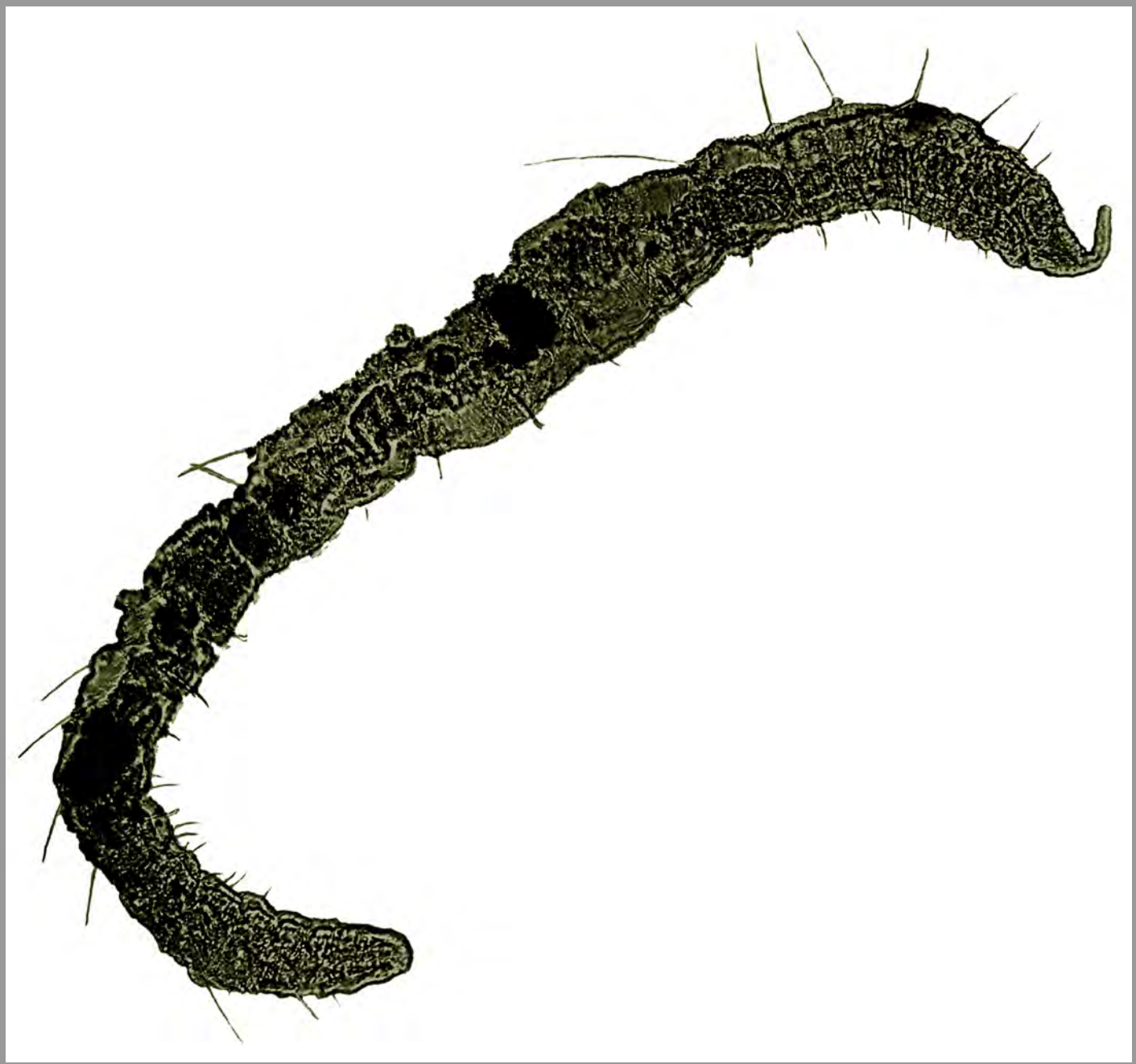
JOURNAL OF CAVE AND KARST STUDIES

December 2001
Volume 63 Number 3
ISSN 1090-6924
A Publication of the National Speleological Society



Journal of Cave and Karst Studies of the National Speleological Society

Volume 63 Number 3 December 2001

CONTENTS

The *Journal of Cave and Karst Studies* (ISSN 1090-6924) is a multi-disciplinary, refereed journal published three times a year by the National Speleological Society, 2813 Cave Avenue, Huntsville, Alabama 35810-4431; (256) 852-1300; FAX (256) 851-9241, e-mail: nss@caves.org; World Wide Web: http://www.caves.org/~nss/. The annual subscription fee, worldwide, by surface mail, is $18 US. Airmail delivery outside the United States of both the *NSS News* and the *Journal of Cave and Karst Studies* is available for an additional fee of $40 (total $58); The *Journal of Cave and Karst Studies* is not available alone by airmail. Back issues and cumulative indices are available from the NSS office. POSTMASTER: send address changes to the *Journal of Cave and Karst Studies*, 2813 Cave Avenue, Huntsville, Alabama 35810-4431.

Cover: *Pristina leidyi* Smith, 1896 (Annelida: Oligochaeta: Nadidae), an aquatic oligochete. This individual (body length, excluding proboscis, 1.72 mm) was collected from soft sediment of a cave stream in Fogelpole Cave, Monroe County, Illinois, in September 1999. The slide-mounted specimen (deposited in the INHS Annelida Collection) was photographed at 100x on an Olympus BX-50 compound microscope, and the image was digitally enhanced. Photograph by Steven Taylor, Illinois Natural History Survey.

James U.L. Baldini - Morphologic and dimensional linkage between recently deposited speleothems and drip water from Browns Folly Mine, Wiltshire, England. *Journal of Cave and Karst Studies 63*(3): 83-90.

MORPHOLOGIC AND DIMENSIONAL LINKAGE BETWEEN RECENTLY DEPOSITED SPELEOTHEMS AND DRIP WATER FROM BROWNS FOLLY MINE, WILTSHIRE, ENGLAND

JAMES U.L. BALDINI[1]
Department of Geology, Geography-Geology Building, University of Georgia, Athens, GA 30602-2501 USA

Dimensional measurements of juvenile speleothems from Browns Folly Mine, Wiltshire, SW England, indicate that rapid drips preferentially deposit calcite on the stalagmite rather than the stalactite. The ratio of stalagmite volume to stalactite volume, termed a speleothem volume ratio (SVR), increases with increasing drip rate. Rapid drip rates result in a reduced period of CO_2 degassing on the ceiling, and consequently less calcite deposition and smaller stalactites. However, extremely low drip rates appear to have an insufficient flux of HCO_3^- and Ca^{2+} to deposit significant amounts of calcite on the roof of the cave. The drip rate most conducive to stalactite deposition is 0.02 mL/min. A positive feedback mechanism resulting in a preferential increase in calcite deposition on the stalactite through time is hypothesized to exist. The relationship between stalagmite basal diameter and drip rate is very significant ($r^2 = 0.44$, $p = 6.31 \times 10^{-14}$, $n = 99$). It may, therefore, be possible to reconstruct paleo-drip rates and subsequently infer paleoclimate.

The internal structure of stalagmites has been scrutinized intensely over the past few decades because of the potential paleoclimatic records contained within (Allison 1926; Gascoyne *et al.* 1981; Genty & Quinif 1996; McDermott *et al.* 1999; Railsback *et al.* 1994). However, understanding the external morphology may assist in the elucidation of the processes responsible for speleothem development and consequently aid in the establishment of linkages between climate and speleothem climate proxies. Few recent studies have focused on the morphology of speleothems.

Allison (1923) attempted to classify stalagmites into 32 different types according to drip rate, air circulation, solute concentration, temperature, and relative humidity. Allison (1923) postulated that drip rates that allow the drop of water to equilibrate with the cave atmosphere on the ceiling of a cave would preclude stalagmite formation. Franke (1965) attempted to classify different stalagmites according to temporal changes in the drip rate. Franke also recognized that changes in a speleothem's morphology could reflect climatic change. Curl (1972, 1973) formulated mathematical relationships predicting the minimum diameter of stalagmites and stalactites. Gams (1981) recognized that progressive increase in size of a stalactite would result in a corresponding decrease in stalagmite size due to the increased surface area on the stalactite from which degassing could occur. Dreybrodt (1996) used a computer program to model stalagmite growth and morphology.

With the exceptions of Allison, Franke, Gams, Curl, and Dreybrodt, previous researchers have considered stalactites and stalagmites separately and have largely ignored the external morphologies of speleothems. This study attempts to view stalactites and stalagmites as an integrated system where changes in stalactite morphology directly affect the formation of the stalagmite. Because the dimensions of the stalagmite are dependant on the drip rate and chemistry of the water feeding it, the size and nature of the stalactite might affect the morphology of the associated stalagmite. The principal objective of this study is to establish relationships between the dimensions of recently deposited speleothems with the characteristics of the precipitating water.

LOCATION

This study was conducted at Browns Folly Mine, Bathford, Wiltshire, in southwestern England (Fig. 1). Browns Folly Mine was opened in 1836 for extraction of building stone. The mine was worked until 1886, when all of its entrances were closed. Mining in nearby mines ceased in 1904, and vegetation re-established itself at that time. For the last 94 years, the secondary woodland that developed was left undisturbed as part of a local nature reserve. The entrances to Browns Folly Mine remained closed until cavers re-opened them in the 1970s, ensuring that speleothems inside the mine developed without human interference for a long period during their growth (Baker *et al.* 1998).

The mine is located at the crest of Bathford Hill at ~150 m msl. The mine was excavated at a uniform depth below the surface (5-15 m), increasing the likelihood that all drip water is meteoric percolation water rather than water derived from fracture flow within the aquifer. Precipitation is almost evenly distributed throughout the year, although increased evapotranspiration during the summer results in reduced water infiltration and lower drip rates (Baker *et al.* 1999). The surface above the mine is covered by a thin brown rendzina soil (Genty *et al.* 2001).

The sampling site is a series of rooms located ~300 m from the nearest entrance (Fig. 2). The area is replete with thousands

[1] Currently at the Department of Geology, University College Dublin, Dublin 4, Ireland.

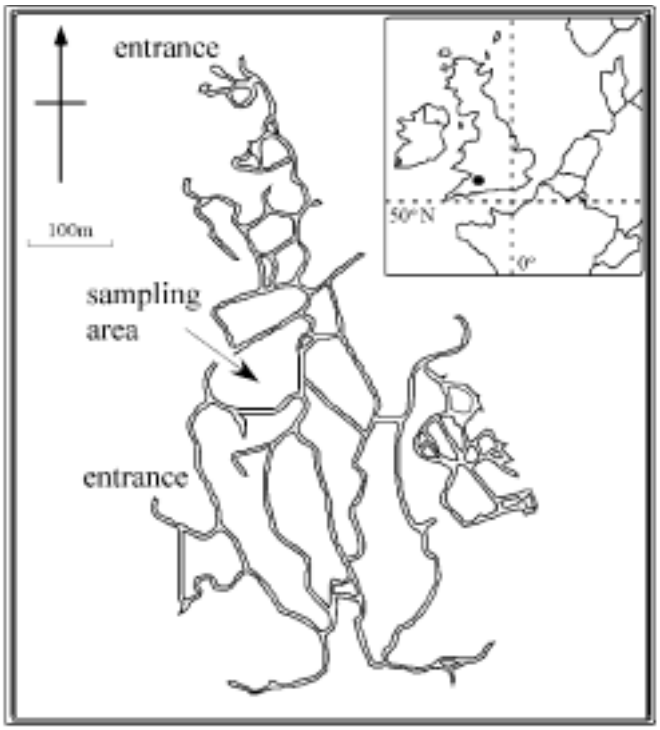


Figure 1. Location and map of Browns Folly Mine in southwestern Great Britain (51°23' N, 2°22' E; Baker & Genty 1999). Only major passages are represented on this map. Several rooms exist adjacent to these major passages that are not shown on the map. The study area is in one of these rooms.

of actively growing stalactites and stalagmites (Fig. 3). The air temperature at the sampling site has been recorded as 10.0 ± 0.4°C with no seasonal variability, and the humidity close to 100%. P_{CO2} within the mine has been measured in the range of 0.0035-0.0040 atm, with no significant seasonal variations (Baker *et al.* 1998).

The host bedrock is the Bath Oolite limestone, a subdivision of the Jurassic Great Oolite Series. It is an oolitic grainstone composed predominantly of calcite with much primary porosity and localized well-developed secondary porosity. Miners referred to the stone as "freestone" because of its lack of fossils and flaws, and because it can be cut freely in any direction without fear of splitting in an undesired fashion (Price 1984).

Browns Folly Mine was chosen for this study for three reasons: 1) The speleothems within the mine have formed within the last 152 years. This removes many of the problems inherent in speleothem studies, such as the possibility of significant climate change; 2) The history of the surface vegetation is known. The ages of the speleothems are not certain, but because vegetation re-established itself in 1904, vegetation has probably been constant for most of their development; 3) The sheer abundance of juvenile speleothems increases the likelihood of obtaining a wide array of drip rates and water chemistries.

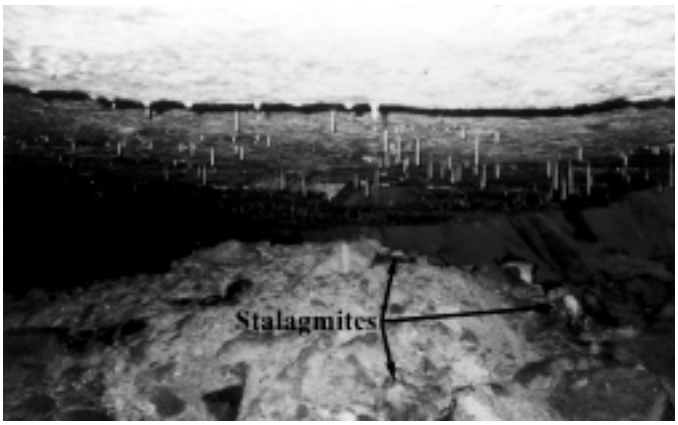


Figure 2. Photograph of stalagmites growing on clasts left in the mine when mining ceased. Stalactites are extremely abundant and are randomly distributed on the ceiling. No preferential development of stalactites along joints was noted.

METHODOLOGY

SPELEOTHEM DIMENSIONS

Speleothem dimensions were measured using a caliper. The diameters were measured at the base (the point of attachment of the speleothem to the roof or floor), at the place where the most conspicuous width change took place, and near the tip of the speleothem. The height of each speleothem was also measured with a caliper. Stalactites showing evidence of breakage were noted as such. A very fragile, translucent framework of calcite with euhedral crystal terminations was assumed to represent undisturbed stalactites, while an unusually thick layer of calcite with no crystal terminations suggested that the stalactite had been broken at some point in time. A few small curtains were present, and because they had roughly boxlike shapes, the length, width, and height were measured. Any other slightly anomalous formations were noted and appropriate measurements were taken. The vast majority of stalactites were soda straws (Fig. 3a), and most of the stalagmites had well-developed cylindrical shapes (Fig. 3b).

The volume of calcite contained within the stalagmites and stalactites was calculated using equation 1, derived from the volume formula for a truncated cone. This equation was determined to best quantify the volume of a speleothem using a reasonable number of measurements.

$$\begin{aligned} volume = \quad & 1/3\ \pi\ (h_1)(R^2_{base} + R_1^2 + R_{base}R_1) \\ & + 1/3\ \pi\ (h_2 - h_1)(R_1^2 + R_2^2 + R_1R_2) \\ & + (1/3\ \pi\ (h_{total} - h_2)R_2^2) \end{aligned} \qquad (1)$$

Where: h_1 = *height from base to first radius measurement (mm)*
h_2 = *height from base to second radius measurement (mm)*
R_{base} = *radius at the base of speleothem (mm)*

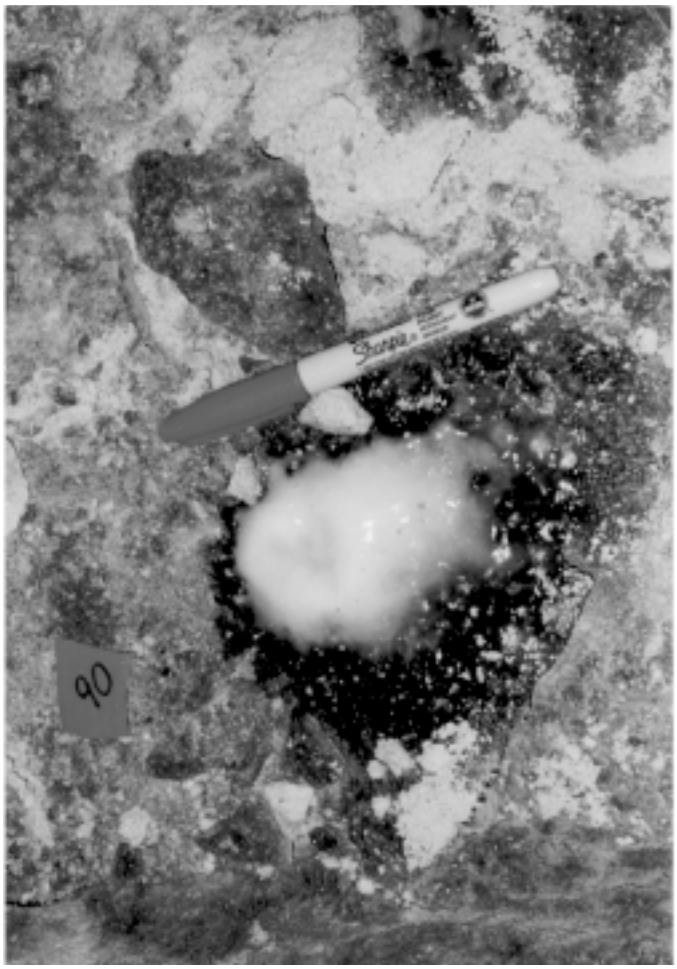


Figure 3a (left). View looking down on a typical stalagmite in Browns Folly Mine.
Figure 3b (right). Photograph of typical stalactites found within the mine. Very thin, crystalline calcite at the tips of soda straws indicated that the stalactite had not been broken. A small ribbon stalactite can be seen on the bottom right of the picture.

