) bedrock features, and 8) speleogenetic features.

Inventory data is keyed to survey stations within Lechuguilla. A team of cavers follows a specific survey, stopping at each station to record geological and mineralogical information on standardized inventory forms. Data from the completed forms is entered into FOXPRO, a relational database manager.

Once data is entered, new databases can be created within FOXPRO for a specific feature or set of features in the cave. The new database is exported to a mapping program that displays all of the survey stations in the cave. Survey stations with features listed in the new database are shown in a different color, and their distribution in the three-dimensional cave system is easily seen.

What is the use of inventory? Scientists, cave managers and explorers all use the information to better understand speleothem distribution, speleogenesis, environment and ecology in Lechuguilla. However, the most important benefit of the LMIP may be increased awareness of the underground environment by explorers who learn by collecting data that a cave is more than a hole in the ground surrounded by rock.

Geochemistry of Carlsbad Cavern Pool Waters

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Water samples from 10 pools throughout Carlsbad Cavern have been collected and analyzed on a quarterly basis for pH, temperature, electrical conductivity, alkalinity, and the concentrations of major and trace inorganic solutes. The temperature, relative humidity, and carbon dioxide concentration of the cave air adjacent to each of the pools were also measured.

Different pools vary markedly in chemical composition from one another. The waters range from very fresh (TDS 300 mg/L) to saline (TDS 10,000 mg/L). The salinity of the pool waters does not correlate with depth beneath the land surface, and the pool at the lowest elevation in the cave (Lake of the Clouds) is among the pools containing the lowest concentrations of dissolved solutes. The most dilute pool waters are of the calcium-magnesium-bicarbonate type, whereas the most saline pool (Iron Pool) contains a magnesium-sulfate water. Based on computer model simulations, most pools are saturated or supersaturated with respect to calcite, and a few pools are also saturated with gypsum or hydromagnesite.

A geochemical tracer study was initiated to assess the leakage rate of water from the pools. The results indicate that bromide concentrations have been declining only slowly following tracer introduction. This suggests that the pools are not leaking at a significant rate during this time period. The low dissolved solute concentrations observed in most of the pools, coupled with the apparent long residence time for the bromide tracer, indicate that the pools are recharged periodically by infrequent precipitation events separated by long quiescent periods of slow evaporation with minimal leakage.

Geology of the Delaware Basin

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A brief background survey of the geology of the Delaware Basin is presented in order to help the caver understand how the caves of the Guadalupe Mountains relate to a regional geological setting. Four episodes of karsting have occurred in the Guadalupe Mountains: Stage 1 fissure karst (Late Permian), Stage 2 spongework karst (Mesozoic), Stage 3 thermal karst (Miocene), and Stage 4 sulfuric acid karst (late Miocene to present). Stage 1 fissure karst is developed along joints and is filled with breccia and a mudstone and/or spar matrix; Stage 2 spongework karst forms a spongework (small holes) matrix in the bedrock; Stage 3 thermal karst is lined with large calcite (dogtooth) spar crystals; and Stage 4 sulfuric acid karst forms the large, explorable, cave passages such as in Carlsbad Cavern and Lechuguilla Cave.

Stage 4 sulfuric acid caves are genetically related to hydrocarbons and economic sulfur deposits (e.g., Culverson sulfur mine) in the basin, and to Mississippi Valley-type lead-zinc deposits (e.g., Queen of Guadalupes gossan) in the reef by a series of sulfur-redox reactions. Caves also occur in the Capitan Limestone of the Apache and Glass Mountain sections of the Delaware Basin. Caves in the Glass Mountains are known to be sulfuric acid caves like those in the Guadalupe Mountains.

History of Sulfuric Acid Theory of Speleogenesis in the Guadalupe Mountains

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Steven Egemeier, in a 1971 report to Carlsbad Caverns National Park, first suggested that the large rooms of Carlsbad Cavern may be the result of solution by sulfuric acid. Egemeier's thesis, published in 1973 at Stanford University, again mentioned the possibility of sulfuric acid origin based on his replacement-solution, sulfuric acid theory for the Kane Caves, Wyoming. Based on field work completed in 1973, and completely independent of Egemeier, David Jagnow published his MS Thesis in 1977, proposing a sulfuric acid origin for the Guadalupe caves. Jagnow attributed the source of the sulfuric acid to oxidation of pyrite in the overlying Yates Formation during uplift of the Guadalupe block. In 1979, Carol Hill did the first sulfur isotope determination on gypsum blocks in the Big Room of Carlsbad Cavern, proving that the gypsum was not derived from the Castille gypsum in the Permian Basin. Hill also determined that endellite was formed under sulfuric acid conditions. In 1979 and 1980, Donald Davis was the first to propose a hydrocarbon source for the hydrogen-sulfide/sulfuric acid origin for gypsum and sulfur.

Since the early 1980s, the theory of sulfuric acid solution for the Guadalupe caves has been largely accepted. Additional studies of endellite, silica deposits, isotopically light gypsum and sulfur, the presence of alunite, natroalunite, tyuyamunite, and other unique minerals all point to basinal degassing of hydrogen sulfide as the most likely source of the sulfuric acid solution. Debate continues over the migration routes of the gases or brines derived from the underlying formations. This unique origin is the reason the Guadalupe Mountains contain spectacular world-class caves.

Hydrology of the Capitan Aquifer: Past and Present

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The Capitan Aquifer, consisting of the Capitan and Goat Seep Limestones and associated carbonate rocks in the San Andres Limestone, supplies large quantities of water to wells used by the City of Carlsbad and associatedirrigation areas. Some wells have produced more than 4,000 gpm. Three stages can be identified in the evolution of this productive aquifer: 1) initial uplift and erosion exposed the aquifer and allowed rainfall to enter and replace or dilute the saline water in the aquifer; 2) leakage through overlying sediments lowered water levels in the aquifer, created breccia pipes, and allowed increased inflow of fresh rainwater; 3) the Pecos River eroded sediments overlying the aquifer, established Carlsbad Springs, and increased circulation, and thus transmissivity, in the aquifer west of the Pecos.

The large caves in the Guadalupes appear to have formed independently of the preexisting trends in transmissivity of the aquifer. Increased groundwater circulation created a zone of very large transmissivity extending from east of the town of Carlsbad to the Dark Canyon well field. Near Whites City, the aquifer is less transmissive, and in the vicinity of Lechuguilla Cave, an increased hydraulic gradient, water-level fluctuations in the cave, and a single test well indicate that the transmissivity may be further reduced.

Much of the recharge to the aquifer takes place north of the Guadalupe Mountains by infiltration of surface runoff and by leakage from perched aquifers in the back-reef sediments. In the Guadalupe Mountains, caves allow observation of the principal mechanisms as infiltration directly along fractures, drainage from perched aquifers, and capillary water slowly moving through the rock matrix.

Canary-Yellow Cave Precipitates: Late-Stage Hydrated Uranyl Vanadate, Uranyl Silicate, and Iron Sulfate Cave Minerals

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Many occurrences of yellow cave deposits have been erroneously or prematurely identified as elemental sulfur. The recent discovery of metatyuyamunite in Spider Cave, Carlsbad Caverns National Park, New Mexico, has prompted more careful examination of these yellow minerals in caves of the Guadalupe Mountains. In addition, similar canary-yellow minerals sites have been investigated in Horsethief Cave, Wyoming, Porcupine Cave, Colorado and a cave in northern Chihuahua, Mexico.

Canary-yellow minerals identified from six different caves by x-ray diffraction analysis and electron microscopy include metatyuyamunite, tyuyamunite, carnotite, boltwoodite, copiapite, coquimbite, and roemerite. Metatyuyamunite, tyuyamunite, carnotite and boltwoodite are all uranium minerals. Copiapite and coquimbite are hydrated iron sulfates; roemerite, usually lavender but sometimes yellow, is also a hydrated iron sulfate. Carnotite, boltwoodite, copiapite, and roemerite have not previously been identified as cave minerals.

Cave Patterns in the Guadalupe Mountains

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Caves in the Guadalupe Mountains have distinctive patterns shared by few caves elsewhere. These patterns reflect an interplay between sulfuric acid speleogenesis and the local geologic setting. The typical Guadalupe cave has a ramifying pattern with branches emanating at various levels from central areas. However, parts of many caves exhibit network or sponge-work patterns and some consist of simple widening of fissures.

The ramifying pattern is typical of caves formed by the oxidation of rising hydrogen sulfide. It entered the caves through presently sediment- choked fissures that extend below major cave levels up to 50 m deep. Such rifts narrow downward and are typically vertical or inclined at angles up to 40°. Large domed rooms are located where oxidation has persisted at the same site for a long time. Outflow from these areas took place through lateral conduits to the most efficient available outlet. Altitudes of lateral passages decreased as the local base level dropped. Because the location of available outlets changed with time, it is common for lateral conduits to extend in a variety of directions. Many of these passages are nearly horizontal but are discordant to bedding, so they almost certainly represent former water tables. Some upper-level passages are not horizontal, but rise in a series of arcs toward former outlets above the present cave levels. This configuration shows that mixing of oxygen-rich water with water must have taken place well below the water table and continued over vertical distances as great as 250 m.

Networks and fissures formed either by dispersed flow rising from below or by local bursts of acidity. Spongework formed by local bursts of acidity in areas of high primary porosity. The large pores in the Capitan limestone favored spongework.

HISTORY SESSION

Session Chair: Susan Holler

The Truth About the Gold of Spanish Cave

Donald G. Davis, 441 S. Kearney St., Denver, CO 80224-1237

For more than 60 years, newspapers, magazines, books, and television have promulgated tales about a lost Spanish gold mine, with skeletons and ancient relics, concealed in the mysterious depths of Spanish Cave in Colorado's mountains. My research from 1960 to 1995, however, has failed to produce sound confirmation that the Spanish ever saw or entered the cave. The "Spanish" cross and artifacts are more probably attributable to an 1870s colony of German settlers below the mountain.

Music in the Mammoth Cave: An Inquiry into an Important Aspect of 19th Century Cave Tourism

Joseph C. Douglas, 11700 Fuqua St. #104, Houston, TX 77034

Music was a significant component of most tourist trips into Mammoth Cave, Kentucky, during the 19th Century. Visitors to the cave often perceived natural and man-made sounds in the cave as musical. Tourists also frequently made their own music while visiting the cave, using voices and instruments. In addition, the guides to the cave typically sang for the tourists during their excursions. Finally, professional musicians, whether members of the Mammoth Cave Hotel band or travelers like Ole Bull, visited the cave and sometimes performed. Although not usually thought of as an important part of caving in the 20th Century, music was an integral part of the cave experience in the 19th Century.

South Carolina's Historic Rockhouse and the Great Flat Rock Revisited

Cato Holler, Jr., P.O. Box 100, Old Fort, NC 28762 and Nancy Holler Aulenbach, 115 Ashley Lakes Drive, Norcross, GA 30092

Two historic South Carolina caves in granitic rock were first described by John Drayton, governor of the Palmetto State, in 1802. In his monumental book entitled A View of South Carolina as Respects Her Natural and Civil Concerns, Drayton paints a romantic description of a large talus cave on Flat Creek, which he refers to as the Rock House. In addition, he refers to "two caverns" located at the base of the Great Flat Rock, now known as Forty Acre Rock. Additional 19th Century literature re-emphasized the significance of these sites.

The latter caves are now part of a Nature Conservancy Preserve and frequently visited, but the location of Rock House Cave has, until recently, been lost with time. While engaged in field work for the Carolina Cave Survey, we mentioned our search for the Rock House to a local hunter, Kenny Henson. After he had read a copy of Drayton's description, he felt that he had come across that very site a short time before. With his excellent directions, we were able to relocated the cave the following day. Indeed, the 19th Century descriptions of the area were not exaggerated: "Upon the whole, the cascade of Juan Fernandez, celebrated by circumnavigators, may be more beautiful; as that of Niagara is more grand and sublime; but still this Rockhouse and cascade would rank high in ornamental gardening with all those..."

Preserving NSS Guidebooks on CD-ROM

Garry Petrie, 19880 NW Nestucca Dr., Portland, OR 97229-2877

Every year more originals of limited publication guidebooks are lost. The conventional process is to preserve books on microfilm.

Today, it is possible to more than preserve the image of the printed page. Using the Help system of Microsoft's Windows, a guidebook's text, maps, and photographs can be saved and made accessible. The text can be indexed, searched, and linked. The photographs can be digitized in full color and resolution. A guidebook on a CD-ROM can give an old document new life and preserve it for hundreds of years.

INTERNATIONAL EXPLORATION

Session Chair: Nancy Pistole

Caves of India: Exploration of an Emerging Significant Karst Region

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The Indian subcontinent was not known for its karst until 1992 when cave explorers from Bristol Exploration Club and Orpheus Caving Club, UK recognized for the first time the great potential for cave development in northeastern India. The extensive deposits of limestone, up to 350 m (1160 ft) thick, occur in the state of Meghalaya (The Abode of The Clouds) just north of Bangladesh. The hot and humid summer climate offers on average 12 m (40 ft) of rainfall annually. In fact, the highest rainfall in the world was measured in the Khasi Hills at 26.5 m/year (87 ft/year). The combination of a limestone massif and torrential precipitation, as predicted, created a significant karst.

Expeditions during 1994 and 1995 provided further evidence of extensive river caves of mainly horizontal profile as well as vertical shafts with depths to 60 m (nearly 200 ft). Tetengkol was surveyed to 5.3 km (3.3 mi) to become the longest cave in the Indian subcontinent. Krem Mawmluh (4.5 km; 2.8 mi), a fine river cave with passages up to 30 m wide by 25 m high (100 ft x 83 ft), was partly damaged by cement waste. Siju Dobhakol (Cave of the Bats), her biota, houses in its 4.4 km (2.7 mi) of passages a large bat colony, among other biota. Along with limestone, calcareous sandstone lends itself to speleogenesis in this region. Entirely formed in such sandstone, Krem Dam was surveyed to 1.3 km (0.8 mi) to yield the longest sandstone cave in this part of the world. The three expeditions have now resulted in nearly 33 km (21 mi) of surveyed cave passage with prospects for considerably more.

Caves of the Republic of Mauritius

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Two sizable volcanic islands constitute the bulk of the Republic of Mauritius. Solutional borehole caves up to 1.25 km in length exist beneath a subdued epikarst, in calcarenite, on the island of Rodrigues. Numerous lava tube caves of varying sizes are on the island of Mauritius proper. Some occur along the length of curvilinear systems. The vulcanospeleology of the island of Mauritius is compared to that of the island of Kauai, Hawaii.

The Caves and Karst of the Rio Encantado Area, Northwest Puerto Rico

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Recent exploration and threats to the karst near the Rio Encantado have spurred new interest in this extensive system. The Rio Encantado cave contains a world-class river traversable for over 15.9 km—a subterranean record. Severa l groups have explored the cave over several years. Much of the cave was explored as separate segments and linked together by passing obstacles of different sorts. Each linked segment has its own character ranging from huge wandering canyons to sporting waterfalls and sumps. Several major (and growing) disconnected fragments remain and potential exists for further integration of both the most upstream portions and tributaries. While the new exploration has excited greater interest, the most pressing concern is the very rapid destruction of the karst landforms due to massive development and quarry activities. The destruction of caves and important geologic features (as well as archaeological sites) has inspired renewed work to document the area and provide data for the proposed creation of a karst preserve.

Caving in Cuba: A Taste of the Forbidden Fruit

Cato Holler & Susan Holler, P.O. Box 100, Old Fort, NC 28762

Cuba consists of one large island and approximately 1600 smaller ones. The main island measures 1230 km long and 219 km across at its widest point, approximately the size of Pennsylvania. Towering mountains, up to ~200 m above sea level, cover one-fourth of the island, which is over 60% limestone. Although Cuba lies only 146 km off the coast of Florida, few US speleologists have visited due to travel restrictions and a long standing embargo.

Since September 1992, Cato and Susan Holler and a handful of other US cavers have made three expeditions to explore Cuban caves. On their first trip, they were the first US cavers to set foot in the Ancon Valley region of western Cuba. They also visited the world-class, 48 km long Santo Tomas Cave.