R_1 = first radius measurement, at height h_1 (mm)
R_2 = second radius measurement, at height h_2 (mm)

Most of the stalactites are soda-straws and have the characteristic hollow central cavity. The approximate volume of this void has been subtracted from the volume derived using equation 4.1 to arrive at the actual volume of carbonate deposited. The central canal is assumed to be a cylinder with a diameter of 3.0 mm extending the length of the stalactite. The mean value for stalactite volume after the correction for the central canal was 91% of the mean value for the uncorrected data set.

DRIP WATER COLLECTION

Drip water samples were collected from Browns Folly Mine June 25-30, 1998, using a collection device constructed of a small polyethylene funnel inserted through a slit in the base of a waxed paper drinking cup. The cup acted as a support and brace for the funnel. A clear plastic bowl (15 cm diameter, 5 cm height) was used as a stand in order to provide a horizontal surface on which a 10 dram (36.9 mL) glass collection vial could be placed. The waxed cup was placed over the plastic stand and the collection vial, with the bottom of the funnel suspended over the collection vial. The device was placed directly underneath the stalactite, usually directly over the stalagmite. Occasionally the stalagmite was in a precarious position, so a pile of rocks was used to support the device. The stalactite was observed until a drop of water formed on the tip, and then the drop was followed through the air into the collection device to ensure the device was in fact directly underneath the correct stalactite. Upon verification of the functionality of the device, the time of placement was recorded in a logbook.

The device was left undisturbed for several hours. The time of collection and the height of water in the vial were noted. In several instances, the collection device was left too long, resulting in the vial overflowing. In these cases, the actual time between consecutive drips was counted using a stopwatch. Times between drips were also obtained for speleothem pairs, defined as a stalactite and its corresponding stalagmite, whose

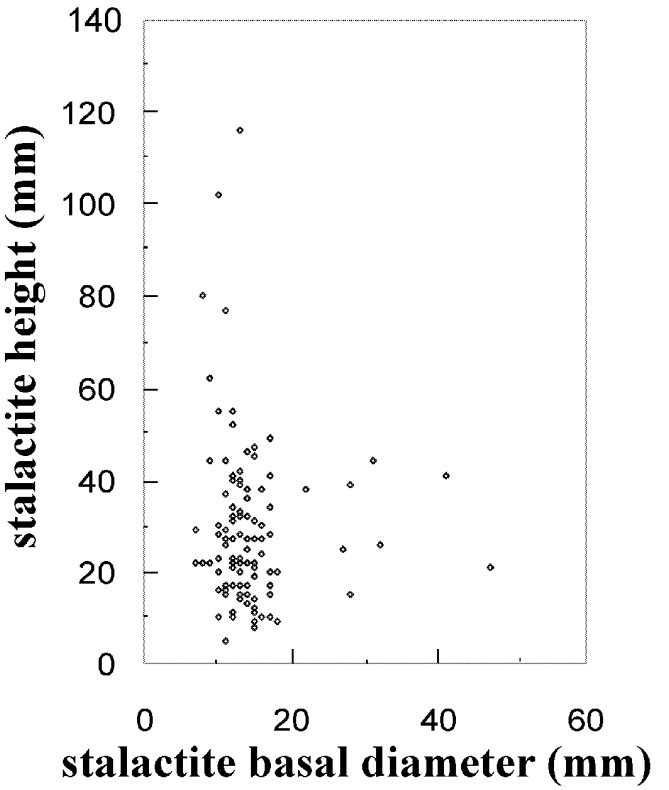


Figure 4a. Stalactite height plotted against stalactite basal diameter. Stalactites apparently can either be wide or tall, but not both simultaneously.

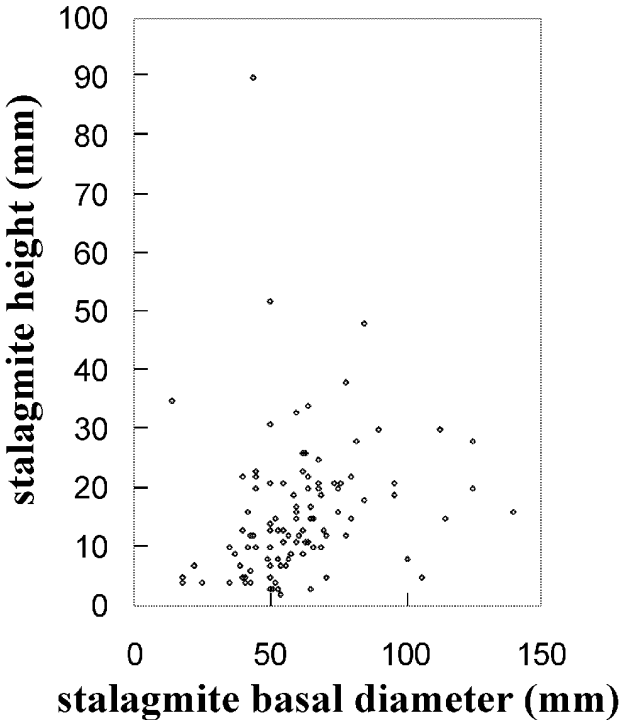


Figure 4b. Stalagmite height plotted against stalagmite basal diameter. No clear trend is evident.

collection vials had not overflowed, thus allowing the volume per drip to be calculated. From the volume per drip, determined to be a constant 0.0749 mL/drop (n = 18, S.D.=7.04 x 10^{-5}), the drip rate in mL/min was calculated for the overflow vials.

For the vials that did not overflow, the volume of the water collected was determined using the volume formula for a cylinder, volume = radius^2 x height x π. The radius was the radius of the collection vials, a constant 12 mm, and the height was the height of the collected water within the vial.

This volume was then divided by the appropriate time to determine the drip rate. Drip rates are expressed in milliliters/minute instead of the commonly used drips/minute in order to report more clearly the volume of water that actually reaches the speleothems.

Total hardness, pH, and alkalinity were measured after the collection of the sample vials using Aquachek test paper having the following ranges: total hardness 0-425 ppm, pH 6.4-8.8, total alkalinity 0-240 ppm. The test strips precluded obtaining very precise measurements, resulting in a large number of identical values. However, the accuracy may have benefited from the test strips because the measurements were obtained *in situ*.

The water samples were treated with hydrochloric acid and then analysed for cations using a Thermo Jarrell-Ash 965 Atomcorp ICP spectrophotometer at the University of Georgia. All water chemistries were extremely constant throughout the suite of waters sampled, and no meaningful relationships were drawn between water chemistry and any other parameters. Thus, the water chemistry will not be discussed in detail in this paper (tabulated as an internet archive on the JCKS website: http:www.caves.org/pub/journal/volume63).

RESULTS

SPELEOTHEM DIMENSIONS

Stalactites in Browns Folly Mine have a mean basal diameter, defined as the diameter of the stalactite at the attachment point to the ceiling, of 14.31 mm (S.D. = 5.943) and a mean height of 28.1 mm (S.D. = 18.561) (Fig. 4a). Stalagmites have a larger mean basal diameter of 60.170 mm (S.D. = 22.056), and are shorter (mean height = 15.641 mm, S.D.=11.987) (Fig. 4b). The stalagmites have highly variable basal diameters, while the stalactites have relatively constant diameters. The diameter of the stalactites tips is extremely uniform, with a mean of 5.491 mm and a standard deviation of 0.791 mm.

DRIP RATES

Drip samples were obtained during a precipitation event three days in duration during an otherwise dry summer. The average drip rate for actively dripping speleothems was 0.768 mL/min (S.D.=5.33), and is highly skewed to the right. The maximum drip rate recorded was 54.29 mL/min. There were

five speleothem pairs that were dry during the sampling period.

The average volume of a drop of water was obtained by using the following formula:

$$volume = R \times T/60 \quad (2)$$

Where: R = drip rate calculated from collected water in vial (mL/min)
T = time between consecutive drips (sec/drop)

The average drop of water had a volume of 0.0749 mL (n = 18, S.D.=7.04 x 10^{-5}), not including two values of 0.1393 mL and 0.0987 mL that were clear outliers in the data set. The precision of this average is remarkable, and serves as a good quality control for the collection of drip water. The only variable in the preceding equation that could have any significant error associated with it is the R term, derived from the amount of drip water captured by the collection device. If significant amounts of drip water had missed the collection funnel or splashed out, the numbers obtained for the volume of a drop of water would be too low. The extremely low standard deviation is an indication that essentially no drip water was lost during collection.

Calcite Saturation Indices

Saturation indices for calcite for the drip water were calculated using the field alkalinities and the Ca^{2+} concentrations. The mean saturation index for calcite for the sampled drip waters was 0.7 ± .5 with a standard deviation of 1.0, where equilibrium for calcite is at a saturation index of 0.0. The highest saturation index was 1.8, and the lowest was –0.9. Water that was supersaturated with respect to calcite composed 64 of the 96 samples. The mean Ca^{2+} concentrations of all the drips sampled was 1.28 mmol/L (n = 93, C.V. = 21.7%), which is 40% lower than the mean Ca^{2+} concentrations obtained for seventeen drips in the mine by Baker *et al.* (1998) of 2.20 mmol/L and a C.V. of 15%. This may be due to the greater number of samples and the wider range of drip types observed in this study.

Relationships within the data

Dimensional Relationships

Empirical observations within Browns Folly Mine suggest that the most rapid drip rates produce the largest speleothems. Drip rate appears to exert considerable control on stalagmite volume. The p-value for a regression line through the log-transformed data (Fig. 5) indicates that the relationship between stalagmite volume and drip rate is significant (r^2 = 0.304, n = 105, p = 1.09 x 10^{-9}). Stalagmite volume (τ) is therefore approximated with:

$$\tau = 10^{(0.503(\log R) + 5.116)} \quad (3)$$

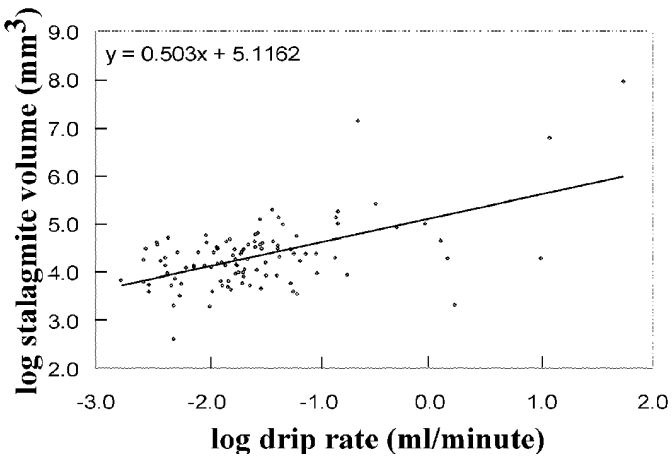


Figure 5. Log stalagmite volume versus log drip rate (r^2 = 0.30, p = 1.09 x 10^{-9}, n = 105).

where: R = drip rate in mL/minute

During the first day of sampling, some large flowstone deposits were observed underneath dry stalactites. During the precipitation event that began on the second day, these large stalagmites were no longer dry but were being fed by rapidly dripping water. Sites that exhibited this sort of flashy discharge were avoided in the drip sampling in order to minimize uncertainty due to temporal variations in drip rates.

Stalagmites formed under lower drip rates, less than ~0.1 mL/min, tended to be elongated cylinders. Conversely, the five stalagmites formed by the most rapidly dripping water (>1 mL/min) were broad and flat, the largest being over a meter wide. Stalagmite basal diameter (w) does increase with increasing drip rate (Fig. 6) according to equation 4 (r^2 = 0.44, p = 6.31 x 10^{-14}, n = 99):

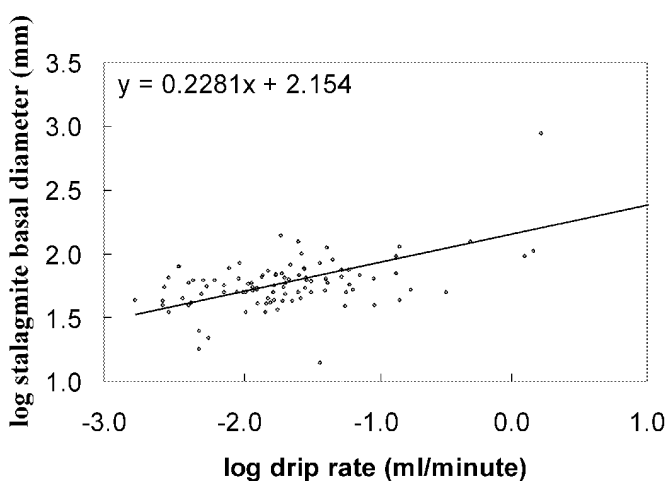


Figure 6. Log stalagmite width versus log drip rate (r^2 = 0.44, p = 6.31 x 10^{-14}, n = 99). Stalagmites with problematic dimensions are not included in this chart.

$$w = 10^{(19.3(\log R) + 67.5)} \quad (4)$$

The stalagmite basal diameter indicates the lateral extent drip water flows along the floor of the mine before completely equilibrating with CO_2 in the mine air. The more rapid the drip rate, the more rapidly the water flows from the center and onto the flanks of the stalagmite, resulting in a wider stalagmite. The drip water will degas completely on the stalagmite, depositing carbonate until the water is no longer saturated with respect to calcite. Therefore, the volume of a stalagmite is predominantly dependent on the amount of Ca^{2+} and HCO_3^- transported to it through time. If drip water chemistry remains constant, a larger volume stalagmite is clearly the result of more rapid drip rates. In some situations the drip may be sufficiently rapid to cause the resultant speleothem to deviate from the classic stalagmite morphology and become a flowstone. The large flowstones observed underneath dry drips are likely to have extremely rapid, ephemeral discharges during precipitation events.

Derivation of paleo-drip rates for ancient stalagmites may be possible utilizing equation 4. Drip rates are often correlative with net amounts of meteoric precipitation or infiltration (Baker *et al.* 1997; Genty & Deflandre 1998; Sanz & Lopez 2000), therefore equation 4 may also have applications for paleoclimatic reconstruction.

The distribution of calcite in stalactites is apparently more complex than in stalagmites (Fig. 4 a,b). An incipient soda straw develops by the degassing of CO_2 from the periphery of a drop of water. Upon reaching a critical mass determined by gravity, fluid density, surface tension, and drop volume (Curl 1972), the drop falls, breaking the thin veneer of calcite at its lowermost point (Allison 1922). The same sequence is repeated with successive drips, until a soda straw stalactite is formed. Blockages of the central canal diffuse water radially along crystal boundaries and subsequently result in lateral growth. Figure 4a demonstrates that stalactites are either long or wide, suggesting that insufficient calcite deposition has occurred to produce a stalactite that is both. Either vertical stalactite growth continues unimpeded, or a blockage of the central canal preferentially encourages lateral over vertical growth.

Previous research (Baker *et al.* 1999; Genty *et al.* 2001) has demonstrated that the drips within Browns Folly Mine vary seasonally depending on water availability, and different drips have different response times to rainfall events. Good statistical correlations exist between speleothem morphology and drip rate despite using drip rates measured only once, in June. This may be because many of the drips sampled had a low coefficient of variation during the course of the year. Some that responded rapidly to a rainfall event were sampled during the period of rapid flow, when most calcite deposition would take place, explaining the correlation with morphology. More drip rate measurements, particularly in the winter, would be very useful and may raise the r^2 values.

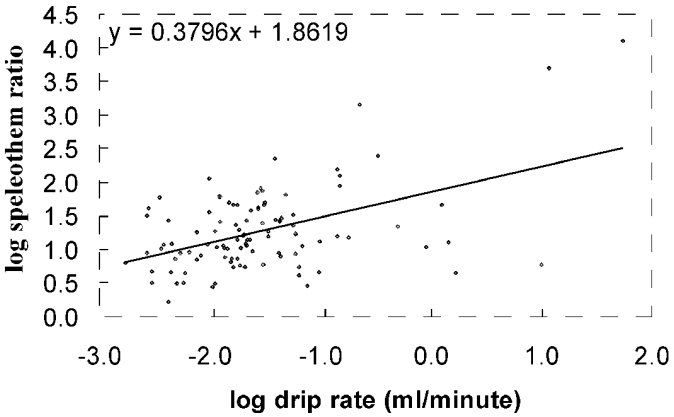


Figure 7. Log speleothem ratio versus log drip rate (r^2 = 0.237, p = 1.85 x 10^{-7}, n = 103). If either the stalagmite or the stalactite was not present in a speleothem pair, that "pair" is not included in the chart. Speleothems with drip rates of 0.00 ml/minute are not included in this chart.

SPELEOTHEM VOLUME RATIOS

The ratio of stalagmite volume to stalactite volume, henceforth known as the speleothem volume ratio (SVR), quantifies the spatial distribution of precipitated carbonate in a speleothem pair. The speleothem volume ratio increases with increasing drip rate (r^2 = 0.237, p = 1.85 x 10^{-7}, n = 103) (Fig. 7), suggesting that a reduction in the amount of time water spends on the stalactite increases the amount of carbonate deposited on the stalagmite. Carbonate deposition on the stalactite removes Ca^{+2} and CO_3^{-2} from the drip water, reducing the amount of raw materials that will reach the stalagmite, consequently producing a smaller stalagmite. As drip rates increase, the amounts of raw materials that can be potentially deposited on the stalagmite also increase, creating a larger stalagmite.