In 1993, the couple returned to rejoin some of their Cuban friends for additional exploration in Santo Tomas, and also the 35 km Majaguas—Canteras system. Following a difficult climb up the steep wall of a mogote, they were privileged to visit a special and rarely visited cave named Marilu. With its sparkling crystal walls and outlandish helictites, it is truly reminiscent of Caverns of Sonora.

In a 1995 visit which carried the Explorer's Club flag, Cato and Susan concentrated on the photodocumentation of several caves in the Matanzas province. Ambrosio has incredible pictographs and Santa Catalina displays a forest of stone mushrooms. The discovery of Cuba's first calcite bubbles, a look at geyser stalagmites, and sharing passages with large tarantulas and boa constrictors added interest to the exploration.

Caving in Switzerland Is Not Only Going 1000 m Deep and 100 km Long

Roman Hapka

Surely you know our little, tiny country for its chocolate and cheese and mountains. As you are a real caver, you know also that this little, tiny country has some of the deepest (-330 m in the Siebenhengsten System, 1060 in the Muttseehvhle) and longest (160 km for the Holloch and 140 km for the Sieben...) caves of the world. But our tiny country also has plenty of tiny caves. To date, the members of the Swiss Speleological Society have explored more than 2000 of them. So, even if you don't like chocolate or hate the smell of cheese or have some problems going up in the mountains, you will like Switzerland. Why? Because you are a real caver.

News in the Kugitangtou Caves Exploration

Vladimir A. Maltsev, Leninsky prosp. 61/1-57, Moscow 117333, RUSSIA

Kugitangtou Ridge caves are atypical in all the senses. Speleothems are extremely variable, beautiful, and rare. Cave fauna age estimation contradict the known geological history of the area. Along with huge and beautiful chambers' existence, all of the last 15 years of finds (including huge new areas) appear from extensive digging through narrow collapsed mazes that makes exploration doubly hard—both for technical and psychological reasons.

Nowadays, the largest cave is Cupp-Coutunn Main, 61 km. long. Four more large caves (1.5 km, 3.2 km, 4.2 km, 8.5 km) share the same hydrological system. In the other 10-15 systems, no systematic exploration has begun, and only 1-3 km caves are known.

The last scientific studies in the caves show very interesting things: how minor changes in the cave environment (digging through narrow passages) may cause speleothem dissolution or vice versa (fast new speleothem growth).

The last expedition (April 1996) displayed two new ecological problems with the Kugitangtou caves, that are yet to be solved: a) As a result of great economic difficulties in Turkmenistan, the caves are again considered as a source of cheap "marble onyx" souvenirs—striped calcite from flowstones. A new mining project might start in about a year. b) The Provull cave, residence of the troglobitic loach (a unique troglobitic fish), is polluted. In spite of all the efforts for its conservation, declared by the Turkmenistan government, a new sheep farm was located nearby, and this spring several tons of sheep feces were moved by a mudflow into the entrance. It's still unknown whether the blind loaches survived after it.

Continuing Exploration in Cueva Cheve, Oaxaca, Mexico

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Cueva Cheve is located in the Sierra Juarez in northern Oaxaca, and is one of the deepest caves in Mexico at -1,386 meters. It is currently almost 25 km long. In February of 1995, a group of cavers camped at the end of the cave for 12 days and attempted to find a way through the massive breakdown choke that has been preventing progress toward the known resurgence at the Rio Santa Domingo. The group had limited success: they worked their way upward through the breakdown, and finally encountered a solid wall and ceiling. This may help lead the way to more open borehole along a fault system, which has characterized the cave so far.

Soconusco Area, Chiapas, Mexico

Nancy Pistole, 4105 Lowell Ave, La Crescenta CA 91214

The small town of Soconusco is located in Chiapas, halfway between Tuxtla Gutierrez and Villahermosa. It is part of Proyecto Cerro Blanco, which also includes the Arroyo Grande and Yerba Buena areas. In the last two years, several groups have discovered, explored, and surveyed many new pits and caves, and several known caves have been connected. Of note, a 250 m pit, La Ventana, was discovered in Cueva Dos Puentes. Cueva La Pedrada has a 217 m entrance pit, and then follows a stream for more than a kilometer until a sump is reached. The latest find, Cueva Darwin, begins with a 180 m entrance pit and connects to Cueva Soconusco. The Muleshoe system was also connected to Cueva Soconusco, making the overall system length close to 5 km. There is a great potential for finding more caves in the area.

PALEONTOLOGY

Session Chair: E. Ray Garton

The Paleoecological Record of the Eastern Grand Canyon Prior to the Last Glacial Maximum

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Previous investigations of solutional cave systems in Grand Canyon National Park have revealed extensive deposits of archaeological and paleontological resources. The dry climate and constant temperatures within these caves have resulted in excellent preservation of plant and animal remains that provide considerable information on the paleoecology of Grand Canyon during the Pleistocene Epoch. These caves commonly contain botanical materials preserved in packrat (genus middens that frequently date to the late Pleistocene. Packrat middens often preserve a high-resolution paleoclimatic record of botanical and faunal relationships that existed near the caves during the period of accumulation. The majority of middens found within the Grand Canyon typically date between 10,000 BP (radiocarbon years Before Present) and 13,000 BP, and middens older than 25,000 BP, and thus recording conditions prior to the height of the most recent glacial event, the Wisconsinan glacial maximum, are relatively rare. Here I report 22 new radiocarbon dates on packrat middens collected in 1984 and 1993. The dates on middens collected from cave sites along the river corridor are slightly older than average, falling between 12,830±70 BP and 16,620±110 BP. The exceptions were middens collected from caves in one minor tributary at River Km 80. Six middens yielded a mid-Wisconsinan glacial age, dating from 29,980±300 to 46,370±3270 BP. These are the oldest dates for middens found in the Grand Canyon. These middens will allow examination of mid-Wisconsinan plant communities that were present prior the last glacial maximum. Further, two sequences of dates were obtained from two cave localities, ranging from 13,970±90 to 46,370±3270 BP for Rebound Cave (six dates) and 18,120±100 to 44,480±1700 (five dates) for Crescendo Cave.

The Second Record of the Extinct Armadillo *Dasypus Bellus* from West Virgina

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The discovery of some 100 osteoderms, one cervical vertebra, one tooth, and other bone fragments of the extinct armadillo, *Dasypus bellus*, from Alaina P Cave in Berkeley County represents the second record for this species from West Virginia. The new discovery is about 200 km (120 mi) northeast of the only previous discovery of *Dasypus bellus* in the state, a single band osteoderm from Organ Cave, Greenbrier County. The discovery from Alaina P Cave represents a northeastern range extension for the species. Both movable band and buckler osteoderms are represented in the Alaina P collection along with some as yet unidentified skeletal fragments. Some of the movable band osteoderms are quite large in comparison with the single specimen from Organ Cave. So far, no other species have been found in Alaina P Cave and the age of the *Dasypus bellus* cannot be determined beyond the probability of being middle to late Pleistocene, ca. 500,000 to 12,000 years BP.

Paleontological Investigations at Kartchner Caverns, Southern Arizona

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Kartchner Caverns is being developed as the 26th State Park in Arizona and is in a developmental phase for tourism. In addition to being an ecologically fragile, geologically complex, and actively wet limestone cave system, the cavern has preserved a valuable paleoecological record. A small scale paleontological survey suggests the cavern may have had variable and possibly short-lived entrances during the course of the Pleistocene and Holocene thus accumulating and preserving sediments and faunal remains that could lead to a better understanding of the ecological changes that occurred in the San Pedro Valley over at least the last 200,000 years.

Paleontological salvage and testing has focused in the Echo Passage and Tarantula Room. Remains of a ground sloth have tentatively been ascribed to the Rancholabrean-age Shasta ground sloth. Most of the sloth bones are at least partly cemented in travertine, with exposed portions extremely friable and covered in wet clay. A new type of preservative proved useful in stabilizing and preserving the wet bone. Removing bone from the travertine was not feasible and therefore the objective was to expose, measure, preserve, and photograph as much of the remains as possible. A Uranium-series analysis is pending for the age of the travertine that covered the sloth.

The Tarantula Room will be the staging area for tours in the cave and therefore the removal of large amounts of apparently Holocene-age sediment is planned. Samples from this debris cone are producing microfaunal remains.