The average measured stalagmite in the mine was 214 times larger than the average measured stalactite. It has been proposed that the rate of stalactite growth increases throughout their development (Gams 1981), while stalagmite growth rates must necessarily decrease. Increased stalactite volume increases the period of drip degassing on the stalactite resulting in more calcite deposition. This is essentially a positive feedback mechanism that culminates in large stalactites whose drips are already equilibrated with respect to calcite when they reach the stalagmite, precluding any further stalagmite growth. Support for this hypothesis would be provided if measured SVRs of ancient speleothems in caves are less than 214. If this hypothesis is correct, paleoclimatic interpretations based on stalagmite stable isotopes, trace elements, or layer thicknesses must be corrected for the gradual, systematic decrease in calcite deposition on the stalagmite.

STALACTITE MORPHOLOGY

The vast majority of the stalactites in the mine are of the soda-straw variety; therefore, the only dimension that differs

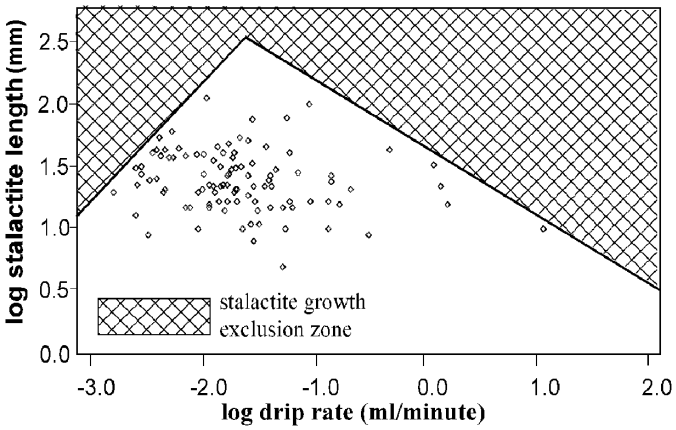


Figure 8. Stalactite length plotted against drip rate. The stippled area is a stalactite growth exclusion zone, which represents stalactite lengths that are impossible given the drip rates, water chemistries, and age of the stalactites. Extremely high drip rates do not seem to favor the formation of long stalactites. A longer period of degassing on the roof of the mine is believed to be responsible for the increase in stalactite length with decrease in drip rate. Drip rates that are too low, however, do not transport enough carbonate and Ca^{2+} to the roof to favor the deposition of long stalactites.

greatly from one stalactite to another is the height. When height is plotted against drip rate, a weakly significant (p-value = 0.03987) inverse relationship is evident (Fig. 8). The data as a whole indicate a decrease in stalactite height with increasing drip rate.

Limits as to how long a stalactite can form at certain drip rates appear to exist (Fig. 8). Low drip rates produce a short stalactite because, although most of the degassing occurs on the stalactite, not enough carbonate has been transported to the stalactite during the course of its existence to create a long stalactite. As drip rate increases, the amount of Ca^{2+} and dissolved CO_2 transported to the stalactite increases, creating a longer stalactite. However, eventually a drip rate is reached that moves water away from the stalactite prior to significant degassing of CO_2, reducing the amount of carbonate precipitated on the stalactite. The drip rate that seems to most favor the longest stalactites is ~0.02 mL/minute.

Stalactites measured in Browns Folly Mine have an average diameter of 5.49 mm (S.D. = 0.79 mm) at their tip, a number wholly consistent with the theory that the smallest possible diameter of calcite soda-straw stalactites on earth is 5.1 mm (Curl 1972). The smallest consistently measured diameter of a soda-straw was 5.0 ± 0.5 mm across the tip. Soda-straw stalactites with this tip diameter comprise a majority of the specimens sampled (66%). Only one soda-straw measuring less than 5.0 mm was found, and it measures 4.0 mm across the tip. The reasons for this anomaly are unknown; no egregious differences between this stalactite and others were noted.

CONCLUSIONS

Evidence obtained from Browns Folly Mine suggests that degassing of CO_2 and subsequent deposition of $CaCO_3$ on a stalactite reduce a spelean drip water's ability to further deposit calcium carbonate on the stalagmite. Slower drip rates increase the amount of time that a drop spends on a stalactite, resulting in increased stalactite sizes and decreased stalagmite sizes.

Speleothem volume ratios, defined as the ratio of stalagmite volume to stalactite volume, increase in value with increasing drip rates, supporting the hypothesis that slow drip rates favor deposition of available $CaCO_3$ on the stalactite. The existence of a positive feedback mechanism resulting in increased stalactite growth rates and decreased stalagmite growth rates through time is hypothesized. Therefore, speleothem volume ratios in ancient caves should be lower than those of younger speleothems, though an exhaustive study is clearly necessary. Paleo-drip rate estimates based on speleothem volume ratios of ancient speleothems in natural caves may have applications in paleoclimatological studies.

Stalactite height is at its greatest at drip rates of ~0.02 mL/minute, suggesting this drip rate is sufficiently rapid to transport raw materials to the growing lattice, and is sufficiently slow to allow for enough degassing of CO_2 to deposit calcite. A stalactite growth exclusion zone demarcating the limits for stalactite heights is a result of drip rate, drip chemistry, and the maximum possible age of the stalactites.

ACKNOWLEDGEMENTS

I would like to extend my sincere appreciation to the faculty at the Department of Geology, University of Georgia, for assisting with this project, and particularly to Dr. L. Bruce Railsback for his tireless editing, invaluable suggestions, and thorough review. I also thank Dr. Andy Baker for providing information regarding the mine and for his valuable input throughout the course of this project. A sincere thank you to my field assistant, Lisa Baldini, without whose assistance and insights this project would never have been completed. I would also like to thank Dr. Frank McDermott for comments on the manuscript and helpful discussions. Suggestions from an anonymous reviewer were extremely useful and greatly improved the paper.

REFERENCES

Allison, V.C., 1923, The growth of stalagmites and stalactites: Journal of Geology, v. 31, p. 106-125.

Allison, V.C., 1926, The antiquity of the deposit in Jacob's Cavern: American Museum of Natural History, Anthropological Papers, v. 19, p. 204-225.

Baker, A., Barnes, W.L. & Smart, P.L., 1997, Variations in the discharge and organic matter content of stalagmite drip waters in Lower Cave, Bristol: Hydrological Processes, v. 11, p. 1541-1555.

Baker, A., Genty, D., Dreybrodt, W., Grapes, J., & Mockler, N.J., 1998, Testing theoretically predicted stalagmite growth rates with Recent annually laminated samples: Implications for past stalagmite deposition: Geochimica et Cosmochimica Acta, v. 62, p. 393-404.

Baker, A., Mockler, N.J., & Barnes, W.L., 1999, Fluorescence intensity of speleothem forming groundwaters: Implications for palaeoclimate reconstruction: Water Resources Research, v. 35, p. 407-413.

Baker, A. & Genty, D., 1999, Fluorescence wavelength and intensity variations of cave waters: Journal of Hydrology, v. 217, p. 19-34.

Curl, R.L., 1972, Minimum diameter stalactites: Bulletin of the National Speleological Society, v. 34, p. 129-136.

Curl, R.L., 1973, Minimum diameter stalagmites: Bulletin of the National Speleological Society, v. 35, p. 1-9.

Dreybrodt, W., 1996, Chemical kinetics, speleothem growth, and climate, *in* Lauritzen, S-E (ed.) Climate change: The karst record: Karst Waters Institute Special Publication #2.

Franke, H.W., 1965, The theory behind stalagmite shapes: Studies in Speleology, v. 1, p. 89-95.

Gams, I., 1981, Contributions to morphometrics of stalagmites: Proceedings of the International Congress of Speleology, v. 8, p. 276-278.

Gascoyne, M., Ford, D.C., & Schwarz, H.P., 1981, Late Pleistocene chronology and paleoclimate of Vancouver Island determined from cave deposits: Canadian Journal of Earth Science, v. 18, p. 1643-1652.

Genty, D., Baker, A., & Vokal, B., 2001, Intra- and inter-annual growth rate of modern stalagmites: Chemical Geology, v. 176, p. 191-212.

Genty, D.D. & Deflandre, G., 1998, Drip flow variations under a stalactite of the Pere Noel cave (Belgium): Evidence of seasonal variations and air pressure constraints: Journal of Hydrology, v. 211, p. 208-232.

Genty, D. & Quinif, Y., 1996, Annually laminated sequences in the internal structure of some Belgian speleothems: Journal of Sedimentary Research, v. 66, p. 275-288.

McDermott, F., Frisia, S., Huang, Y., Longinelli, A., Spiro, B., Heaton, T.H.E., Hawksworth, C.J., Borsato, A., Keppens, E., Fairchild, I.J., van der Borg, K., Verheyden, S., & Selmo, E., 1999, Holocene climate variability in Europe: Evidence from δ-18O, textural and extension-rate variations in three speleothems: Quaternary Science Reviews, v. 18, p. 1021-1038.

Price, E., 1984, The Bath Freestone Workings: Bath, U.K., The Resurgence Press.

Railsback, L.B., Brook G.A., Chen, J., Kalin, R., & Fleisher, C., 1994, Environmental controls on the petrology of a late Holocene speleothem from Botswana with annual layers of aragonite and calcite: Journal of Sedimentary Research, v. A64, p. 147-155.

Sanz, E. & Lopez, J.J., 2000, Infiltration measured by the drip of stalactites: Ground Water, v. 38, no. 2, p. 247-253.

Kurt A. Buhlmann - A biological inventory of eight caves in northwestern Georgia with conservation implications. *Journal of Cave and Karst Studies 63*(3): 91-98.

A BIOLOGICAL INVENTORY OF EIGHT CAVES IN NORTHWESTERN GEORGIA WITH CONSERVATION IMPLICATIONS

KURT A. BUHLMANN[1]
University of Georgia, Savannah River Ecology Laboratory, Aiken, SC 29802 USA

A 1995 biological inventory of 8 northwestern Georgia caves documented or re-confirmed the presence of 46 species of invertebrates, 35 considered troglobites or troglophiles. The study yielded new cave records for amphipods, isopods, diplurans, and carabid beetles. New state records for Georgia included a pselaphid beetle. Ten salamander species were in the 8 caves, including a true troglobite, the Tennessee cave salamander. Two frog, 4 bat, and 1 rodent species were also documented. One cave contained a large colony of gray bats. For carabid beetles, leiodid beetles, and millipeds, the species differed between the caves of Pigeon and Lookout Mountain. Diplurans were absent from Lookout Mountain caves, yet were present in all Pigeon Mountain caves. A comparison between 1967 and 1995 inventories of Pettijohns Cave noted the absence of 2 species of drip pool amphipods from the latter. One cave had been contaminated by a petroleum spill and the expected aquatic fauna was not found. Further inventory work is suggested and the results should be applied to management strategies that provide for both biodiversity protection and recreational cave use.

Georgia is a cave-rich state, with most caves occurring in two distinct physiographic regions, the Cumberland Plateau and the southwestern Coastal Plain. Caves in the Cumberland Plateau lie primarily in the counties of Dade, Walker, and Chattooga.

A comprehensive inventory of Georgia caves was conducted in 1967 (Holsinger & Peck 1971). Reeves *et al.* (2000) reported additional faunal records. Other scattered references to the cave fauna of Georgia can be found in Loomis (1939: millipeds), Hubricht (1943: amphipods), Chamberlin & Hoffman (1958: millipeds), Hyman (1954: planarians), Barr (1965, 1981: beetles), Cooper (1968: salamanders), Holsinger (1969, 1978: amphipods), Cooper & Iles (1971: fish), and Peck (1973: beetles). Dearolf (1953), Nicholas (1960), and Holsinger & Culver (1988) provide checklists of species and reviews of the regional biogeography of cave faunas.

The goals of this study were to conduct biological inventories for cave-adapted species of northwest Georgia caves that were under state management responsibility and receive varying levels of recreational use, and/or were believed to have significant biodiversity and conservation value. Results may be useful in the development of cave management and conservation plans and will contribute to knowledge of the distribution and biogeography of Georgia's cave fauna.

METHODS

Between 15 July and 14 October 1995, biological inventories were conducted in 8 caves within northwestern Georgia's Cumberland Plateau. Five caves were examined on Pigeon Mountain in Walker County: Pettijohns Cave [PJ] on 15 July (a), 5 August (b), and 14 October (c); Anderson Springs Cave [AS] on 30 July (a) and 6 August (b); Ellisons Cave [EC] on 29 July; Nash Waterfall Cave [NW] on 5 August; and Pigeon Cave [PC] on 16 July (a) and 30 July (b). One cave was examined in Chattanooga Valley in Walker County: Fricks Cave [FC] on 16 September. Two caves were examined in Cloudland Canyon State Park at the base of Lookout Mountain in Dade County: Case Cave [CC] and Sittons Cave [SI], both on 26 August (a) and 17 September (b) (Fig. 1).

The study followed methods used by Holsinger & Peck (1971) and Buhlmann (1992). Cave habitats sampled included streams, drip pools, phreatic lakes, decaying wood, cave walls, and mud banks. Bait, usually liver cat food, was left in terrestrial habitats and checked on a return visit. Aquatic fauna in cave streams and drip pools were collected with small aquarium dip nets and suction tubes; baited containers were set in deep pools. The first inventory of each cave included a search for all representative habitat types and collection of organisms. A second visit was made to some caves 1-2 weeks later to collect specimens from the bait stations and revisit selected habitats. Four caves (PC, AS, CC, and SI) were each visited twice during this study. Three caves (FC, EC, and NW) were visited once and 1 cave (PJ) was visited 3 times.

Invertebrates were preserved in 70% ethanol for later identification. Only a minimum number of specimens were collected for species identification. Invertebrate taxa were sorted and shipped to recognized experts of the various taxonomic groups (see ACKNOWLEDGMENTS) where they remain or have been deposited in museum collections. Data were collected on habitats, species abundance, and human disturbance. Simply documenting presence or absence was the greatest level of detail attainable for many species. Nomenclature used in the

[1] Current address: *Conservation International, Center for Applied Biodiversity Science, 1919 M Street, NW, Suite 600, Washington DC 20036 USA*
K.BUHLMANN@conservation.org

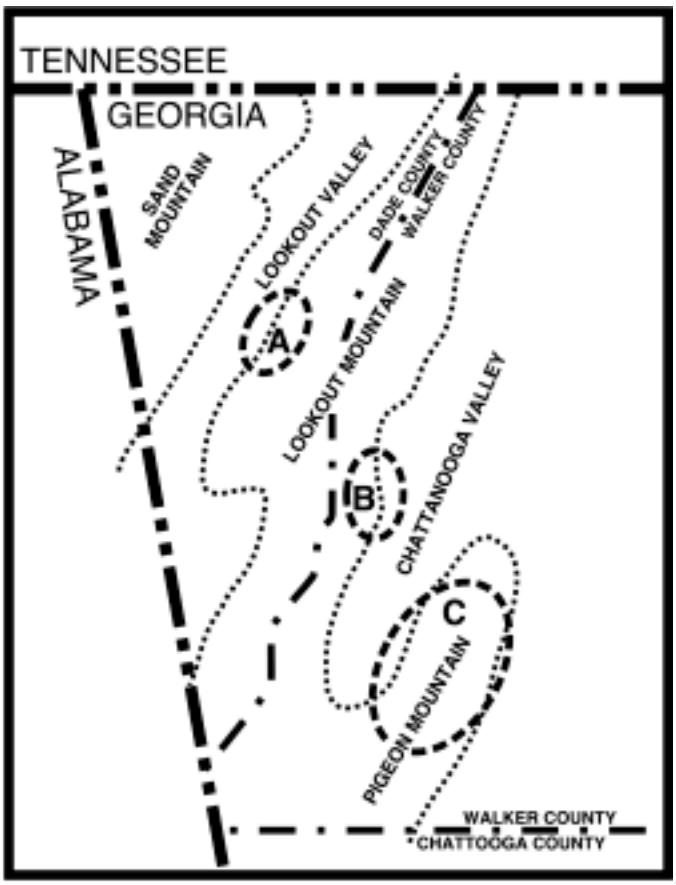


Figure 1. General location of eight caves inventoried during the study (in ellipses): A. - Cloudland Canyon State Park (Case Cave [CC] and Sittons Cave [SI]); B. - Chattanooga Valley (Fricks Cave [FC]); C. - Pigeon Mountain (Pettijohns Cave [PJ], Anderson Springs Cave [AS], Ellisons Cave [EC], Nash Waterfall Cave [NW], and Pigeon Cave [PC]).

Results follows Peck (1998), unless other literature was required.

Cave organisms were classified into one of four categories of cavernicoles (Barr 1963a, 1968). Troglobites (TB) are obligatory cave species with morphological adaptations for the cave environment and do not exist in surface environments. Troglophiles (TP) may frequent caves and are capable of completing all stages of their life cycle within a cave, but also occur in surface habitats. Trogloxenes (TX) are species that may use cave environments seasonally or for portions of their life cycle, yet must also be in association with surface environments. Accidentals (AC) are those species that are often found in caves but generally exist there only temporarily. Results focus on troglobitic and troglophilic species, with some exceptions.

RESULTS

Class Turbellaria (flatworms), Order Tricladida, Family **Kenkiidae:**
Sphalloplana sp. (TB): PJ(a). One specimen was collected in a pool at the base of a waterfall. The specimen may be *Sphalloplana georgiana* (Hyman) which was described from a cave in Dade Co., GA (Hyman 1954).
Class Malacostraca, Order Isopoda (isopods), Family **Asellidae:**
Caecidotea cyrtorhynchus Fleming and Steeves **(**TB): PJ(a); NW; AS(a,b). Individuals were especially abundant in the out-flowing, permanent stream in AS.
Caecidotea sp. (undescribed or possibly *Caecidotea catachaetus* Fleming and Steeves (TB): EC; SI(b). Specimens were collected in a pool in the drying cave stream in SI. Two species of aquatic troglobitic isopods are currently known from GA, *C. cyrtorhynchus* and *C. catachaetus* (Fleming & Steeves 1972).
Lirceus sp. (TP): NW. Specimens were collected from drip pools.
Family **Ligiidae**:
Ligidium elrodi Packard (TP): EC; PC(a). This terrestrial species was found around the entrance to NW. *L. elrodi* are perhaps becoming adapted to cave life (Schultz 1970). They inhabit wet, damp places, including the margins of springs and streams. The specimens found at NW are *L. elrodi hancockensis* (Schultz) (J. Lewis, pers. comm.).
Family **Trichoniscidae:**
Amerigoniscus sp. (possibly undescribed, TB): CC(a); SI(a). Prepared dissections of this terrestrial isopod did not match known species from the area (J. Lewis, pers. comm.).
Miktoniscus sp. (probably *Miktoniscus alabamensis* Muchmore, TP): PC(a). *M. alabamensis* is a widely ranging species known from AL, FL, and VA (Muchmore 1964).
Order Amphipoda (amphipods), Family **Crangonyctidae**:
Crangonyx antennatus Packard (TB): FC; SI(b); PJ(a); AS(a,b). Specimens in FC and AS were collected from streams with cobble bottom. Specimens from SI and PJ were collected from mud-bottomed streams. *C. antennatus* is widespread, and recorded from caves in southwest VA, eastern TN, northwestern GA, and northern Alabama (Holsinger & Culver 1988).
Stygobromus minutus Holsinger (TB): NW. One specimen was collected in a drip pool. The species was previously collected from mud-bottomed drip pools in PJ (Holsinger 1978).
Order Decapoda (crayfishes), Family **Cambaridae:**
Cambarus sp. (TX): EC; SI(a,b). Several specimens were observed in cave streams, but no troglomorphic species were found.
Class Arachnida, Order Pseudoscorpiones (pseudoscorpions)
No specimens were found. Troglobitic species of pseudoscorpions have been previously found in Chattooga, Dade, and Walker County, GA caves (Holsinger & Peck 1971), but not in any of the caves investigated during this study.
Order Acari (parasitic mites)
unknown sp. (AC): PC(a); CC(a); NW; FC. Several genera of mites were collected, but all are believed to represent surface species carried into caves by bats. Holsinger & Peck (1971) reported a cave-adapted mite from PJ.
Order Opiliones (harvestmen), Family **Phalangodidae:**
Bishopella sp. (TP): PC(a); EC; NW; CC(a,b); SI(b); FC; PJ(c). Adult and juvenile specimens of *Bishopella* were collected in seven caves during this study and Reeves *et al.* (2000) subsequently collected *Bishopella* in AS. *Bishopella* have well-developed eyes and have been collected occasionally from epigean habitats (Goodnight & Goodnight 1960). The genus *Bishopella* likely includes several species that have been reported as *Phalangodes laciniosa* (Crosby & Bishop**)** from northwestern GA caves, including SI, PJ, and also northern AL and central TN caves (Holsinger & Peck 1971).
Order Araneae (spiders), Family **Agelenidae:**
Calymmaria sp. (TP): NW. Adults of both sexes were collected and may represent *Calymmaria cavicola* (Banks), a species described from other Walker Co. caves, as well as caves in TN and AL (Heiss 1982).
Family **Amaurobiidae:**
Coras juvenilis Keyserling (TX?): FC. Female and immature specimens were collected and apparently represent a state record for the species (M. Draney, pers. comm.). *C. juvenilis* has not been reported from caves, although congeners (*Coras cavernorum* Barrows from NC and *Coras taugynus* Chamberlin from AL) have been found in caves (Muma 1946).

Family **Leptonetidae:**
Leptoneta sp. (TP): PJ(a,c). Immature specimens were collected. *Leptoneta* is represented in the western and southeastern U.S. by ~35 species; many are cave dwellers (Roth 1993). Holsinger & Peck (1971) collected an undescribed *Leptoneta* in PJ.
Family **Linyphiidae:**
Phanetta subterranea (Emerton) (TB): PC(a); FC; SI(a). *Phanetta* is a monotypic genus (Millidge, 1984). It has been reported from caves in PA, MD, WV, VA, TN, KY, IL, IN, and AL (Peck & Lewis 1978; Roth 1988). *P. subterranea* is known from GA caves in Floyd, Walker, and Dade Co., including SI (Holsinger & Peck 1971).
Family **Mysmenidae:**
Maymena ambita (Barrows) (TX): EC. This spider is not a strict cave-dweller. It has been found in caves in AL, TN, and KY (Gertsch 1960), as well as one other Walker Co., GA cave (Holsinger & Peck 1971).
Family **Nesticidae:**
Nesticus sp. 1 (TB): PC(a); AS(a). This was a small, eyeless purple spider (M. Draney, pers. comm.). More specimens are needed.
Nesticus sp. 2 (TP): CC(a,b). Several species of *Nesticus* with restricted ranges are known from caves in TN and VA (Holsinger & Culver 1988; Coyle & McGarity 1991) and recent genetic analyses indicate considerable genetic divergences among recognized taxa within the genus *Nesticus* (Hedin 1997). Distributional data from Hedin (1997) and a report by Reeves *et al*. (2000) of *Nesticus georgia* in Sittons Cave (SI) indicate that these specimens from CC may represent *N. georgia* Gertsch.
Family **Tengellidae:**
Liocranoides sp. (TP): PJ(a,c); AS(a). The specimens are likely *Liocranoides gertschi* Platnick (Platnick 1999). Specimens of this spider previously reported from several Walker County caves (Holsinger & Peck 1971) as *Liocranoides unicolor* Keyserling, are likely *L. gertschi.*
Family **Tetragnathidae:**
Meta menardi (Latreille) (TP): NW; PC(a); FC. This orb weaver was frequently seen in some cave entrances. It is also found under bridges, in damp ravines, and hollow logs (Marusik & Koponen 1992; M. Draney, pers. comm.). Reeves *et al.* (2000) reported *Meta* from FC and SI.
Family **Theridiidae:**
Achaearanea porteri (Banks) (TX): FC. This spider has been recorded from MD to TX (M. Draney, pers. comm.). The previous GA records are not from caves (Levi 1955).
Class Diplopoda (millipeds) Order Spirostrepida Family **Cambalidae:**
Cambala hubrichti Hoffman (TX): FC. These large pinkish-gray millipeds were abundant on gray bat (*Myotis grisescens*) guano in FC. *C. hubrichti* is also known from caves in western SC (Chamberlin & Hoffman 1958).
Order Chordeumatida Family **Cleidogonidae:**
Pseudotremia eburnea Loomis (TB): CC(a,b); PJ(b); EC. *P. eburnea* was described from a cave in Dade County, GA (Loomis 1939; Chamberlin 1946), and was reported from CC by Shear (1972) and from PJ by Holsinger & Peck (1971). Reeves *et al.* (2000) reported *P. eburnea* from several additional Georgia caves.
Pseudotremia sp. 1 (TB): NW. These female specimens probably represent *P. eburnea*, but could be a different species (R.L. Hoffman, pers. comm.).
Pseudotremia sp. 2 (TB): SI(a). Holsinger & Peck (1971) also collected an undescribed *Pseudotremia* from SI.
Pseudotremia aeacus Shear (TB): PC(a,b). *P. aeacus* was described from a cave in Dade Co., GA (Shear 1972); the PC specimens may represent a new subspecies (R.L. Hoffman, pers. comm.).
Family **Trichopetalidae:**
Scoterpes austrinus Loomis (TB): PJ(c); EC; NW; AS(a,b); SI(b). *S. austrinus* was previously found in several caves, including PJ (Holsinger & Peck 1971), and as well as caves in DeKalb Co., AL (Loomis 1943).
Scoterpes sp. (TB): NW; PC(a,b); FC; CC(b). These specimens are perhaps *S. austrinus* or represent a new species. Holsinger & Peck (1971) suggested that at least two subspecies (or species) of *Scoterpes* exist in GA caves. Additional specimens, specifically adult males, are required (R.L. Hoffman, pers. comm.).
Order Polydesmida Family **Xystodesmidae:**
Cherokia georgiana Bollman (AC): PC(a). Specimens were collected at the entrance to PC. *C. georgiana* is not usually considered a cave inhabitant.
Class Chilopoda (centipedes) Order Lithobiomorpha Family **Lithobiidae:**
Typhlobius ?caecus Bollman (TX?): FC. The posterior end of a female lithobiid centipede was found. An intact adult male would be very valuable since records for cave-dwelling centipedes are scarce and their status as troglobites has not been determined (R.L. Hoffman, pers. comm.).
Class Insecta, Order Collembola (springtails), Family **Entomobryidae:**
Pseudosinella christianseni Salmon (TB): PJ(a,b,c); PC(a); EC; NW; AS(a,b); FC; CC(a,b); SI(a,b). Springtails were found in every cave visited and were often abundant around damp and decaying wood. *P. christianseni* is an artificial taxon that will eventually be split into a series of species, all of which are highly troglomorphic (K. Christiansen, pers. comm.).
Pseudosinella n. sp. (TP): EC; NW; PC(a); FC. *Pseudosinella* n. sp. is not troglomorphic, but all of the *P.* n. sp. specimens collected are the same species (K. Christiansen, pers. comm.).
Family **Isotomidae:**
Folsomia candida Willem (TP): PJ(b). *F. candida* is an opportunistic troglophile and has been recorded from caves over a wide area of the United States (Christiansen 1982).
Family **Tomoceridae:**
Tomocerus bidentatus Folsom (TP): EC; NW; PC(a); CC(b). *T. bidentatus* is a common and widespread collembolan in caves in the eastern U.S. It is lightly pigmented with small eyes (Christiansen 1982; Holsinger & Culver 1988).
Order Diplura (diplurans or bristletails), Family **Campodeidae:**
Litocampa sp. "P" (TB): PJ(a,c); EC; AS(a,b); PC(a); NW; FC. Diplurans were found on undisturbed mud banks. *Litocampa* sp. "P" was previously known only from PJ and a cave in Chattooga Co., GA. This study found five new cave localities for this possible Georgia endemic (L. Ferguson, pers. comm.). *Litocampa* are not known from CC and SI. Three *Litocampa* species are known from GA caves (Ferguson 1981). The species designation of "P" corresponds with a coding system for unnamed species (L. Ferguson, pers. comm.).
Order Orthoptera, Family **Rhaphidophoridae** (cave and camel crickets):
Ceuthophilus gracilipes (Haldeman) (TX): The common "camel" cricket was found in the entrances of all 8 caves. Hundreds of camel crickets were observed under a ledge at the entrance to PC(b). *C. gracilipes* occurs throughout the eastern United States in forested habitats as well as cave entrances and no systematic effort was made to collect them.
Euhadenocecus puteanus Scudder (TP): PC(a); EC; AS(a); FC; CC(a). *E. puteanus* is widely distributed throughout the Appalachian region and the Interior Low Plateaus and is closely associated with cave environments (Holsinger & Culver 1988). It has been recorded from GA caves in Dade, Walker, and Polk Co. (Holsinger & Peck 1971).
Order Diptera (flies), Family **Heleomyzidae:**
undetermined Heleomyzidae (TP): These flies were observed on the ceilings and damp walls near the entrance zones of all caves. No systematic effort was made to collect cave flies.
Order Coleoptera (beetles), Family **Carabidae** (ground beetles)**:**
Pseudanophthalmus georgiae Barr (TB): PJ(a,c); EC. One of the PJ specimens collected was white. Holsinger & Peck (1971) collected this species, undescribed at that time, in PJ and Mountain Cove Farm Cave. It is also known from Blowing Springs Cave (Barr 1981). The EC specimen represents a new cave record for *P. georgiae*.
Pseudanophthalmus fulleri Valentine (TB): SI(a). *P. fulleri* was previously known from SI (Barr 1981). It was also collected in several Dade and Walker Co. caves by Holsinger & Peck (1971) and Reeves *et al.* (2000) and is also known from caves in Hamilton Co., TN.
Family **Leiodidae** (scavenger beetles)**:**
Ptomaphagus fiskei Peck (TB): PJ(a,b,c); EC; PC(b); AS(a,b). *P. fiskei* was especially abundant at bait stations in PJ. *P. fiskei* appears to be restricted to Pigeon Mountain. According to Peck (1973), no *Ptomaphagus* are known from caves in the valley between Pigeon and Lookout Mountains. No *Ptomaphagus* were found in FC.
Ptomaphagus whiteselli Barr (TB): CC(a,b); SI(a,b). *P. whiteselli* was previously known from SI (Barr 1963b) and CC (Peck 1973). It is the only *Ptomaphagus* known from caves between Sand and Lookout Mountains in DeKalb Co., AL and Dade Co., GA (Peck 1973).
Family **Pselaphidae** (pselaphid beetles)**:**
Batrisodes sp. (TX): PC(a). The specimens may be *Batrisodes globosus* (LeConte), a widely distributed species in eastern North America and record-

ed from caves in AL, GA, and VA (Barr 1964; Park 1947; Holsinger & Peck 1971).

Speleochus sp. (TB): PC(a). PC produced the only specimen of this undescribed species known from GA. The genus *Speleochus* is only known from central TN, northeast AL, and Walker Co., GA (T. Barr, pers. comm.). Species in this genus seem rare and they appear to be most abundant during cold, wet weather (Jan-Feb) when they may be more easily observed because their interstitial habitats are flooded. (T. Barr, pers. comm.).

Family **Staphylinidae** (rove beetles) (TX)**:**

Staphylinid beetles were collected in PJ, NW, PC, and FC and are in the possession of T. Barr. Staphylinid beetles were commonly found at bait traps. None of the species known are restricted to caves (Holsinger & Culver 1988).

Class Osteichthyes, Order Perciformes, Family **Cottidae:**

Cottus bairdi (mottled sculpin, TX): FC. Several sculpins were observed in the FC stream; 1 was collected and dissected, but no food items were found in the stomach.

Class Amphibia, Order Anura (frogs and toads), Family **Ranidae:**

Rana palustris LeConte (pickerel frog, TX): EC; AS(a); NW. 5 frogs were observed inside the entrance to EC; 1 frog each was found in AS and NW. Pickerel frogs have been commonly observed inside VA caves (K.A. Buhlmann, pers. obs.).

Rana clamitans Latreille (green frog, AC): EC; NW. 1 frog each was found near the entrances in EC and NW. Unlike pickerel frogs, green frogs are not commonly reported from caves.

Order Caudata (salamanders) Family **Plethodontidae**:

Gyrinophilus porphyriticus (Green) (northern spring salamander, TP): PJ(a); EC; AS(a,b); PC(a,b). The PJ specimen was a pale larva that was re-absorbing its gills. 1 adult individual was observed in the cave stream in EC. An adult and a larva were each observed in AS. In PC(a) 4 larval individuals and 1 adult were observed in the cave stream. Also in PC(b), 2 very large larval individuals were collected at the back of the cave, 370 m from the entrance, in the terminal siphon. These very pale larvae with seemingly reduced eyes were deposited in the U.S. National Museum of Natural History, Washington D.C. (USNM 497685, 497686).

Gyrinophilus palleucus McGrady (Tennessee cave salamander, TB): FC. 4 larval individuals were observed in the cave's out-flowing stream and 1 specimen was collected (USNM 497687). The nearest AL records for *G. palleucus* are ~16 km west of Chattanooga Valley on the AL/GA line near Rising Fawn, GA (Godwin 1995). Cooper (1968) reported a GA specimen but the locality is uncertain. The FC specimens confirm the presence of *G. palleucus* in GA (Buhlmann & Wynn 1996).

Eurycea lucifuga Rafinesque (cave salamander, TP): All individuals reported were observed and not collected: PJ(a), 3 adults; PC(a), 2 adults and several larvae in the cave stream; EC, 1 adult and several larvae in cave stream pools; AS(a), 9 adults and AS(b), 5 adults; NW, 5 adults; CC(a,b), 1 adult each; SI(a), 4 adults and SI(b), 1 adult. Cave salamanders are often encountered in caves throughout the Appalachian and Cumberland regions.

Eurycea longicauda (Green) (longtail salamander, TX): All individuals reported were observed, not collected: AS(a), 4 adults and AS (b), 5 adults; FC, 1 adult. Longtail salamanders, although closely related to cave salamanders (*E. lucifuga*), are occasionally, although not commonly found in caves.

Plethodon glutinosus (Green) (slimy salamander, TX): EC; PJ(b); AS(a,b); NW; CC(a). In EC, 64 slimy salamanders were seen inside the Historic Entrance in the first 50 m, and an additional 81 salamanders were seen between 51-60 m of this entrance. 20 more were observed inside the New Entrance to EC, totaling 165. 10 slimy salamanders were seen at the entrance to PJ(b); 9 were seen in AS(a) and 4 were observed in AS(b); 2 were observed in NW; and 1 was observed in CC(a). The large numbers of *P. glutinosus* in the entrance to Ellisons Cave seemed unusual and warrant further study.

Plethodon dorsalis (Cope) (zigzag salamander, AC): PJ(c). 1 specimen was observed 10 m inside the entrance.

Plethodon serratus Grobman (southern redback salamander, AC): AS(b). 1 adult was observed at the entrance.