LATE PLEISTOCENE PALEOECOLOGY OF THE MISSOURI OZARKS VIA MAMMALIAN FAUNA FROM LITTLE BEAVER CAVE, PHELPS COUNTY, MISSOURI: A PRELIMINARY REPORT

Blaine W. Schubert, Quaternary Studies Program, Northern Arizona University, Flagstaff, AZ 86011-5644

Paleontological investigations of caves in the Ozarks have yielded extensive faunal records for the last “Ice Age” or Pleistocene Epoch (1.8 Ma to 11 Ka). However, past analyses of Pleistocene cave deposits in the Ozarks lacked adequate temporal and/or stratigraphic control, due to unsuccessful attempts at radiocarbon dating. Excavations during the summer of 1994 and 1995 (with Russell Graham, Illinois State Museum) confirmed a rich faunal deposit with extinct, extralimital, and locally extant mammals. New techniques in targeting individual amino acids in bone (Tom Stafford, INSTAAR) in conjunction with advanced radiometric dating (accelerator mass spectrometry: AMS) have been utilized to gain temporal control. A total of three AMS 14C dates on bone samples represent the Pleistocene/Holocene boundary (10,000-11,000 yr. BP).

Extralimital species recorded from Little Beaver Cave include the meadow vole (red-backed vole) and porcupine. Extinct species from the cave are Jefferson’s ground sloth and the beautiful armadillo. An AMS 14C date of 11,000±60 yr. BP on an armadillo scute represents the youngest directly dated specimen for this Dasypus variant. According to this date, the proposed extinction or possible migration and/or size reduction of did not occur prior to the Pleistocene/Holocene transition in this area of Missouri. In addition, finding a boreal extralimital species associated with the presumed neotropical inferred from helps support the hypothesis that the terminal Pleistocene Ozarks had a more equable climate than today.

SPECIAL PALEONTOLOGY SYMPOSIUM ON PORCUPINE CAVE, PARK COUNTY, COLORADO

Session Chair: E. Ray Garton

PORCUPINE CAVE, PARK COUNTY, COLORADO: THE CARNIVORE FAUNA

Elaine Anderson, Research Associate in Zoology, Denver Museum of Natural History, Denver, CO 80107

At least 20 species of carnivores, eight of which are extinct, are represented in the Porcupine Cave mammalian fauna. They include the oldest record of black-footed ferret (and the first Irvingtonian records in the western United States of a fisher (wolverine (cf. short-faced skunk (and cheetah (cf. The Canidae include coyote, the extinct Edward’s wolf, red, kit and gray foxes, and a small unknown species of The are represented by badgers (the most numerous carnivore present), wolverines, two weasels (long-tailed weasel and ermine), mink, black footed ferret, a new species of marten, fisher, three species of skunks (spotted, striped, and short-faced), and otters. Specimens of the are rare, but include the bobcat and an extinct cheetah (including partial skulls of two cheetah kittens). An isolated premolar may represent the coati (a member of the So far there are no bears, saber-toothed cats, or other large cats in the fauna. There were at least 35 species of rodents, lagomorphs and hoofed-animals which provided prey for the carnivores. From the large number of specimens of carnivores (more than 200 specimens were collected in 1994 alone), it seems likely that Porcupine Cave functioned as a carnivore trap during at least part of its long history. Wolves, badgers, skunks and perhaps some other smaller carnivores denned, brought in prey, or died in the cave. Today, eleven extant species of carnivores are found in Park County, and four others have been extirpated within the last 120 years. Remains from ten of these species have been found in Porcupine Cave, thus these carnivores have had a long history in the area.

PORCUPINE CAVE, PARK COUNTY, COLORADO THE IRVINGTONIAN FAUNA

Elaine Anderson, Research Associate in Zoology, Denver Museum of Natural History, Denver, CO 80107 & Louis H. Taylor, Research Associate in Earth Sciences, Denver Museum of Natural History, Denver, CO 80107

The Irvingtonian fauna from Porcupine Cave was collected from strata distributed through as much as 1.5 million years. Several thousand specimens of land snails, fish, amphibians, reptiles, birds and mammals have been recovered. Fossils occur in a fissure and in several rooms in the cave. Deposits from the areas known as The Pit and Velvet Room are stratified and record major environmental changes—from relatively humid glacial to warmer, dry interglacial conditions.

The fauna (in general) reflects these changes; marmot and pika remains occur within the glacial layers while prairie dogs, ground squirrels, and sagebrush voles are common in the interglacial layers. Fish are rare. Amphibians include frogs, toads, and salamanders. Lizards and snakes, especially garter snakes, are present. The avian fauna includes several raptors, a goose, a grouse, a wader, and many passerines. At least 65 different species of mammals are present, more than at any other Irvingtonian site in North America. Some 35 species of lagomorphs, rodents, and hoofed animals served as prey for the 20+ species of carnivores.

Shrews and bats are rare; rabbits are abundant; and rodents, including many extinct species, are common. Extinct taxa include horses, peccary, camel, antilocaprids, musk-ox, wolf, cheetah, and a mylodont ground sloth. So far, remains of proboscideans, bears, and large cats have not been found in the cave possibly because of their large size or because of an incomplete sampling record.

Porcupine Cave, Park County, Colorado: What Drives Community Reorganization? Implications of Superposed Fauna From Porcupine Cave

Anthony D. Barnosky, Mountain Research Center, Montana State University, Bozeman, MT 59717 & Christopher J. Bell , Museum of Vertebrate Zoology, University of California, Berkeley, CA 94720

Information from a richly fossiliferous, stratified sequence of fossil vertebrates from the Pit locality in Porcupine Cave sheds light on how climate change may or may not drive major reorganizations of vertebrate communities (especially the mammalian component). Biostratigraphic and paleomagnetic dating and correlations suggest that the sequence spans at least one transition from glacial to interglacial times between approximately 365,000 and 487,000 years ago, and that lower parts of the sequence include additional glacial-interglacial transitions that predate the Brunhes-Matuyama boundary. The major transition between glacial and interglacial times corresponds with changes in the mammalian community that include: 1) changes in relative abundance of various taxa, and 2) at least local extirpation of very few taxa. However, the no-analog assemblage of species that existed during the cold time did not disintegrate as the climate shifted to a warmer regime. Community changes that took place in the middle Pleistocene did not approach the magnitude of community changes that took place at the terminal Pleistocene shift from the last glacial into the present interglacial, which included wholesale restructuring of species assemblages through extinction of assemblages. The differences in community response to climate change indicate that the late Pleistocene-Holocene transition is not the universal model for the response of mammals to global warming, and that other transitions should be examined to understand what responses are common to all global warming events, and which responses are unique to specific events.

Porcupine Cave, Park County, Colorado: The Microtine Rodents and the Changing Face of Irvingtonian Microtine Rodent Biochronology

Christopher J. Bell, Museum of Vertebrate Zoology, University of California, Berkeley, CA 94720 & Anthony D. Barnosky, Mountain Research Center, Montana State University, Bozeman, MT 59717

A stratified sequence of sediments in the Pit Locality of Porcupine Cave produced a diverse mammalian assemblage including at least 11 species of microtine rodents. At 2900 meters, Porcupine Cave represents the first high-elevation site to produce an extensive microtine rodent assemblage; the fauna is unique and includes taxa widespread in the Irvingtonian, taxa that are relatively rare, and many associations of taxa that have never previously been found together. Three possible explanations for the associations of these taxa are proposed. The presence of taxa that are elsewhere known only from lower elevations at earlier times suggests that Porcupine Cave may be sampling from a refugium habitat (cf. sp.). The seemingly anomalous occurrence of taxa that are elsewhere known from much later times may indicate that the cave is situated along a dispersal corridor in the Rocky Mountains and therefore samples early populations of presumed immigrant taxa (sp.). Detailed morphological analysis of fossils of one lineage (reveals a gradational change in complexity of both lower and upper molars and suggests that the cave may be sampling a population undergoing speciation. This morphological change does not appear to be correlated with a transition from glacial to interglacial climatic conditions that is reflected in the sediments.