Plethodon petraeus (Wynn, Highton, and Jacobs) (Pigeon Mountain salamander, TX): PJ(b). 1 very large adult was observed at the entrance. *Plethodon petraeus* was expected in larger numbers around the entrance to PJ. It was apparently very abundant around the PJ entrance when it was first discovered (Wynn *et al.* 1988), but may since have been collected for the pet trade (A. Wynn, pers. comm.). Incidental to the cave inventory, another location for *P. petraeus* was discovered, representing the northernmost locality for this Pigeon Mountain endemic. The locality is not reported here in order to protect the population.

Desmognathus fuscus (Green) (northern dusky salamander, AC): PC(a); EC; NW. At PC, several individuals were found near the entrance under rocks in the in-flowing cave stream. 2 salamanders were observed at the entrance to EC and 1 was observed at the entrance to NW.

Pseudotriton ruber (Latreille) (red salamander, AC): PC(b); AS(a,b). In PC, 2 adult red salamanders were seen in the cave stream. In AS(a), 1 adult was observed and in AS(b), 2 adults were observed. Red salamanders are not usually considered cave associates.

Class Mammalia, Order Chiroptera **(** Bats), Family **Vespertilionidae:**

Pipistrellus subflavus (Cuvier) (eastern pipistrelle, TX): PJ(a), 1 observed; PC(a), 1 obs; EC, 68 obs; AS(a), 36 obs; FC, several obs; SI(a), 1 obs. and SI(b), 5 obs. Eastern pipistrelles are the most common cave bat in eastern North America (Harvey 1992). They usually hang singly in the warmer parts of the cave. Martin & Bearden (1990) reported *P. subflavus* to be abundant in both EC and AS during inventories conducted Jan 1989-Feb 1990.

Myotis lucifugus (LeConte) (little brown bat, TX): EC, 1 was observed.

Myotis grisescens (Howell) (gray bat, TX): FC; SI(b). At FC, a bachelor colony of 10,000-15,000 individuals was observed. At SI(b), 4 gray bats were observed, 2 were females. Large piles of guano in FC indicate that the cave has been used by gray bats for many years. FC is relatively pristine, and has been closed to caving for nearly 30 years (A. Padgett, pers. comm.). Gray bats are listed as federally Endangered and ~95% of the global population of gray bats hibernates in 8 caves in TN, MO, KY, AL, and AR (Harvey 1992). The 4 gray bats observed in SI likely represent individuals on migration (C. Hobson, pers. obs.). However, a gray bat stain on the ceiling indicates that SI may have historically harbored a gray bat maternity colony.

Myotis septentrionalis (Trouessart) (northern long-eared bat, TX): CC(a), 1 long-eared bat was observed; SI(b), 3 male long-eared bats were observed.

Order Rodentia (gnawing mammals), Family **Cricetidae:**

Neotoma floridana (Ord) (eastern woodrat, TX): Although no woodrats were observed during the study, their presence within each cave was recorded as active or historic after investigating droppings and nests: PJ, historic; EC, active; PC, active; NW, active; CC, historic. No woodrat sign was found in AS, FC, and SI. Woodrat populations have been declining in the northeastern United States and the species is monitored by several state Natural Heritage Programs (C. Hobson, pers. comm.).

COMPARISON OF THE 1967 AND 1995 STUDIES OF PETTIJOHNS CAVE

The most comprehensive Georgia cave study was conducted in 1967 and one of the caves studied was PJ (Holsinger & Peck 1971). A comparison of the 1967 and 1995 studies found some faunal differences in PJ, primarily with regards to missing aquatic fauna in 1995 (Table 1). *Stygobromus minutus* and *S. dicksoni*, amphipods that inhabit drip pools (Holsinger 1978) were not found in 1995, nor were they found by Reeves *et al*. (2000).

The 1967 study also reported terrestrial isopods, pseudoscorpions, and cave-adapted mites, none of which were found by the 1995 study. Pseudoscorpions and mites are often difficult to detect in caves, yet terrestrial isopods (*Amerigoniscus*) should have been found by the methods used in 1995. The milliped, *Cambala hubrichti*, collected in 1967, was not found in 1995. Interestingly, this study found *C. hubrichti* abundantly in FC where it appeared to be associated with gray bat (*M. grisescens*) guano deposits. The 1995 study documented an additional species each of troglophilic spider, collembolan, and beetle from PJ, although all are known from other caves.

TABLE 1. A comparison of invertebrate troglobites (TB) and troglophiles (TP) collected from Pettijohns Cave, Walker County, Georgia, during June 1967 (Holsinger & Peck 1971) and this study, July-October 1995. Names used by Holsinger & Peck are given in parentheses.

SPECIES	Holsinger & Peck, 1971	This Study
Sphalloplana sp.		X
Caecidotea cyrtorhynchus	X (as *Asellus* sp.)	X
Amerigoniscus sp.	X (as *Caucasonethes* sp.)	
Crangonyx antennatus	X	X
Stygobromus minutus	X (as *Stygobromus* sp.)	
Stygobromus dicksoni	X (as *Stygobromus* sp.)	
Microcreagris sp.	X	
Rhagidia sp.	X	
Bishopella sp.	X (as *Phalangodes laciniosa*)	X
Leptoneta sp.	X	X
Liocranoides sp.		X
Pseudotremia eburnea	X	X
Scoterpes austrinus	X	X
Cambala hubrichti	X (as *Cambala minor*)	
Pseudosinella christianseni	X (as *Pseudosinella hirsuta*)	X
Pseudosinella n. sp .		X
Folsomia candida		X
Litocampa sp. P	X (as *Plusiocampa* sp.)	X
unidentified Heleomyzidae	X (as *Amoebalaria defressa*)	X
Pseudanophthalmus georgiae	X (as *Pseudanophthalmus* sp.)	X
Ptomaphagus fiskei	X (as *Ptomaphagus* sp.)	X
TOTALS	17	15

DISCUSSION

SPECIES AND DISTRIBUTION

A total of 46 invertebrate taxa were identified during the study. Of those, 21 are considered troglobites, 14 are troglophiles, and the remainder were classified as trogloxenes (9) or accidentals (2). Harvestmen (*Bishopella* sp.) and springtails (*Pseudosinella* sp.) are believed to represent several different species and further taxonomic work is needed. Other collected specimens, mainly non-troglobitic, have been given to others who are working with the material (W. Reeves, Clemson Univ.). The pselaphid beetle (*Speleochus* sp.) was found only in Pigeon Cave and represents a new, undescribed species for Georgia. The amphipod, *Stygobromus minutus* collected in NW, was previously known only from PJ (Holsinger 1978), but was not found there during this study. Possible new species of millipeds were also collected in NW and *Pseudotremia* sp. 2 is a possible endemic to SI. An undescribed springtail (*Pseudosinella*) was collected in three of the Pigeon Mountain caves, as well as in FC. The dipluran (*Litocampa* sp. "P") was previously known only from PJ, but was found in all Pigeon Mountain caves studied, as well as FC. EC yielded a new cave record for the beetle, *P. georgiae*. For vertebrate species, 10 salamanders, 2 frogs, 1 fish, 4 bats, and 1 rodent were encountered. In FC, the Tennessee cave salamander (*Gyrinophilus palleucus*) was re-confirmed as a component of Georgia's fauna and a large population of federally endangered gray bats (*Myotis grisescens*) was found.

Caves on Pigeon Mountain contained more species than the caves studied in Chattanooga Valley or on Lookout Mountain (PJ=17, EC=17, NW=17, PC=17, AS=14, FC=13, CC=13, and SI=11). The faunas of the Pigeon Mountain caves were similar, although several species were found in only 1 or 2 caves. However, faunal composition differed between the caves of Pigeon and Lookout Mountains. The terrestrial isopods (*Amerigoniscus* sp.) were found only in the 2 Lookout Mountain caves. Conversely, diplurans (*Litocampa* sp. "P") were found in all Pigeon Mountain caves and FC, but not the Lookout Mountain caves. The leiodid beetles were represented by 2 species with *P. fiskei* occurring in 4 of 5 Pigeon Mountain caves, while *P. whiteselli* was found in both Lookout Mountain caves. The troglobitic carabid beetles showed a similar 2 species distribution, with *P. georgiae* occurring in 2 Pigeon Mountain caves, and *P. fulleri* being found in CC. The apparent absence of both *Pseudanophthalmus* and *Ptomaphagus* from FC is interesting in terms of biogeography. Peck (1973) had previously hypothesized that the cave-adapted beetles may be restricted to the flat-bedded limestones of the Appalachian Plateau. Peck's hypothesis would explain the absence of beetles in FC and is also supported because different leiodid and carabid beetles are found on Lookout and Pigeon Mountains.

The habitats within each cave may determine the faunal composition. AS has an out-flowing cave stream that originates within Pigeon Mountain and contained large populations of aquatic isopods (*C. cyrtorhynchus*), as well as some amphipods (*C. antennatus*). Similarly, SI contained a large out-flowing stream and stygobitic crustaceans were also noted, although in smaller numbers. Few aquatic cave organisms were found in caves that contained in-flowing streams, notably EC and PC. Small drip pools were noted in NW and contained the amphipod, *S. minutus*, known previously only from PJ, as well as an undescribed isopod (*Lirceus* sp.), and illustrate the importance of these habitats. CC has deep connections to phreatic water and a 2.5 m change in water level was noted between the two visits. The phreatic lakes of CC were previously known to contain amphipods, isopods, and cave fish (A. Padgett, pers. comm.). Limited observations indicate that cave fish and Tennessee cave salamanders are most likely to be found in Georgia caves that have connections to phreatic waters. Cave stream mud banks represent habitat for many of the terrestrial invertebrates. Flooding streams deposit organic material that is scavenged by leiodid beetles, diplurans, millipeds and collembolans. The untrampled mud banks in AS and FC contained the largest numbers and diversity of terrestrial cave fauna.

MANAGEMENT IMPLICATIONS

All 8 caves inventoried are in public ownership or protected by private owners. Four of the Pigeon Mountain caves are on the Crockford-Pigeon Mountain Wildlife Management Area (CPMWMA) and 1 is immediately adjacent in private ownership. Cloudland Canyon State Park (CCSP) on Lookout Mountain contains CC and SI. The Georgia Department of Natural Resources owns both CPMWMA and CCSP and The

Southeastern Cave Conservancy owns FC. Therefore, the opportunity exists to effectively manage all of these caves for both biodiversity protection and recreation.

PJ is probably the most frequently visited recreational cave in Georgia. As many as 350 people have visited the cave in one month and as many as 75 on a given weekend (Georgia DNR, unpubl. data). There are many passages and although all receive human traffic, some are more heavily used than others. The greatest numbers of collembolans and diplurans were found in PJ rooms and passages that contained signs of heavy human use and garbage. It is unknown if the presence of additional food resources results in increased populations of cave fauna or if it serves to attract and concentrate cave organisms. If it serves to concentrate organisms, then are populations ultimately reduced by trampling? These questions could be addressed with future research. Few bats were observed in PJ and more Pigeon Mountain salamanders were expected based on discussions with biologists who had observed them in the past. Overall, PJ contained a great diversity of cave life, particularly terrestrial species. Aquatic organisms seemed rare in PJ, perhaps a result of trampling in drip pools and streams. No amphipods (*Stygobromus* sp.) were found during this study in PJ, yet two drip pool species, *S. dicksoni* and *S. minutus* were recorded previously (Holsinger & Peck 1971). However, not all stream passages were explored and refugia may exist, particularly in the less traveled passages. Protection of certain passages might provide refugia for cave organisms while continuing to provide recreational opportunities for cavers. *Stygobromus dicksoni* is also known from several caves in northeastern AL and northwestern GA (Holsinger 1978; Reeves *et al.* 2000).

CC was heavily abused during the 1960s as indicated by dates on discarded soda cans and batteries. The entrance to CC is currently gated with a steel pipe tunnel and solid door. The gate should be re-designed because it alters air flow and prevents access to bats. The expected aquatic fauna in CC was absent. The large, deep phreatic pools of CC should have yielded populations of troglobitic amphipods and isopods, which were present in the early 1970s (A. Padgett, pers. comm.). A cave fish (*Typhlichthes subterraneus*) had been collected from CC in 1971 and was deposited in the University of Georgia Natural History Museum, Athens. This study detected petroleum in the cave stream and mud sediments. A truck carrying petroleum products wrecked on Highway Rt. 136 in the late 1970s on Lookout Mountain above CC (A. Padgett, pers. comm.). It is probable that this spill accounts for the lack of aquatic cave fauna in CC and illustrates the fragile nature of cave ecosystems and the difficulty in protecting them.

The remaining caves studied did not appear to have any significant management concerns. Periodic monitoring should occur to assess long term trends in cave faunal populations. FC was the most pristine cave visited and is significant in terms of its fauna and should be a high priority site for long-term cave biodiversity protection in Georgia.

There are many limestone caves in northwestern Georgia. Further inventory and research should address the protection of the landscape around caves (e.g., Aley & Aley 1991) in order to protect cave habitats and fauna (e.g., Fong 1995; Jacobson 1995). Caves are unique natural habitats and contain endemic and rare species. Further study of the biota and ecology of Georgia caves is therefore warranted.

ACKNOWLEDGMENTS

For providing critical review of the manuscript I thank J.R. Holsinger, S.J. Taylor, J.J. Lewis, J.B. Jensen, and two anonymous reviewers. For identifying specimens I thank: T.C. Barr, K.A. Christiansen, D.A. Crossley, M. Draney, L.R. Ferguson, R.L. Hoffman, J.R. Holsinger, J.J. Lewis, S.B. Peck, D. Ubick, and A.H. Wynn. Cavers and biologists who participated on one or more field trips included: C. Anderson, J. Bearden, M. Branch, L. Clarke, J.P. Demuth, G. Eck, C.A. Hobson, N. Holcomb, T. Holcomb, K. Huffines, R. Kappel, J.A. Ott, J. Ozier, A. Padgett, K. Padgett, M.A. Pilgrim, J. Respess, D. Sorrell, S. Sotona, D. Wohl, G. Yanochko, H. Young, and S. Young. A. DeBiase and B. Taylor of SREL allowed use of their laboratory for sorting specimens. A. Padgett, N. Holcomb, and J. Bearden of the Georgia Department of Natural Resources provided logistical support. Financial support was provided by The Athens Speleological Society, The Georgia Speleological Survey, The Dogwood City Grotto, The Clayton County Cavers, The Chattanooga Grotto, The Southeastern Region of the NSS, and the Georgia DNR. Manuscript preparation was supported by the University of Georgia's Savannah River Ecology Lab through Contract #DE-FC09-96SR18546 with the U.S. Department of Energy and the Center for Applied Biodiversity Science, Conservation International. I thank the owners for access to caves on their property (PC, FC) and for allowing access to state-owned caves that required crossing private property. Finally, I thank J.R. Holsinger for encouraging me to undertake this project.

REFERENCES

Aley, T. & Aley., C., 1991, Delineation and hazard area mapping of areas contributing water to significant caves, *in* Cave Management Symposium, Bowling Green, Kentucky, p. 1-10.

Barr, T.C., Jr., 1963a, Ecological classification of cavernicoles: Cave Notes, v. 5, p. 9-12.

Barr, T.C., Jr., 1963b, Studies on the cavernicole *Ptomaphagus* of the United States (Coleoptera: Catopidae): Psyche, v. 70, p. 50-58.

Barr, T.C., Jr., 1964, Non-troglobitic Carabidae (Coleoptera) from caves in the United States: Coleopterist's Bulletin, v. 18, p. 1-4.

Barr, T.C., Jr., 1965, The *Pseudanophthalmus* of the Appalachian Valley (Coleoptera:Carabidae): American Midland Naturalist, v. 73, p. 41-72.

Barr, T.C., Jr., 1968, Cave ecology and the evolution of troglobites: Evolutionary Biology, v. 2, p. 35-102.

Barr, T.C., Jr., 1981, *Pseudanophthalmus* from Appalachian caves (Coleoptera: Carabidae): The *engelhardti* complex: Brimleyana, v. 5, p. 37-94.

Buhlmann, K.A., 1992, A Natural Heritage Inventory of seven cave beetles of the genus *Pseudanophthalmus* and an assessment of their respective habitats, Virginia Natural Heritage Technical Report # 92-30, 14 p.

Buhlmann, K.A. & Wynn, A.H., 1996, Geographic distribution: *Gyrinophilus palleucus* in Georgia: Herpetological Review, v. 27, p. 147-148.

Chamberlin, R.V., 1946, On some millipedes of Georgia: Entomological News, v. 1946 (June), p. 149-152.

Chamberlin, R.V. & Hoffman, R.L., 1958, Checklist of the millipedes of North America: Bulletin U.S. National Museum, v. 212, p. 1-236.

Christiansen, K.A., 1982, The zoogeography of cave Collembola east of the Great Plains: NSS Bulletin, v. 44, p. 32-41.

Cooper, J.E., 1968, The salamander *Gyrinophilus palleucus* in Georgia, with notes on Alabama and Tennessee populations: Journal of the Alabama Academy of Sciences, v. 39, p. 182-185.

Cooper, J.E. & Iles., A., 1971, The southern cavefish, *Typhlichthys subterraneus*, at the southeastern periphery of its range: NSS Bulletin, v. 33, p. 45-49.

Coyle, F.A. & McGarity, A.C., 1991, Two new species of Nesticus spiders from the southern Appalachians (Araneae, Nesticidae): Journal of Arachnology, v. 19, p. 161-168.

Dearolf, K., 1953, The invertebrates of 75 caves in the United States: Proceedings: Pennsylvania Academy of Sciences, v. 27, p. 225-241.

Ferguson, L.M., 1981, Systematics, evolution, and zoogeography of the cavernicolous campodeids of the Genus *Litocampa* (Diplura: Campodeidae) in the United States [Ph.D. thesis]: Virginia Polytechnic Institute and State University, 374 p.

Fleming, L.E. & Steeves, H.R.III., 1972, Two new species of troglobitic asellids from the United States: American Midland Naturalist, v. 87, p. 245-249.

Fong, D.W., 1995, Technical/Agency Draft Recovery Plan: Madison Cave Isopod (*Antrolana lira*): U.S. Fish and Wildlife Service.

Gertsch, W.J., 1960, Descriptions of American spiders of the family Symphytognathidae: American Museum Novitates, 40 p.

Godwin, J.C., 1995, Reassessment of the historical localities of the Tennessee Cave Salamander (*Gyrinophilus palleucus*) in Alabama, Alabama Natural Heritage Program - Final Report, 32 p.

Goodnight, C.J. & Goodnight, M.L., 1960, Speciation among cave Opilionids of the United States: American Midland Naturalist, v. 64, p. 34-38.

Harvey, M.J., 1992, Bats of the eastern United States, Arkansas Game and Fish Commission, 46 p.

Hedin, M.C., 1997, Speciational history in a diverse clade of habitat-specialized spiders (Araneae: Nesticidae: *Nesticus*): Inferences from geographic-based sampling: Evolution Biology, v. 51, p. 1929-1945.

Heiss, J.S., 1982, A systematic study of the spider genus *Calymmaria* [Ph.D. thesis]: University of Arkansas, 159 p.

Holsinger, J.R., 1969, Biogeography of the freshwater amphipod crustaceans (Gammaridae) of the central and southern Appalachians, The distributional history of the biota of the southern Appalachians, Part I. Invertebrates: Blacksburg, Virginia Polytechnic Institute Press, p. 19-50.

Holsinger, J.R., 1978, Systematics of the subterranean amphipod Genus *Stygobromus* (Crangonyctidae), Part II. Species of the eastern United States: Smithsonian Contributions to Zoology, v. 266, p. 1-144.

Holsinger, J.R. & Culver, D.C., 1988, The invertebrate cave fauna of Virginia and a part of eastern Tennessee: Zoogeography and Ecology: Brimleyana, v. 14, p. 1-164.

Holsinger, J.R. & Peck., S.B., 1971, The invertebrate cave fauna of Georgia: NSS Bulletin, v. 33, p. 23-44.

Hubricht, L., 1943, Studies on the Nearctic freshwater Amphipoda, III: American Midland Naturalist, v. 29, p. 683-712.

Hyman, L.H., 1954, North American triclad Turbellaria: Three new cave planarians: Proceedings U.S. National Museum, v. 103, p. 563-573.

Jacobson, T.R., 1995, Technical/Agency Recovery Plan: Cave Crayfish (*Cambarus aculabrum*), U.S. Fish and Wildlife Service, Jackson, 25 p.

Levi, H.W., 1955, The spider genera *Coressa* and *Achaearanea* in America North of Mexico (Araneae, Theridiidae), American Museum Novitates no. 1718, 33 p.

Loomis, H.F., 1939, The millipedes collected in Appalachian caves: Bulletin of the Museum of Comparative Zoology, v. 86, p. 165-193.

Loomis, H.F., 1943, New cave and epigean millipedes of the United States, with notes on some established species: Bulletin of the Museum of Comparative Zoology, v. 92, p. 373-410.

Martin, R.A. & Bearden, J., 1990, An examination of bat populations in caves located on the Crockford-Pigeon Mountain Wildlife Management Area, Georgia Department of Natural Resources, p. 6.

Marusik, Y.M. & Koponen, S., 1992, A review of *Meta* (Araneae, Tetragnathidae), with descriptions of two new species: Journal of Arachnology, v. 20, p. 137-143.

Millidge, A.F., 1984, The erigonine spiders of North America. Part 7. Miscellaneous genera (Araneae, Linyphiidae): Journal of Arachnology, v. 12, p. 121-169.

Muchmore, W.B., 1964, New terrestrial isopods of the genus *Miktoniscus* from the eastern United States (Crustacea: Isopods: Oniscoidea): Ohio Journal of Science, v. 64, p. 51-57.

Muma, M.H., 1946, North American Agelenidae of the genus *Coras* Simon; American Museum Novitates, no. 1329, p. 20.

Nicholas, B.C., 1960, Checklist of the macroscopic troglobitic organisms of the United States: American Midland Naturalist, v. 64, p. 123-160.

Park, O., 1947, Observations on *Batrisodes* (Coleoptera: Pselaphidae), with particular reference of the American species east of the Rocky Mountains: Chicago Academy of Sciences Bulletin, v. 8, p. 45-132.

Peck, S.B., 1973, A systematic revision and the evolutionary biology of the *Ptomaphagus* (Adelops) beetles of North America (Coleoptera; Leiodidae; Catopinae), with emphasis on cave-inhabiting species: Bulletin of the Museum of Comparative Zoology, v. 145, p. 29-162.

Peck, S.B., 1998, A summary of diversity and distribution of the obligate cave-inhabiting faunas of the United States and Canada: Journal of Cave and Karst Studies, v. 60, p. 18-26.

Peck, S.B. & Lewis, J.J., 1978, Zoogeography and evolution of the subterranean invertebrate faunas of Illinois and southeastern Missouri: Bulletin of the National Speleological Society, v. 40, p. 39-63.

Platnick, N.I., 1999, A revision of the Appalachian spider Genus *Liocranoides* (Araneae: Tengellidae): American Museum Novitates, no. 3285, p. 9-13.

Reeves, W.K., Jensen, J.B., & Ozier, J.C., 2000, New faunal and fungal records from caves in Georgia, USA: Journal of Cave and Karst Studies, v. 62, p. 169-179.

Roth, V.D., 1988, Linyphiidae of America North of Mexico. Checklists, synonymy and literature cited: Gainesville, Florida, American Arachnological Society.

Roth, V.D., 1993, Spider genera of North America with keys to families and genera, and a guide to literature: Gainesville, Florida, American Arachnological Society.

Schultz, G.A., 1970, Descriptions of new subspecies of *Ligidium elrodi* (Packard) comb. nov. and notes on other isopod crustaceans from caves in North America (Oniscoidea): American Midland Naturalist, v. 84, p. 36-45.

Shear, W.A., 1972, Studies in the milliped order Chordeumida (Diplopoda): A revision of the family Cleidogonidae and a reclassification of the order Chordeumida in the New World: Bulletin of the Museum of Comparative Zoology, v. 144, p. 151-352.

Wynn, A.H., Highton, R., & Jacobs, J.F., 1988, A new species of rock-crevice dwelling *Plethodon* from Pigeon Mountain, Georgia: Herpetological Review, v. 44, p. 135-143.

Mark J. Wetzel and Steven J. Taylor - First records of freshwater oligochaetes (Annelida, Clitellata) from caves in Illinois and Missouri, USA. *Journal of Cave and Karst Studies 63*(3):99-104.

FIRST RECORDS OF FRESHWATER OLIGOCHAETES (ANNELIDA, CLITELLATA) FROM CAVES IN ILLINOIS AND MISSOURI, USA

MARK J. WETZEL AND STEVEN J. TAYLOR

Illinois Natural History Survey, Center for Biodiversity, 172 N.R.B., 607 E. Peabody Drive, MC-652, Champaign, IL 61820-6917 USA MJW: mjwetzel@uiuc.edu; SJT: sjtaylor@inhs.uiuc.edu

Aquatic oligochaetes were collected from the fine sediments of eight cave streams in Illinois and Missouri from June 1998 through January 2000. Five families, 9 genera, and 15 taxa are reported. Rhyacodrilus subterraneus *(Tubificidae) represents a new state record for Illinois, and 10 species*—Dero digitata, D. nivea, *and* Pristina leidyi *(Naididae) and* Limnodrilus cervix, L. hoffmeisteri, L. udekemianus, Rhyacodrilus falciformis, R. sodalis, R. subterraneus, *and* Varichaetadrilus angustipenis *(Tubificidae)—represent new state records for Missouri. Of the species collected,* Haplotaxis *cf.* gordioides *(Haplotaxidae),* P. leidyi, *and* L. hoffmeisteri, R. falciformis, R. subterraneus, *and* Tubifex tubifex *(Tubificidae) have previously been reported from caves in North America. These are the first published records of freshwater oligochaetes in caves of Illinois and Missouri.*

The fauna of Illinois and Missouri caves has been the subject of several faunal surveys (Craig 1977; Gardner 1986; Lewis 1974; Lewis *et al.* 1999; Peck & Lewis 1978; Peck & Christiansen 1990; Webb *et al.* 1993). While several of these studies listed edaphobitic oligochaetes (families Acanthodrilidae, Komarekionidae, Lumbricidae, and many Enchytraeidae), none reported the presence of aquatic Oligochaeta. Illinois' epigean aquatic oligochaete fauna includes 86 species in 44 genera representing seven families (Wetzel 1992), some of which are from karst springs (Webb *et al.* 1995; Webb *et al.* 1996, 1998b). Aquatic oligochaetes are poorly known in Missouri, but a similar degree of diversity is expected to occur there.

Elsewhere in North America, records of aquatic oligochaetes from cave streams are sparse (e.g., Brinkhurst 1986; Cook 1971, 1975; Holsinger & Culver 1988; Kathman & Brinkhurst 1984; Reeves & Reynolds 1999; Reeves *et al.* 2000), but phreatic and hyporheic habitats are known to harbor a variety of aquatic oligochaetes (Gibert *et al.* 1994; Rodriguez 1996; Rodriguez & Coates 1996; Strayer 2001; Strayer *et al.* 1995), including a new family of freshwater annelids (Parvidrilidae: *Parvidrilus strayeri* Erséus, 1999) recently described from the hyporheic zone of a spring-fed stream (Erséus 1999). Culver *et al.* (2000) noted that the under-representation of groups such as the aquatic oligochaetes in published accounts might alter our understanding of the taxonomic pattern of cave biodiversity in the United States.

We examined aquatic oligochaetes collected from the fine sediments of streams in several of the longest caves in Illinois and Missouri (Middleton & Waltham 1986) in conjunction with studies of the fauna and water quality of caves in the karst areas of southwestern Illinois and southeastern Missouri (Taylor & Webb 2000; Taylor *et al.* 2000).

SITE DESCRIPTIONS

Aquatic oligochaetes were obtained from four caves in Illinois: Fogelpole Cave, Illinois Caverns, and Krueger-Dry Run Cave (all in Monroe County) and Stemler Cave (St. Clair County) (lengths: >24 km, 8.8 km, ~11 km, and 1800 m, respectively [Webb *et al.* 1998a]), and from four caves in Perry County, Missouri: Crevice Cave, Mertz Cave, Mystery Cave, and Rimstone River Cave (lengths: 45.5 km [Middleton & Waltham 1986; Walsh 1997], ~2.9 km [Vandike 1985], ~25.7 km [Walsh 1997], and 22.6 km [Middleton & Waltham 1986], respectively). All of these caves are situated in well-developed sinkhole plain karst terrain in the Salem Plateau (Fig. 1), where the dominant land use is row-crop agriculture (corn, soybeans, wheat). Other prominent land uses include hay fields, livestock pastures, woodlots, rural housing, and farmsteads. The urbanized area associated with Perryville, Missouri, is within the drainage basin of Crevice and Mertz caves (Vandike 1985) and extensive rural development associated with the growth of the St. Louis metropolitan area threatens karst groundwater quality of the Illinois sites (Panno *et al.* 1996, 1999; Taylor *et al.* 2000).

METHODS

The Illinois caves were sampled on a monthly basis from early February 1999 through early January 2000. Perry County, Missouri, caves were sampled on 5 July (Crevice Cave and Mertz Cave), 20 June (Mystery Cave), and 6 September (Rimstone River Cave) 1998. During each visit, three (six in Mystery Cave) samples were taken from the dark zone of each cave in near-shore, silty sediments in pools of the main stream passages by pushing a 4.7 cm diameter clear plastic tube into the substrate to a depth of 5 cm. Core samples were placed in Whirl-Pak™ bags, fixed in 10% buffered formalin for at least

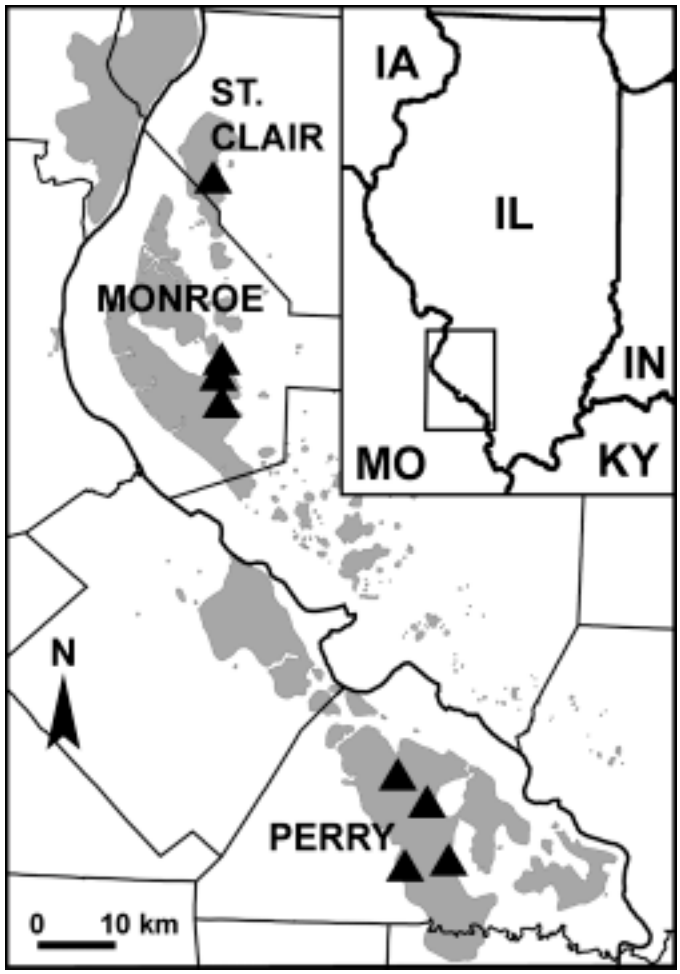


Figure 1. Karst terrain of southwestern Illinois and southeastern Missouri. All caves sampled (triangles) lie in the shaded sinkhole areas (Panno *et al.* 1999) in the labeled counties.

48 hours, then rinsed with water before transferring to 70% ethanol for temporary storage. Oligochaetes were picked from samples and carefully cleaned of minute sand and detrital material, processed through an ethanol series, washed in punctilious ethanol, placed in an ethanol/xylene solution for 30 minutes, then mounted in Permount™ on standard microscope slides under cover slips. Compound microscopes equipped with Nomarski Differential Interference Contrast were used for identification. Identifications and distribution data follow the original descriptions of Sperber (1948), Brinkhurst (1978), Brinkhurst & Jamieson (1971), Brinkhurst & Wetzel (1984), Klemm (1985), Kathman & Brinkhurst (1998), and Collado & Schmelz (2000). All specimens are deposited in the Illinois Natural History Survey (INHS) Annelida Collection, Champaign.

RESULTS

Oligochaetes representing 5 families, 10 genera, and 15 distinct taxa were identified from the samples (Table 1). Of the 1582 specimens examined, many were fragments of whole specimens, and the majority of specimens were sexually immature. Thus, much of the material could not be identified. A few undetermined specimens representing the oligochaete families Enchytraeidae, Lumbriculidae, and Naididae (genus *Pristina*) were collected, plus a single specimen of another clitellate annelid group, the Branchiobdellida. No edaphobitic oligochaetes were present in any of the sediment samples.

DISCUSSION

Of the 13 oligochaete species determined from this material, one represents a new record for Illinois and 10 represent new records for Missouri (Table 1). Although most of the caves have been previously sampled for aquatic fauna, all oligochaete species collected during this study represent first records for the caves in which they were found.

SPECIES ACCOUNTS

HAPLOTAXIDAE

Haplotaxis cf. *gordioides* (Hartmann, 1821). This species is the only recognized haplotaxid occurring in North America north of Mexico (Kathman & Brinkhurst 1998). We refer to this taxon with "cf" because the species limits within the genus *Haplotaxis* are not clear, there is a large size range between the largest and smallest specimens of *Haplotaxis* cf. *gordioides*, and the pattern of dorsal chaetae is variable. Although other *Haplotaxis* species have been described from sexually mature individuals elsewhere in the world (Brinkhurst 1988), no fully mature specimen of *H.* cf. *gordioides* has been reported from North America. The limited and seemingly disjunct distributional information for *H.* cf. *gordioides* and other haplotaxids is likely an artifact of collecting effort, particularly since the majority of records are from groundwater habitats (cisterns, wells, springs, caves, hyporheic and phreatic waters) (Brinkhurst 1986; Kathman & Brinkhurst 1998; Strayer 2001). Cook (1975) reported *H. gordioides* from a cave in West Virginia, and Kathman & Brinkhurst (1984) reported it from a cave in Tennessee.

NAIDIDAE

Dero digitata (Müller, 1773), a cosmopolitan species, is common and widespread in surface waters throughout North America.

Dero nivea Aiyer, 1930, a cosmopolitan species, is uncommon but widespread in surface waters throughout North America.

Pristina jenkinae (Stephenson, 1931), although widespread in surface waters throughout North America, is collected only occasionally.