Porcupine Cave, Park County, Colorado: The Biology of Packrats as Cave Dwellers

Robert B. Finley, Jr., Research Associate in Zoology, Denver Museum of Natural History, Denver, CO 80107

To speleologists the packrat (woodrat), genus is one of a host of animals to be found in caves, and one that has drawn increasing interest because of the wide ramifications of its interactions with the outside world. Those species (of that live in caves also are adapted primarily for life outside of caves and bring evidence of their outside activities into caves in the form of food materials and litter; sticks, bones, scat, and other collected items; and nests made of fine fibrous materials in which they raise their young. They also leave on the rock ledges and walls solid dark deposits and urine stains commonly known to cavers as amberat. Curiosity as to the nature of these introduced materials and how they get there can best be answered with some knowledge of the characteristics and behavior of the packrats that are responsible. This presentation will give some of the basic biology of packrats and show how they make use of caves. An understanding of basic Neotoma ecology will also help cavers appreciate how and why packrat deposits and middens are such a unique resource for study of the past history and evolution of life on earth, both outside and inside of caves. The abundant fragments of plant material and predator scats dropped on the middens and rock shelves by packrats provide an excellent record of ecological communities and climatic changes that have occurred outside the den or cave over thousands of years.

Porcupine Cave, Park County, Colorado: The Geomyid Fauna

Doug Nelson, Department Associate in Earth Science, Denver Museum of Natural History, Denver, CO 80107

Irvingtonian pocket gophers in the Porcupine Cave fauna are of the genus and are represented by at least three species: cf. (extant), cf. (extant), and an indeterminate species. Both of the extant taxa inhabit montane meadows at high elevations in

the western United States. Specimens of the indeterminate taxon are characterized by a narrow, rectangular trigonid on the lower fourth premolar, and are distinct from the other two taxa. Only a single taxon of gopher is present in each of the stratified levels containing gopher fossils in the Denver Museum of Natural History excavation site in the Velvet Room, suggesting that the different species of pocket gophers were not sympatric. The pocket gophers occur in layers with (packrats), (ground squirrels), (prairie dogs), and (rabbits), suggesting that pocket gophers only lived near Porcupine Cave during interglacial episodes.

Porcupine Cave, Park County, Colorado: The Lagomorph Fauna

Colleen N. Ramos, Department Associate in Zoology, Denver Museum of Natural History, Denver, CO 80107

Modern rabbits and hares (Family Leporidae) evolved in the early Pleistocene, but due to difficulty in identifying fossil rabbits, little is known about their early speciations. Pikas (Family Ochotonidae) evolved in the Pliocene and, although rare as fossils, are relatively easier to identify. The genera and are present in the Porcupine cave faunas.

Lagomorphs are the most common fossil group in Porcupine Cave; several thousands of specimens have been catalogued (in over 1100 different entries) into the collections of the Denver Museum of Natural History. Morphometric analysis of modern leporids has enabled identification of the fossil rabbit material and will provide insights into the evolutionary history of the Irvingtonian rabbits from Porcupine Cave. The presence of pikas in the Porcupine Cave fossil assemblages is evidence of cold conditions.

Porcupine Cave, Park County, Colorado: Taphonomy of Irvingtonian Fossils

Donald L. Rasmussen, Research Associate in Earth Sciences, Denver Museum of Natural History, Denver, CO 80107 & Elaine Anderson, Research Associate in Zoology, Denver Museum of Natural History, Denver, CO 80107

Porcupine Cave is in a remote part of South Park at an elevation of 9500 ft (2900 m), is the highest Pleistocene vertebrate site in North America, and contains the richest and most diverse Irvingtonian (early and medial Pleistocene) mammalian fauna in North America. During the Irvingtonian, Porcupine Cave had numerous entrances; all were receiving debris which was washed deep into the cave. Some entrances were used by carnivores for dens, some openings were used by marmots and rabbits, and all openings were used by woodrats (packrats) that built extensive middens and nests deep within the cave. Carnivores left the chewed bones of their prey and even their own bones in areas close to the surface; marmots, rabbits, and other small animals left their skeletons when they fell into the cave and were unable to escape; but most of the bones and teeth, many of which were gnawed, were hauled in by the woodrats. The woodrats even carried in carnivore scat and raptor pellets which were loaded with small jaws, bones and teeth. A partial skeleton of a large camel indicates that at least one entrance trapped large mammals. At about 350,000 years ago, all of the entrances became completely plugged and Porcupine Cave was isolated from the outside, even from the woodrats. Porcupine Cave remained sealed until the late 1800s when it was inadvertently opened by prospectors. These prospectors were the first to find fossil bones in the cave, but the Pleistocene age of the fossils was not recognized until almost a century later.

Porcupine Cave, Park County, Colorado: Geologic History of the Cave

Donald L. Rasmussen & Robert G. Raynolds, Research Associates in Earth Science, Denver Museum of Natural History, Denver, CO 80107

Porcupine Cave is located in Ordovician Manitou carbonates which occur in a prominent N-S ridge along the southwestern part of South Park in central Colorado. Manitou strata dip 30 degrees to the east and the cave system is developed conformably within these tilted beds. Karsting of the Manitou carbonates began in the medial Ordovician during a long period of subaerial exposure and prior to deposition of the overlying transgressive Ordovician Harding Sandstone. The Manitou carbonates were again karsted during vadose and phreatic enlargement of the cave during one or more stages in post-Harding and pre-Laramide time. Numerous cupolas on the ceilings throughout the cave were formed during this time and prior to Laramide tilting (about 50 Ma); their symmetrical hemispherical shapes are now inclined in the same direction as the dipping strata. Subsequent to the final stages of cave enlargement and cupola formation, there was extensive collapse (breakdown) of large blocks from the walls and ceilings (during Laramide tectonism?). This was followed by one or more wet periods during which cave formations developed—prior to the great infilling of clastics during the early and medial Pleistocene (Irvingtonian). Irvingtonian strata are stratified, consist mainly of extensive talus cones, and may contain beds of mud nodules and flowstones. Access by animals existed for one million years or more until the cave was totally sealed from the outside approximately 350,000 years ago. Deposition essentially ceased after the Irvingtonian except for debris from frost- wedging, local ceiling collapse, and evaporation crusts which formed on top of older Pleistocene deposits.

Porcupine Cave, Park County, Colorado: Paleomagnetic Stratigraphy

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Magnetostratigraphic studies in Porcupine Cave were made in the Pit and the Velvet Room. Carbonate-cemented material from the Carnegie Museum excavations in the Pit was analyzed in the late 1980s by Fred Luiszer and Victor Schmidt, and results indicated a probable reversed polarity history. The Denver Museum excavation in the Velvet Room has been sampled annually, beginning in 1993 and was hindered by the strata's dry, unconsolidated character of the strata. All samples were taken from strata at the toe of a talus cone, with the strata dipping approximately 10 degrees. The 1993 sampling effort was unsuccessful because strata in the cubes became disaggregated. In 1994, a large sample of the oldest stratified material was encased in a plaster jacket, dried, and impregnated with epoxy. Of the 29 oriented cubes cut from the block, most preserved the magnetic signal poorly, and only three samples suggested reversed polarity. In 1995, samples were taken using a piston corer/extruder device which was able to obtain tightly packed samples of oriented silty material. Clear reversals were identified. Our present interpretation is that the bulk of the strata in the Velvet Room is reversed and was probably deposited during the Matuyama reversed polarity chron. The majority of the collections from the Velvet Room are thus in excess of 0.78 million years in age. Extinct microtine rodents recovered from the same strata support this interpretation.