Pristina leidyi Smith, 1896, a cosmopolitan species, is uncommon but relatively widespread in surface waters throughout North America. This species was recently reported

Table 1. Aquatic Oligochaeta (Annelida, Clitellata) collected from caves in southwestern Illinois and southeastern Missouri from 1998 to 2000.

	Fogelpole Cave	Krueger-Dry Run Cave	Illinois Caverns	Stemler Cave	Crevice Cave	Mertz Cave	Mystery Cave	Rimstone River Cave	Illinois New Record	Missouri New Record
Order Lumbriculida										
Family Lumbriculidae										
unidentified specimens	+			+						
Order Haplotaxida										
Family Haplotaxidae										
Genus *Haplotaxis* Hoffmeister, 1843										
Haplotaxis cf. *gordioides* (Hartmann, 1821)		+		+						
Order Enchytraeida										
Family Enchytraeidae										
unidentified specimens		+					+			
Order Tubificida										
Family Naididae										
Genus *Dero* Oken, 1815										
Dero digitata (Müller, 1773)		+			+					+
Dero nivea Aiyer, 1930							+			+
Genus *Pristina* Ehrenberg, 1828										
Pristina jenkinae (Stephenson, 1931)				+						
Pristina leidyi Smith, 1896	+				+	+				+
Pristina sp.		+		+						
Family Tubificidae										
Genus *Limnodrilus* Claparède, 1862										
Limnodrilus cervix Brinkhurst, 1963		+			+					+
Limnodrilus hoffmeisteri Claparède, 1862	+	+	+	+	+	+	+			+
Limnodrilus udekemianus Claparède, 1862						+				+
Genus *Rhyacodrilus* Bretscher, 1901										
Rhyacodrilus falciformis Bretscher, 1901							+			+
Rhyacodrilus cf. *sodalis* (Eisen, 1879)						+				+
Rhyacodrilus subterraneus Hrabe, 1963		+		+			+	+	+	+
Genus *Tubifex* Lamarck, 1816										
Tubifex tubifex (Müller, 1774)	+									
Genus *Varichaetadrilus* Brinkhurst & Kathman, 1983										
Varichaetadrilus angustipenis (Brinkhurst & Cook, 1966)	+	+			+	+				+
Varichaetadrilus sp.							+			

from caves in South Carolina (Reeves & Reynolds 1999; Reeves 2000).

TUBIFICIDAE

Limnodrilus cervix Brinkhurst, 1963 is widespread and commonly collected in surface waters throughout North America, and has been introduced into Europe and Asia. Although commonly collected from organically enriched habitats (Kathman & Brinkhurst 1998), *L. cervix* is not as tolerant of environmental extremes as is *Limnodrilus hoffmeisteri* Claparède.

Limnodrilus hoffmeisteri Claparède, 1862, a cosmopolitan species, is perhaps the most commonly collected freshwater oligochaete worldwide. It occurs in a wide variety of surface water habitats, reaching very high abundance in organically enriched areas - often with *Tubifex tubifex* (Brinkhurst 1975, 1996). The most commonly collected oligochaete during this study, the presence of *L. hoffmeisteri* may reflect organic enrichment associated with fecal contamination in the study area (Taylor *et al.* 2000). Kathman & Brinkhurst (1984) reported *L. hoffmeisteri* from caves in Tennessee.

Limnodrilus udekemianus Claparède, 1862, a cosmopolitan species, is found in organically polluted waters as well as oligotrophic habitats. It is widespread but rarely abundant in surface waters throughout North America (Klemm 1985).

Rhyacodrilus falciformis Bretscher, 1901, a rare Holarctic groundwater species, was first reported in North America from a creek on Vancouver Island, British Columbia (Brinkhurst 1978); this species has since been documented from Cascade Cave (Vancouver Island), the Hudson River in New York (Brinkhurst 1986), from Fraction Run, a small groundwater-influenced stream in Will County, Illinois (Wetzel 1992), and Montana (Kathman & Brinkhurst 1998). The collection of *R. falciformis* from Mystery Cave extends its range to the south and is the second report of this species from a cave in North America.

Rhyacodrilus cf. *sodalis* (Eisen, 1879), considered widespread but rare in North America, is of somewhat uncertain taxonomic status because of variability in morphology (Brinkhurst & Cook 1966; Kathman & Brinkhurst 1998; Klemm 1985). Cook

(1975) reported *R. sodalis* from a cave in West Virginia.

Rhyacodrilus subterraneus Hrabe, 1963, a rare Holarctic groundwater species, was first reported in North America from a hyporheic habitat in New York by Strayer & Bannon-O'Donnell (1988). More recent records document its occurrence in Tennessee (Kathman & Brinkhurst 1998), and in hyporheic habitats in Alabama, Kentucky, New York, Ohio, Tennessee, and Virginia (Strayer 2001). During their studies, Strayer (2001) and Strayer & Bannon-O'Donnell (1988) noted that *R. subterraneus* was the most widespread and commonly collected hyporheic tubificid; despite its abundance, they collected no mature specimens. Although most specimens were collected from deeper sediments by Strayer (2001)—supporting its status as an interstitial specialist (Hrabe 1963)—Strayer (2001) occasionally collected it from surface stream sediments, as did Timm *et al*. (1996). Our specimens, all immature, extend the known range of *R. subterraneus* farther west in North America**.**

Tubifex tubifex (Müller, 1774), a cosmopolitan species that is not commonly encountered, is locally abundant in habitats of marginal water quality—pristine alpine and subalpine lakes (Klemm 1985), the bottoms of large, unproductive, oligotrophic lakes (e.g., Lake Superior), grossly polluted and organically enriched sites with low oxygen tensions, and aquatic habitats supporting few other species (Brinkhurst 1996). In areas with heavy organic pollution, *T. tubifex* is usually associated with *L. hoffmeisteri*, where the two species are often the dominant oligochaetes or even the dominant or exclusive benthic invertebrates (Brinkhurst 1996). Brinkhurst (1970) also suggested that *T. tubifex* may prefer situations in which other species find it difficult to survive—either because there is too little active decomposition, or too much. *Tubifex tubifex* is widespread in North America and has been reported from a cave in Virginia (Holsinger 1966).

Varichaetadrilus angustipenis (Brinkhurst & Cook, 1966), an uncommon but widespread Nearctic species east of the Mississippi River and east of Manitoba (Kathman & Brinkhurst 1998), has recently been reported from California (Kathman & Brinkhurst 1998) and Arizona (Wetzel *et al.* 1999). The senior author has identified *V. angustipenis* from numerous springs and springruns in Illinois (Webb *et al*. 1995; Webb *et al*. 1996, 1998b), from Montezuma Well in Arizona (Wetzel *et al.* 1999), and from resurgence springs of the Edwards Aquifer in Texas (unpublished records, INHS Annelida Collection). Extensive collecting in Illinois and other states and provinces in North America by the senior author has failed to produce *V. angustipenis* from habitats other than those associated with or influenced by groundwater. The collection of *V. angustipenis* from Crevice and Mertz caves in Missouri represents a new record for the state. An aberrant (developing?) specimen of the genus *Varichaetadrilus*, probably attributable to *V. angustipenis*, was collected from Mystery Cave.

The abundance of new records in this study emphasizes the paucity of available information on North American aquatic Oligochaeta in caves. In reviewing the faunal studies of caves in Illinois and Missouri, and several studies of North American cave faunas (Franz *et al*. 1994; Holsinger 1963, 1966; Holsinger & Culver 1988; Holsinger & Peck 1971; Kathman & Brinkhurst 1984; Lewis 1983; Peck 1988; Reeves *et al.* 2000), few species-level identifications of aquatic annelids were included among the extensive lists of reported taxa. Our data indicate the presence of a diverse and relatively abundant aquatic oligochaete fauna in Midwestern cave streams associated with loess-covered karst terranes developed in Ordovician and Mississippian age bedrock (Panno *et al.* 1999). Aquatic clitellate annelids should receive careful consideration in ecological studies of cave environments because they comprise a significant and prevalent component in aquatic cave communities.

ACKNOWLEDGMENTS

Funding for this research was supported in part by the U.S. Department of the Interior-Fish & Wildlife Service, Illinois Department of Transportation, Illinois Department of Natural Resources, and the Illinois Natural History Survey. We thank G. Adams, J. Angel, L. Brennan, R. Haley, C. Hespin, J. Kath, C. Lee, D. Mahon, B. Molano-Flores, P. Moss, S.V. Panno, G. Resch, J. Roberts, G. & G. Schropp, H. Stuck, D. Tecic, M. Tiritilli, R. Toomey, K. Victory, S. Langowski, D.W. Webb, C.P. Weibel, P. Wightman, and R. Young for their assistance with field work in Illinois and Missouri caves. We also thank H. Stuck and W. Borchert for laboratory assistance, and D.W. Webb, C.P. Weibel, C.A. Phillips, G.A. Levin, D.L. Thomas, S.V. Fend, D.C. Ashley, and one anonymous reviewer for assistance with this manuscript.

REFERENCES

Brinkhurst, R.O., 1970, Distribution and abundance of tubificid (Oligochaeta) species in Toronto Harbour, Lake Ontario: Journal of the Fisheries Research Board of Canada, v. 27, p. 1961-1969.

Brinkhurst, R.O., 1975, Oligochaeta, *in* Parrish, F.K., ed., Keys to the water quality indicative organisms of the southeastern United States: Cincinnati, OH, U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring and Support Laboratory, p. 69-85.

Brinkhurst, R.O., 1978, Freshwater Oligochaeta in Canada: Canadian Journal of Zoology, v. 56, no. 10, p. 2166-2175.

Brinkhurst, R.O., 1988, A taxonomic analysis of the Haplotaxidae: Canadian Journal of Zoology, v. 66, no. 10, p. 2243-2252.

Brinkhurst, R.O., 1996, On the role of tubificid oligochaetes in relation to fish disease with special reference to the Myxozoa: Annual Review of Fish Diseases, v. 6, p. 29-40.

Brinkhurst, R.O. & Cook, D.G., 1966, Studies on the North American Aquatic Oligochaeta. III: Lumbriculidae and additional notes and records of other families: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 118, no. 1, p. 1-33.

Brinkhurst, R.O. & Jamieson, B.G.M., 1971, Aquatic Oligochaeta of the world: Buffalo, New York, University of Toronto Press.

Brinkhurst, R.O. & Wetzel, M.J., 1984, Aquatic Oligochaeta of the world: Supplement: Canadian Technical Report of Hydrography and Ocean Sciences no. 44, p. v+101.

Collado, R. & Schmelz, R.M., 2000, *Pristina silvicola* and *Pristina terrena* spp. nov., two new soil-dwelling species of Naididae (Oligochaeta, Annelida) from the tropical rain forest near Manaus, Brazil, with comments on the genus Pristinella: Journal of Zoology, London, v. 252, p. 509-516.

Cook, D.G., 1971, *Trichodrilus allegheniensis* n. sp. (Oligochaeta, Lumbriculidae) from a cave in southern Tennessee: Transactions of the American Microscopical Society, v. 90, no. 3, p. 381-383.

Cook, D.G., 1975, Cave-dwelling aquatic Oligochaeta (Annelida) from the eastern United States: Transactions of the American Microscopical Society, v. 94, no. 1, p. 24-37.

Craig, J.L., 1977, Invertebrate faunas of caves to be inundated by the Meramec Park Lake in eastern Missouri: NSS Bulletin, v. 39, no. 3, p. 80-89.

Culver, D.C., Master, L.L., Christman, M.C. & Hobbs, H.H., III., 2000, Obligate cave fauna of the 48 contiguous United States: Conservation Biology, v. 14, no. 2, p. 386-401.

Erséus, C., 1999, *Parvidrilus strayeri*, a new genus and species, an enigmatic interstitial clitellate from underground waters in Alabama: Proceedings of the Biological Society of Washington, v. 112, no. 2, p. 327-337.

Franz, R., Bauer, J. & Morris, T., 1994, Review of biologically significant caves and their faunas in Florida and south Florida: Brimleyana, v. 20, p. 1-109.

Gardner, J.E., 1986, Invertebrate fauna from Missouri caves and springs: Natural History Series, Missouri Department of Conservation.

Gibert, J., Danielopol, D.L. & Stanford, J.A., 1994, Groundwater ecology: San Diego, California, Academic Press.

Holsinger, J.R., 1963, Annotated checklist of the macroscopic troglobites of Virginia with notes on their geographic distribution: National Speleological Society Bulletin, v. 25, no. 1, p. 23-36.

Holsinger, J.R., 1966, A preliminary study of the effects of organic pollution of Banners Corner Cave, Virginia: International Journal of Speleology, v. 2, p. 75-89.

Holsinger, J.R. & Culver, D.C., 1988, The invertebrate cave fauna of Virginia and a part of eastern Tennessee: zoogeography and ecology: Brimleyana, v. 14, p. 1-162.

Holsinger, J.R. & Peck, S.B., 1971, The invertebrate cave fauna of Georgia: National Speleological Society Bulletin, v. 33, no. 1, p. 23-44.

Hrabe, S., 1963, *Rhyacodrilus subterraneus* n. sp., eine neue Tubificiden-Art aus dem Brunnen in der Umgebund von Leipzig: Zoologische Anzeiger, v. 170, p. 249-252.

Kathman, R.D. & Brinkhurst, R.O., 1984, Some benthic invertebrates from Tennessee and Kentucky caves: Journal of the Tennessee Academy of Science, v. 59, no. 1 & 2, p. 19-21.

Kathman, R.D. & Brinkhurst, R.O., 1998, Guide to the freshwater oligochaetes of North America: College Grove, Tennessee, Aquatic Resources Center.

Klemm, D.J., 1985, A guide to the freshwater Annelida (Polychaeta, naidid and tubificid Oligochaeta, and Hirudinea) of North America: Dubuque, Iowa, Kendall/Hunt Publishing Company.

Lewis, J.J., 1974, The invertebrate fauna of Mystery Cave, Perry County, Missouri: Missouri Speleology, v. 14, no. 4, p. 1-19.

Lewis, J.J., 1983, The obligatory subterranean invertebrates of glaciated southeastern Indiana: NSS Bulletin, v. 45, p. 34-40.

Lewis, J.J., Moss, P.L. & Tecic, D.L., 1999, A conservation focused evaluation of the imperiled troglobitic fauna of the sinkhole plain karst of southwestern Illinois: The Nature Conservancy.

Middleton, J. & Waltham, T., 1986, The underground atlas - a gazetteer of the world cave regions: Great Britain, Robert Hale Ltd.

Panno, S.V., Krapac, I.G., Weibel, C.P. & Bade, J.D., 1996, Groundwater contamination in karst terrain of southwestern Illinois: Illinois State Geological Survey Environmental Geology Series Report, v. 151, p. 1-43.

Panno, S.V., Weibel, C.P., Wicks, C.M. & Vandike, J.E., 1999, Geology, hydrology, and water quality of the karst regions of southwestern Illinois and southeastern Missouri: ISGS Guidebook 27, Champaign, Illinois State Geological Survey.

Peck, S.B., 1988, A review of the cave fauna of Canada, and the composition and ecology of the invertebrate fauna of caves and mines in Ontario: Canadian Journal of Zoology, v. 66, p. 1197-1213.

Peck, S.B., 1989, The cave fauna of Alabama: Part I. The terrestrial invertebrates (excluding insects): NSS Bulletin, v. 51, p. 11-33.

Peck, S.B. & Christiansen, K., 1990, Evolution and zoogeography of the invertebrate cave faunas of the Driftless Area of the Upper Mississippi River Valley of Iowa, Minnesota, Wisconsin, and Illinois, U.S.A.: Canadian Journal of Zoology, v. 68, p. 73-88.

Peck, S.B. & Lewis, J.L., 1978, Zoogeography and evolution of the subterranean invertebrate faunas of Illinois and southeastern Missouri: NSS Bulletin, v. 40, no. 2, p. 39-63.

Reeves, W.K., 2000, *Caecidotea carolinensis* (Isopoda: Asellidae): First record of a stygobite from South Carolina: Journal of Cave and Karst Studies, v. 62, no. 1, p. 8-19.

Reeves, W.K., Jensen, J.B. & Ozier, J.C., 2000, New faunal and fungal records from caves in Georgia, USA: Journal of Cave and Karst Studies, v. 62, no. 3, p. 169-179.

Reeves, W.K. & Rrynolds, J.W., 1999, New records of cave-dwelling earthworms (Oligochaeta: Lumbricidae, Megascolecidae and Naididae) and other annelids (Aeolosomatida, Branchiobdellida and Hirudinea) in the southeastern United States, with notes on their ecology: Megadrilogica, v. 7, no. 10, p. 65-71.

Rodriguez, P., 1996, *Stylodrilus californianus* n. sp., a new lumbriculid (Annelida: Oligochaeta) from North America: Hydrobiologia, v. 333, p. 161-164.

Rodriguez, P. & Coates, K.A., 1996, A new American Stylodrilus species (Lumbriculidae, Oligochaeta): Canadian Journal of Zoology, v. 74, no. 1, p. 92-96.

Sperber, C., 1948, A taxonomical study of the Naididae: Zoologiska Bidrag fran Uppsala, v. 28, p. 1-296.

Strayer, D.L., May, S.E., Nielsen, P., Wollheim, W. & Hausam, S., 1995, An endemic groundwater fauna in unglaciated eastern North America: Canadian Journal of Zoology, v. 73, no. 3, p. 502-508.

Strayer, D.L., 2001, Ecology and distribution of hyporheic microannelids (Oligochaeta, Aphanoneura, and Polychaeta) from the eastern United States: Archiv für Hydrobiologie, v. 131, no. 3, p. 493-510.

Strayer, D.L. & Bannon-O'Donnell, E., 1988, Aquatic microannelids (Oligochaeta and Aphanoneura) of underground waters of southeastern New York: American Midland Naturalist, v. 119, p. 327-335.