Porcupine Cave, Park County, Colorado: Regional Geologic Setting

Robert G. Raynolds and Donald L. Rasmussen, Research Associates in Earth Science, Denver Museum of Natural History, Denver, CO 80107

The Porcupine Cave area has a remarkable geologic history. The cave bearing Ordovician Manitou dolomite lies disconformably on Precambrian granite and is part of a regionally continuous Paleozoic passive margin succession. Early dissolution and fissure formation in the Manitou is marked by a widespread weathering surface and internal ancient karst features. Burial, erosional and uplift events during the Paleozoic dramatically changed the site's landscape. At the end of the Paleozoic, the cave area was buried by over 10000 ft of marine and fluvial strata (mostly Pennsylvanian and Permian in age). By early Mesozoic time, the area was peneplaned, setting the stage for several marine and non-marine depositional events. During the late Cretaceous, the Western Interior Seaway completely inundated the area. In the latest Cretaceous and earliest Tertiary, the Laramide mountain building episode broke the area into high mountain ranges and intervening basins that mimicked the Ancestral Rockies (formed during the late Paleozoic). By medial Eocene time, the area stood as gently rolling terrain and Porcupine Cave was near the surface for the first time since the early Paleozoic. Late Eocene and Oligocene volcanoes released a series of massive ignimbrite, lava and lahar flows. Drainages were blocked, lakes formed, and the landscape was draped with a thick succession of volcanic, fluvial, lacustrine and ash rich eolian deposits. Miocene uplift rejuvenated the landscape and headward-cutting drainages exhumed the Eocene landscape. Porcupine Cave was again near the surface and during the early Pleistocene was open to the surface.

Porcupine Cave, Park County, Colorado: Response to Climate Change in Dental Remains of Middle Pleistocene Cynomys at Porcupine Cave

Tina I. Rouse, Department of Integrative Biology & Museum of Paleontology, University of California, Berkeley, CA 94720 & Anthony D. Barnosky, Mountain Research Center, Montana State University, Bozeman, MT 59717

Porcupine Cave, a high elevation (2900 m) middle Pleistocene site in the Colorado Rocky Mountains, contains many chambers with abundant remains of fossil prairie dogs (During the deposition of the fossils, the region experienced a series of transitions between cool, moist glacial conditions and warmer, drier interglacials. Both subgenera of (i.e., white-tailed, [and black- tailed, [are present, appearing in upper strata which include a glacial-interglacial transition. Currently the subgenera are not generally sympatric. Analysis of the climate space now inhabited by the two subgenera suggests that their sympatry at Porcupine Cave during the middle Pleistocene required effectively warmer and/or drier July conditions in order to allow black-tailed prairie dogs to exist in the area. Climatic inferences from another no-analog assemblage, and suggest effectively moister conditions in January; hence, approximately 400,000 years ago the Porcupine Cave area probably experienced wetter winters and drier summers than presently. Analysis of Porcupine Cave specimens over the climate transitions and comparison to other fossil specimens from throughout North America has proceeded with the aid of a computer morphometric program called MORPHOSYS creating analyses of both interpopulational and intrapopulational morphological changes which suggest a complex morphological response to middle Pleistocene climate changes.

Porcupine Cave, Park County, Colorado: The Artiodactyla and Perissodactyla Faunas

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Fossils of the Order from Porcupine Cave are represented by approximately 100 different bones, partial jaws, and teeth which have been curated into the Denver Museum of Natural History (DMNH) collections. This collection indicates the presence of the tayassuid sp. (peccary), cervids sp. (deer) and sp. (elk), antilocaprids (pronghorns), ovibovine bovids (musk-oxen), and the camelid sp. (camel). Two-thirds of these specimens are from the stratified deposits in the DMNH excavation site in the Velvet Room. At this site, antilocaprids, and are present throughout the stratigraphic section, but and have only a single specimen each. The ovibovine is absent at this site but is known elsewhere in the cave in deposits with a similar age—as are all of the other artiodactyls, the ovibovine, and the antilocaprids represent extinct taxa. They are smaller than other known Irvingtonian forms and probably represents a new taxon. The ovibovine most likely also represents a new taxon, and was as large as the living musk-ox. The antilocaprids include two taxa: one larger and one much smaller than the extant genus.

The fauna is represented by a limited number of specimens, many of which are fragmentary. However, several teeth and foot bones and a partial scapula indicate at least two extinct taxa of one of which is close in size to the extant horse.

RESCUE SESSION

Session Chair: Barbara Moss

Developing a Self Rescue Training Curriculum for the Western Region—A Work in Progress

Cindy Heazlit, 5672 Bluegrass Lane, San Jose, CA 95118

Cavers in the Western Region often travel to very remote areas to do their caving. Many of these areas are not serviced by either SAR or cave rescue teams. Outside response to a cave accident could take hours, even days. In the meantime, the caving party must deal with the accident using only the people and equipment at hand. There has been little information available about the techniques needed for this type of rescue. In the Autumn of 1994 several Western Region cavers formed a committee to research and develop these techniques.

SURVEY AND CARTOGRAPHY SESSION

Session Chair: Roger Bartholomew

Methods to Facilitate Faster Sketching

Mike Futrell, 302 Roseland East, Springfield, OH 45503

The speed of the sketcher more often than not determines the speed of the survey crew and, thus, the amount of passage mapped during the trip. Methods for increasing the rate of sketching fall into two categories: devote less time towards non-sketching activities, and simply sketch faster.

The first point seems obvious. Traveling, eating, talking, and digging are non-sketching activities. Standing around, looking at rocks with a book and pencil in hand is also a non-sketching activity—if the pencil is not moving, you are not sketching. Clean hands, teeth marks on the book, bruised elbows, and the ability to efficiently organize a crew are some indicators of a speedy sketcher.

The Berkshire County, Massachusetts Cave Survey Project: An Introduction and Status Report

William D. Howcroft, 5741/2 St. Lawrence Ave., Reno, NV 89509, <howcroft@hydro.unr.edu>

The small, marble caves of Berkshire County, Massachusetts represent one of the first focus areas of organized caving in the United States. Despite over 50 years of exploration, these caves have remained largely unsurveyed until recently. A systematic survey of all "significant" solution caves and holes, otherwise deemed to be historically relevant, has been conducted for the purposes of documentation and publication. After three years of effort, the project is estimated to be approximately 80% complete with a total Grade 5 survey length in excess of two miles. Included within this figure is Great Radium Springs Cave, New England's second longest solution cave. Pettibone Falls Cave, previously assumed to be Massachusetts' longest cave, has been reassigned to a fourth place position.

Computer Graphics—A FreeHand Way to Generate and Display Your Cave Maps

Bob Richards, 1206 Spinnaker Way, Sugar Land, TX 77478

Cave cartographers will be replacing pen and ink with mouse and monitor as home PCs and graphics software packages become cheaper and easier to use. The use of FreeHand software as a fundamental drawing tool is just one such package available to cave cartographers.

Regardless of how powerful an illustration package is, it won't be useful if you can't draw with it. FreeHand enables you to draw pristine line art and smooth-as-silk technical drawings. Tasks that use to be exceedingly nerve-wracking or downright unlikely 10 years ago—like getting two thick pen lines to meet and form a perfectly sharp or smooth corner—are a breeze now. With very little effort and not much in the way of experience, one can be drawing cave maps that would have made you bleed, sweat, and cry—were you to approach the task using traditional drafting tools.

FreeHand works its precision magic by looking at artwork in terms of objects, which are independent, mathematically defined lines and shapes. For this reason, drawing programs are sometimes said to be object oriented. Understanding how one's object—your cave map —is entered, set-up and executed using a variety of FreeHand tools is essential in creating a successful computer generated cave map.

Effects of Blunders on Survey Accuracy

Fred L. Wefer, Butler Cave Conservation Society, 4600 Duke Street #1310, Alexandria, VA 22304 <fwefer@mitre.com> & Rob Kolstad, BSDI, 5575 Tech Center Dr. #110, Colorado Springs, CO 80919 <kolstad@bsdi.com>

A useful way to classify survey errors is based on the predictability of individual error and the statistical distribution of a large number of errors. This yields three basic error types: Random Errors are not predictable and are caused by rounding measurements, the limited graduation on the instruments, etc. They are typically small and normally distributed. Systematic Errors are predictable, hence correctable. They are caused by instrument misalignment, and personal tendencies, for example. They are typically small and follow a pattern.

Blunders are not predictable and have an unknown distribution. They are caused by cold, fatigue, and sloppiness, for example. They typically occur infrequently, follow no specific pattern, can be of either sign, and of almost any magnitude. Seven types of blunders have been identified and studied.

Loop closures are often used to determine survey accuracy. To explore error attributed to instruments or techniques (vs. blunders), we modeled a typical cave that was then "surveyed" perfectly.

These perfect survey numbers were corrupted to simulate standard instruments (e.g., 1o azimuth accuracy). Loop closure results demonstrated an "average loop closure error" due to instruments. Finally, the observations were perturbed using various blunders. Loop closure errors were again studied.

Blunders are difficult to find and nearly impossible to correct. The best strategy is to anticipate and prevent them. Some techniques for obviating blunders are: use equipment graduated in degrees, use an azimuth compass (not bearing), paint over the percent grade scale, set declination to zero and leave it, follow good survey team procedures, use fore and back shots, verify computer input, compare the plotted traverse line with the sketch, and learn all the positions on the survey team.

US EXPLORATION

Session Chairs: Stan Allison & Jim Pisarowicz

Diving the Lakes of Lechuguilla

David Bunnell, 320 Brook Rd., Boulder Creek, CA 95006

During the past five years, exploratory cave dives were conducted in three of Lechuguilla's lakes: Blue Giants, Stud Lake, and Castrovalva. All three are perched lakes, well above the water table. While submerged stals are clearly visible from above at Blue Giants, the other lakes proved to have submerged stals as well. Stud Lake also contained subaqueous helictites of a form unique to that locale. Thus, all three lakes were dry for lengthy periods of time before being flooded, probably during the last ice age. In Blue Giants, a steeply sloping tube was followed for 200 ft (60 m) to a flowstone seal at -90 ft (27 m). In Stud Lake, an airbell 60 ft (18 m) wide and a much larger chamber beyond were found. The lake is over 300 ft (90 m) long and up to 30 ft (9 m) deep. At Castrovalva, I was joined by Ron Simmons and we found only small 10-20 ft (3-6 m) long pockets off the main lake, which was never deeper than 25 ft (8 m). We did find a cluster of six large stals coated with mammillary crusts which I'm calling mammillagmites. None of the lakes appears to have any potential for further passages beyond but were awesome cave dives!

The Discovery and Exploration of Barberry Cave

Mike Ficco, 1650 Barnes Mill Rd. Apt. 1211, Marietta, GA 30062-3884 & Ben Schwartz, Justamere Farm, Doe Hill, VA 24433

Barberry Cave is the latest important discovery in the Burnsville Cove area of west-central Virginia. The cave represents a key component of a complex Cave-Sinking Creek System and the Chestnut Ridge Cave System. The discovery and ongoing exploration of Barberry is the result of the persistence and dedication of a handful of individuals who have had to develop unique approaches to overcome the multiple challenges which the cave has presented. The cave has rewarded its explorers with large and sometimes beautifully decorated passages, intermingled with the requisite "Chestnut Ridge horror". The belief that Barberry holds clues to the interconnection of caves in the Burnsville Cove has driven its explorers to take dramatic steps to facilitate exploration of this great Virginia cave.

Hurricane Cave

Mike Frazier, 2207 Hagerman, Colorado Springs, CO 80904

Hurricane cave is an amalgamation cave formed entirely in the 1.0 Ga Pikes Peak Granite. It is located on the drainage of the Pikes Peak monolith, El Paso County, Colorado.

The cave is formed along a fault and takes water from two streams which join together just above the insurgence. Heavy stream down- cutting forms beautiful scalloped chimney passage in some areas. The cave is vertical, wet and involves crawling and squeezing through tight complex boulder piles. Some portions of the cave become impassable during heavy spring run-off.

The cave water is snow-melt that never ranges far above 32º Fahrenheit. In addition to the cold water, a constant wind blows through the cave making hypothermia a constant danger. Other dangers in this cave include possible rockfall and the possibility of becoming disoriented or falling. Current length is 2533 ft (772 m). Current depth is 553 ft (168.64 m). Hurricane is the deepest known granite cave in the world. Source: Atlas Great Caves (Bosted, et al., 1989).

Prospecting for Caves in Utah's House Range

Dale Green, 4230 Sovereign Way, Salt Lake City, UT 84124

The House Range is in west-central Utah, about 40 mi (65 km) east of the Nevada border. The Range is 65 mi (105 km) long, trending from north to south. The northern two-thirds is mostly limestone. As with most other ranges in the Great Basin, the House Range has only one cave of major size and a few smaller ones. Several years of haphazard, random searches for rumored caves produced almost nothing and a great amount of time was wasted in duplication of effort. In order to determine exactly what caves actually existed, a project was undertaken in 1985 to systematically observe all exposed limestone surfaces n the northern 32 mi (52 km) of the Range. Colored geologic maps superimposed on topographic maps were carried and the route and observations were marked directly on them in the hopes of finding other large caves. The main tools used for route finding were a digital altimeter and compass. Binoculars were particularly handy for peering into inaccessible holes and checking shadows. About 2 dozen new caves were found but most of them were small. However, an equal number of digging prospects were located. The elusive second large cave in the House Range is probably behind one of these prospects but the entrance has been filled with packrat debris.

Update, Tongass Cave Project, Southeast Alaska

David M. Klinger, PO Box 537, Leavenworth, WA 98826

Cavers of the Tongass Cave Project continue to find, explore and map an ever increasing number of caves on Prince of Wales Island, Dall Island, Heceta Island, Chichagof Island and other islands of the Alexander Archipelago in southeast Alaska. Especially exciting finds have been made on Heceta Island. Arabica Cave has the possibility of becoming the longest cave in Alaska.

An Update on Exploration in the Mystery-Rimstone Karst Perry County, Missouri

Philip L. Moss, 2621 Columbia Lakes Dr. Apt 2-D, Columbia, IL 62236-2616

The Mystery-Rimstone karst contains about 40 mi of mapped passage to date. Talks and articles have been presented previously of the exploration of Mystery Cave (17 mi/20 km) and Rimstone River Cave (17.5 mi/28.5 km). In he early 1980s, two significant caves were explored and mapped that have added to our understanding of this karst area. These caves are Hot Caverns (3 mi/5 km) and Maple Leaf Cave (2.5 mi/4 km). Hot Caverns is primarily two side passages feeding a short continuation of the main stream of Rimstone River Cave. Maple Leaf Cave is a large, fossil trunk that I have interpreted to have once been a downstream continuation of Mystery Cave and a segment that would have connected it with Rimstone River Cave.

New Mexico Gypsum Karst Project

Steve Peerman, 1757 Defiance Rd., Las Cruces, NM 88001

The New Mexico Gypsum Karst Project (GypKaP), sponsored and organized by the Southwestern Region of the NSS, has been working for the last 9 years in the gypsum karst area of south central New Mexico. We are approaching 150000 ft (45.7 km) of mapped passage in that time in a large number of gypsum caves. While many of these caves are small, others are quite extensive, some over 2 mi (3 km) long. Over that time we have developed a working relationship with a number of private ranch owners and managers in an area the size of the island of Puerto Rico. Landowner relations continue to be a major emphasis of our efforts.

We are now beginning to understand the processes at work there. We continue to make new discoveries, both in the sense of exploration, and in the understanding of the karst area. This presentation will give an overview of the accomplishments of the project along with a photographic "taste" of the New Mexico gypsum cave and karst environment.

Discovery of a Pristine Lava Cave at Trout Lake, Washington

Garry Petrie, 19880 NW Nestucca Dr., Portland, OR 97229-2877

Seventy miles from Portland, the lava flows west of the small town of Trout Lake, Washington continue to yield new discoveries. In 1994, a long, pristine and beautiful cave was discovered. The cave, Chubby Bunny, a.k.a. Fat Rabbit, rivals the flow's other major cave, Dynamited and Deadhorse. Chubby Bunny contains infinitely detailed, vivid red pahoehoe flows, sand formations, lavacicles, and complex passage topology. Unfortunately, the upper end of the cave appears to have been buried by an earlier road building effort. Access to this 7000 ft (~2100 m) long cave is now strictly controlled by the United States Forest Service.

Four Years of Exploration in Wyoming's Gros Ventre Wilderness

Garry Petrie, 19880 NW Nestucca Dr., Portland, OR 97229-2877

Many years ago, the Gros Ventre mountains were forgotten for "not having enough focused drainage" to support cavern development. While a great cave on the scale of Great Ex or Columbine Crawl appears to be absent in the Gros Ventres, the immense limestone deposit has many significant caves. For the last four successive years, a diverse group of cavers has documented over two dozen caves. The caves include Marmot's Nest, Big Crapper, Initiate Pit, Gray Bird, Pikas Revenge, and Blue Bell. These caves are typical cold and wet alpine caves. With thousands of acres of limestone to explore, more discoveries are expected in the future.

The Discovery and Exploration of Breezeway Cave, Colorado

Richard Rhinehart, 1718 Lorraine Street #B2, Colorado Springs, CO 80906

Fresh from the discovery of the Cave of the Winds' celebrated Silent Splendor, Colorado cavers turned to other promising excavations. While many resulted in modest extensions to the caves of Williams Canyon, nearly a decade passed before another major discovery.

Following instinct, science and luck, cavers excavated an overlooked canyon-side hole. Quickly, they pushed their way through unstable breakdown and climbed into Cowboy Heaven, the first of the great rooms and corridors of Breezeway Cave.

During the first few weeks of exploration, the ever-present breeze was followed past wind-eroded stalactites deep into the mountain. Cavers crossed a series of pools known as the Holy Waters to reach the Celestial City, a chamber frescoed with white beaded helictites reminiscent of Silent Splendor. From there, excavation of clay-filled crawlways opened several spectacular helictite chambers: Vanity Fair, the Elkhorn Chambers and Heavens Gate. Exploration in Breezeway quickly out paced ongoing survey efforts. One major corridor led to Stone River and High Plains, Guadalupian-like chambers filled with pools, flowstone and massive dripstone. Another dropped through a twisty squeeze called the Sidewinder to a precipitous mud-walled canyon known as Rattlesnake.

Several thousand feet were discovered in the cave's lower level, including the beautiful Velvet Underground. In the 18 months since the last major discovery, cavers are continuing excavation efforts to discover new extensions. With a little bit of luck, Breezeway will continue to surprise and delight for decades to come.

Exploration of the Kazumura Cave System, Hawaii

Bob Richards, 1206 Spinnaker Way, Sugar Land, TX 77478

Kazumura is an exciting wild cave—a vast, sinuous tunnel with numerous lava falls and chambers. Kazumura is formed entirely in 500 year old basalt flow on the flank of Kilauea, the world's most active volcano. A 9 person expedition led by Kevin Allred last fall mapped an additional 13 km which extended the cave system to a record 60 km for a lava tube cave. A major breakthrough in the Olaa Cave during the expedition extended the cave to a US depth record of 1099 m. A 42 km, 1000 m deep through trip was accomplished by team members at expedition's end. This marathon trek took 2 days to complete. It is believed that there are many extremely long caves on the island, only a few of which have been entered. The Big Island holds the promise of enormously long lava tube caves, some of which possess the vertical range of the deepest limestone caves. The Kazumura Cave System is just one of them.

Jewel Cave Exploration

Mike Wiles, Jewel Cave National Monument, Custer, SD 57730

Jewel Cave was discovered around 1895, staked as a mining claim in 1900, and became one of the first National Monuments in 1908. Its hundred-year history notwithstanding, most of the cave's exploration has taken place since 1959, particularly because of climbers-turned-cavers, Herb and Jan Conn. Since then, exploration has progressed at a modest average of two-and-a-half mi a year. This has been accomplished by a small group of volunteers working closely with the Park Service.

The cave is a complex maze of phreatic passages ubiquitously lined with calcite crystals, from which it derives its name. In spite of nearly 600 ft (180 m) of vertical relief, exploration requires no vertical work more than handlines and an occasional webbing-ladder. It does require quickness and agility for cavers to negotiate the twists, turns, and tight spots quickly enough to reach the end of the cave with sufficient time to explore. This has resulted in some distinctive caving practices that will be of interest.

Once thought to be a small cave, Jewel now has over 100 mi (160 km) of passages mapped. Barometic winds predict a volume of five billion cubic feet, or about 5000 average-sized mi (8100 km). Regardless of actual size, strong barometric breezes at the far reaches of the cave indicate that most of the cave is still undiscovered.

VERTICAL SESSION

Session Chair: Tray Murphy

The Use of the Counterbalance Lift For Self Rescue

Cindy K. Heazlit, 5672 Bluegrass Lane, San Jose CA 95118-3513

It is sometimes necessary to lift someone up a drop. There are many ways to accomplish this task. One of the easiest methods is the Counterbalance Lift. The lift is quite different from other counterbalance methods. This particular 2:1 lift requires no additional rope, no rerigging of the rope, no special equipment, and can be accomplished by a single person. The lift is so easy that the Western Region Self Rescue Committee has included it in its self rescue curriculum.

Developing a Self Rescue Training Curriculum for the Western Region—A Work in Progress

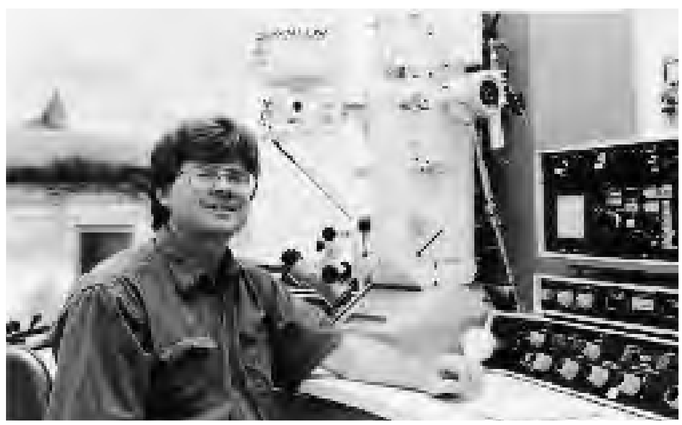
Cindy Heazlit, 5672 Bluegrass Lane, San Jose, CA 95118-3513

Cavers in the Western Region often travel to very remote areas to do their caving. Many of these areas are not serviced by either SAR or cave rescue teams. Outside response to a cave accident could take hours, even days. In the meantime, the caving party must deal with the accident using only the people and equipment at hand. There has been little information available about the techniques needed for this type of rescue. In the Autumn of 1994 several Western Region cavers formed a committee to research and develop these techniques. The committee developed a curriculum for teaching self rescue to the average caver, and has started to teach classes within the Western Region. The talk will cover the basic needs of the wilderness caver, the specific problems faced by Western Region cavers, the development of a curriculum for self rescue, and the lessons learned during this development work.

Warren Campbell received his PhD from Colorado State University in 1984. He first wanted to use a thermal camera in a cave area in 1970. His paper proves that persistence pays. At the University of Alabama in Huntsville since 1991, he and his students are involved in protecting the endangered Alabama cave shrimp.

Peter F. Bellinger was born in New Haven, Connecticut, and was educated at Yale (BA 1942, PhD 1952). He served as a publications officer in the US Army and has taught at the University of the West Indies in Jamaica and at Yale; he is presently Professor of Biology at California State University, Northridge.

James C. Cokendolpher has an MSc in biology. He has published numerous papers and books on creatures (mostly anthropods) both in and outside of caves from many parts of the world. He is currently self-employed as a photographer/illustrator and consultant.



Victor Polyak is the radiation safety officer for Texas Tech University and is currently pursuing a PhD in geology. He is studying cave clay and carbonate minerals of the Guadalupe Mountains.

Kenneth Christiansen, NSS 4114 (Fellow). BA 1948 Boston University; PhD 1951 Harvard. Works with Biospeleology (Taxonomy, Ecology, Evolution and Biogeography) of Collembola. Visiting Researcher Laboratoire Souterrain Moulis France 1962, 1967-68. Visiting researcher Karst Institute Guilin, China 1990. Published numerous papers on cave biology North America and some on Mexico, France, China, and Hawaii.
For photo see *Journal of Cave and Karst Studies 58*(1): 61.

Next — Special Topic Issue on:

CAVE ARCHAEOLOGY

An Ancient Rocky Mountain Caver

The Chronology of Early Agriculture and Intensive Mineral Mining in the Salts Cave and Mammoth Cave Region

The Cave of Las Ruinas (Cerro Rabon, Oaxaca, Mexico): A Mazatecan Postclassic Funerary and Ritual Site

The Cueva Cheve Tablet

Regional Variation in Maya Cave Art

Excavations in Buried Cave Deposits: Implications for Interpretations

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