Taylor, S.J., Webb, D.W. & Panno, S.V., 2000, Spatial and temporal analyses of the bacterial fauna and water, sediment, and amphipod tissue chemistry within the range of *Gammarus acherondytes*: Illinois Natural History Survey Center for Biodiversity Technical Report, v. 2000, no. 18, p. 1-115.

Taylor, S.J. & Webb., D.W., 2000, Subterranean Amphipoda (Crustacea) of Illinois' Salem Plateau: Spatial and temporal components of microdistribution: Illinois Natural History Survey Center for Biodiversity Technical Report, v. 2000, no. 27, p. 1-62.

Timm, T., Erséus, C. & Lundberg, S., 1996, New and unusual records of freshwater Oligochaeta from the Scandinavian peninsula: Nordic Journal of Freshwater Research, v. 72, p. 15-29.

Vandike, J.E., 1985, Movement of shallow groundwater in the Perryville karst area, southeastern Missouri, Water Resources Report: Rolla, Missouri, Missouri Department of Natural Resources, Division of geology and Land Survey.

Walsh, J., 1997, Selected Ordovician, [sic] & Devonian age caves, caving the stratigraphic successions of Missouri - Part II, *in* Taylor, R.L., ed., Exploring Missouri caves - A guidebook for the 1997 Convention of the National Speleological Society, Sullivan, Missouri, June 23-27, 1997: Huntsville, Alabama, National Speleological Society, Inc., p. 145-184.

Webb, D.W., Taylor, S.J. & Krejca, J.K., 1993, The biological resources of Illinois' caves and other subterranean environments: Illinois Natural History Survey Center for Biodiversity Technical Report, v. 1993, no. 8, p. 1-168.

Webb, D.W., Wetzel, M.J., Reed, P.C., Phillippe, L.R. & Harris, M.A., 1995, Aquatic biodiversity in Illinois springs: Journal of the Kansas Entomological Society, v. 68, no. 2 suppl, p. 93-107.

Webb, D.W., Wetzel, M.J., Reed, P.C., Phillippe, L.R. & Young, T.C., 1996, Biodiversity, hydrogeology, and water quality of 10 karst springs in the Salem Plateau Section of Illinois, *in* Davis, M., ed., Research on agricultural chemicals in Illinois groundwater: Status and future directions VI. Proceedings of sixth annual conference, Illinois Groundwater Consortium, Makanda, Illinois, March 27-28, 1996: Carbondale, Southern Illinois University, p. 146-185.

Webb, D.W., Page, L.M., Taylor, S.J. & Krejca, J.K., 1998, The current status and habitats of the Illinois Cave Amphipod, *Gammarus acherondytes* Hubricht and Mackin (Crustacea: Amphipoda): Journal of Cave and Karst Studies, v. 60, no. 3, p. 172-178.

Webb, D.W., Wetzel, M.J., Reed, P.C., Phillippe, L.R. & Young, T.C., 1998, The macroinvertebrate biodiversity, water quality, and hydrogeology of ten karst springs in the Salem Plateau Section of Illinois, USA, *in* Botosaneanu, L., ed., Studies in crenobiology - The biology of springs and springbrooks: Leiden, The Netherlands, Backhuys Publishers, p. 39-48.

Wetzel, M.J., 1992, Aquatic Annelida of Illinois: Introduction and checklist of species: Transactions of the Illinois State Academy of Science, v. 85, no. 1 & 2, p. 87-101.

Wetzel, M.J., Oberlin, G. & Blinn, D.W., 1999, The aquatic Oligochaeta (Annelida: Clitellata) of Montezuma Well, Arizona: A near thermally constant limnocrene: Southwestern Naturalist, v. 44, no. 4, p. 514-518.

CAVE SCIENCE NEWS

CONSERVATION EDITOR NEEDED BY JCKS

The *Journal of Cave and Karst Studies* seeks a new Associate Editor of Conservation. The responsibilities of the Associate Editors include soliciting articles, arranging for appropriate reviews of papers in their fields of expertise, working with authors to prepare their manuscripts for publication, making recommendations concerning acceptance and rejection of submitted papers, and assisting the Editor in gathering material for the non-refereed section of the *Journal*. Advice from the Associate Editors, along with the *Journal's* Advisory Board, is commonly solicited on editorial policy decisions.

The *Journal* desires a pro-active caver with contacts in the cave and karst conservation and management community, and experience in scholarly publishing. Interested candidates are asked to send a letter of interest by February 1, 2002, to the editor at: Hose@chapman.edu.

EBAY CHANGES ARTIFACTS POLICY TO HELP PROTECT SPELEOTHEMS

IMPORTANT ANNOUNCEMENT: On Saturday, September 1st, eBay changed their Artifacts Listing Policy to include speleothems. I want to thank everyone who spoke with and/or emailed eBay Community Watch over the past two years to help eliminate the listing of speleothems. It's evident your comments did not go unnoticed.

Two of the Community Watch comments I received were "if we only knew the state and federal laws" and, "the auction ended before we could delist the item." Approximately 2 weeks before Convention, I mailed the Chairman of the Board, President, Vice-president and General Counsel of eBay a copy of all of the Federal laws and state statutes regarding the protection of speleothems and caves.

When I returned from Convention, I had a message to call the General Counsel. For a week we discussed cave conservation, eBay politics, and how their Artifacts Policy could be changed. Below is an annotated copy of the new eBay Artifacts Policy with the changes in ***bold italics***.
(http://pages.ebay.com/help/community/png-artifacts.html):

Artifacts, Grave-Related Items and Native American Crafts

Many artifacts***, cave formations (speleothems, stalactites and stalagmites)*** and grave-related items are protected under federal laws such as, ***The Federal Cave Resources Protection Act of 1988,*** and the Native American Grave Protection and Repatriation Act. eBay cooperates with the Department of the Interior, ***Department of Agriculture,*** Bureau of Indian Affairs and Federal Bureau of Investigation in determining what items may lawfully be sold under these laws. Please follow these general guidelines when listing related items on eBay.

Artifacts - Artifacts taken from any federal, state, public ***Department of Interior (NPS, BLM, USFWS) and Department of Agriculture Agencies (USFS),*** Native American land, or battlefield are prohibited for sale.

Cave Formations - The sale of speleothems, stalactites and stalagmites taken from caves on any federal land is prohibited by federal law. See The Federal Cave Resources Protection Act of 1988. Many states also prohibit the sale and/or removal of speleothems, stalactites and stalagmites taken from caves. Please be sure your item complies with all applicable laws before listing it for sale.

The revised policy, however, does not prevent speleothems from occasionally being listed. There are over 300,000 items on daily and the eBay Community Watch Team cannot check them all. Cavers still must monitor the auctions, and, if we find a cave formation for sale, immediately email eBay Community Watch found under Contact Rules and Safety (http://pages.ebay.com/help/basics/select-RS.html), referencing the item and the new Artifacts Policy. I have been advised when we do this, eBay Community Watch will immediately contact the seller and have the item delisted. This system is not perfect; however, eBay has made a stand for cave conservation and together we can make a difference.

YAHOO CHANGES AUCTION POLICY TO HELP PROTECT SPELEOTHEMS

IMPORTANT ANNOUNCEMENT: On November 1st, Yahoo changed their Auction Listing Policy to include speleothems. The Yahoo's policy is simple and can be found at http://user.auctions.shopping.yahoo.com/html/guidelines.html.

After eBay change their policy on September 1st, I sent a similar detailed document to their General Counsel Matt Robinson and two weeks later we developed the below policy. Although it is not perfect, the policy is one that can be enforced by the Yahoo Auction Team.

Items that are prohibited by Yahoo!

It is the responsibility of both the seller and the buyer to ensure that the items listed for auction and bought by the winning bidder are appropriate for sale under all applicable laws and regulations. In addition, every item listed on Yahoo! Auctions must be consistent with Yahoo!'s policies, as determined in Yahoo!'s sole discretion. Yahoo! expressly reserves the right to, but has no duty to, refuse, reject or remove any listing in Yahoo!'s sole discretion.

There are some things that you may not list or sell under any circumstances. These include:

14. Speleothems, stalactites and stalagmites from caves on federal land or as prohibited by state or federal law.

The revised policy, however, does not prevent speleothems from occasionally being listed. There are over 100,000 items on daily and the Yahoo cannot check them all. Cavers still must monitor the auctions, and, if we find a cave formation for sale, immediately email Yahoo found under Auction Abuse http://add.yahoo.com/fast/help/us/auct/cgi_abuse referencing the item and the new Policy. I have been advised when we do this, Yahoo will immediately contact the seller and have the item delisted.

The two largest Internet Auction Companies, eBay and now Yahoo, have taken a position for cave conservation and speleothem protection. Together we can all make a difference.

Tom Lera - Liaison for International Speleothem Protection, NSS servation Committee

KARST FRONTIERS: FLORIDA AND RELATED ENVIRONMENTS

THE KARST WATERS INSTITUTE CONFERENCE SERIES
MARCH 6-10, 2002

The Karst Waters Institute will host another of their excellent special topic meetings in spring 2002. This interdisciplinary conference will focus on exploring the biology, chemistry, and geology of Cenozoic carbonate aquifers in Florida, and in related environments around the World.

Oral sessions will be invited, abstracts for the poster session can be volunteered. Total participation is planned at 100-120 people. For more information contact: mylroie@geosci.MsState.edu or 662-325-8774.

HESS APPOINTED EXECUTIVE DIRECTOR OF THE GEOLOGICAL SOCIETY OF AMERICA

The Geological Society of America recently announced that NSS member and karst hydrogeologist Jack Hess will become their Executive Director on December 15, 2001. Hess wrote his Pennsylvania State University PhD dissertation on the hydrology of the Mammoth Cave, Kentucky area under the direction of Will White. He has spent most of his career associated with the Desert Research Institute at the University of Nevada, most recently serving as Director of the Institute.

OBITUARY
GEORGE HUPPERT
NSS 7717

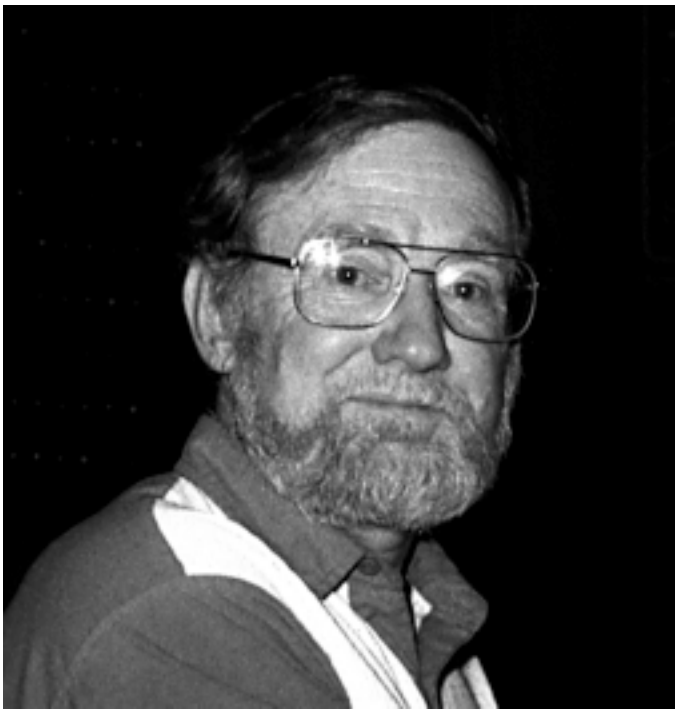
Dr. George Huppert, Conservation Editor of the Journal of Cave and Karst Studies, died on October 14, 2001, in a head-on car crash in the Roosevelt Lake area near Globe, Arizona, while exploring prior to the National Karst and Cave Management Symposium held in Tucson. George was a prolific writer on cave and karst conservation and management topics, and had spent many years of service to the National Speleological Society (NSS), the NSS Cave Conservation and Management Section (CCMS), the American Cave Conservation Association (ACCA), the International Union of Speleology (UIS), and most of the National Cave and Karst Management Symposia. He was 56 years of age at the time of his death, and is survived by his wife Betty J. Wheeler, one son, 3 nephews, and 2 nieces.

In his life, George accumulated six university degrees in Geography, Geology and related subjects. He read two or more newspapers daily, and several hundred books, professional journals, and magazines per year. George was devoted to the study of the earth and nature, with an insatiable thirst for knowledge. He wrote most of the dissertations for his advanced degrees on cave related topics, including Papoose Cave in Idaho and a Survey of Cave Conservation in America. He joined the University of Wisconsin at La Crosse in 1979, and became Professor of Geography and Earth Science. He was twice voted Chair of the Department of Geography and Earth Science.

George's caving included trips to hundreds of caves (905 that he recorded) in many parts of the U.S.; and to caves in Canada, Jamaica, San Salvador Island (Bahamas), Cuba, England, France, Australia, China, Hong Kong, Hawaii, Hungary, Czech Republic, Slovenia, and Brazil. He was particularly delighted to visit the "Kras" area of Slovenia, which is the first area of solutional caves scientifically described ("type-section"), and where groundwater resources are fragile. (This work defined what is now known as a "karst" area.) George was also honored to visit the famous Lascaux Cave in France. This famous cave, with Paleolithic drawings and paintings of animals, is one of 16 sites named together as the "Decorated Grottoes of the Vezere Valley" and is designated a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Site. The drawings and paintings in the cave are exceedingly fragile and, therefore, visitation is extremely restricted.

George spent thousands of hours volunteering in the NSS and other organizations. He was a founder and officer of the American Cave Conservation Association, and a founder and President of the NSS Cave Conservation and Management Section. He was at various times a Director of the Section, and was the coordinator for the NSS Convention Conservation Session for many years. He was a Fellow of the NSS, and was the 1996 recipient of the NSS Conservation Award, given each year to an individual who, through specific actions, has demonstrated an outstanding dedication to the cause of cave conservation. Ironically, George was a prime mover in convincing the Conservation and Management Section to continue to present the old style NSS Conservation Award to Internal Organizations after the NSS changed their award to an Individual Award; George chaired the Section Awards Committee for many years.

At the time of his death, George was an Adjunct Secretary of the UIS Bureau, and served for a time as the US Delegate to the UIS. Prior to 1996, he served on the International Geographical Union Commission on Sustainable Development & Management of Karst Terrain.



George attended and presented papers at many of the National Cave Management Symposia, on topics ranging from Underground Wilderness to Cave Laws to Show Cave Owners Perceptions of the NSS. He was co-editor of the Proceedings for the 1987 meeting at Rapid City. At the time of his death, he was collaborating with Tom Lera on a book on Cave Protection Laws.

There is no doubt that George will be sorely missed, not only by his family and friends, but also by the entire cave conservation community.

[A George Huppert Memoriam Page has been established on the NSS CCMS Web Site at http://www.caves.org/ccms/huppert/]

Rob Stitt
(with inputs from Betty Wheeler, Arthur Clarke, and Abel Vale).

BCI - STUDENT SCHOLARSHIP DEADLINE IN DECEMBER

Approximately 15 grants ranging from $500 to $2,500 will be made in 2002, to support research that helps document bats' roosting and feeding habitat requirements, their ecological or economic roles, or their conservation needs. Students enrolled in any college or university, worldwide, are eligible to apply. Projects must have bat conservation relevance. The application deadline for 2002 scholarships is 15 December 2001.

Application information and forms are available on our web page at http://www.batcon.org/schol/schol.html or email aengland@batcon.org or write to:

Bat Conservation International
Student Scholarship Program
P.O. Box 162603
Austin, TX 78716-2603 USA

SELECTED ABSTRACTS FROM THE 2001 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN MOUNT VERNON, KENTUCKY

ARCHAEOLOGY

WHERE THE BUFFALO ROAM: ROCK-ART AT GUSTAFSONS CAVE IN ARKANSAS

Jean Allan, District Archaeologist, Bankhead Ranger District, U.S. Forest Service, POB 278, Double Springs, AL 35553 USA
W.W. Varnedoe, 5000 Ketova Way SE, Huntsville, AL 35803 USA
Charles Lundquist, 214 Jones Valley Drive SW, Huntsville, AL, 35802 USA

There are seven panels of aboriginal rock art in the upper chamber of Gustafsons Cave located in the Sylamore District of the Ozark-St. Francis National Forest in Arkansas. The images are predominantly black pictographs. There are also several red pictographs and at least one fine line incised petroglyph. The figures include a panel of six bison, a panel of numerous anthropomorphs, some with evident genitals, and other panels with animal figures, including one turtle and several resembling centipedes. Other pictographs are geometric or unrecognizable. Our recorded efforts included a detailed map of the upper cave chamber.

THE PREHISTORY OF OWL CAVE, MAMMOTH CAVE NATIONAL PARK, KENTUCKY

Kenneth Carstens, Department of Geosciences, Murray State University, Murray, KY 42071 USA ken.carsten@murraystate.edu

Archaeological excavations in Owl Cave occurred between December 1975 and January 1976. Excavated deposits were grouped into three cultural zones ranging from 8000 BC to 1000 BC, or essentially throughout the Archaic Tradition.

ARCHAEOLOGY IN MAMMOTH CAVE

George Crothers, William S. Webb Museum, 1020A Export St., University of Kentucky, Lexington, KY 40506-9854 USA gmcrot2@uky.edu
Charles Swedlund, Cobden, IL USA
Robert Ward, Mammoth Cave National Park, POB 30, Mammoth Cave, KY 42259 USA

Mammoth Cave, Kentucky, is one of the most historically visited caves in North America. Archaeological remains in the cave date from prehistoric mining of gypsum and other sulfate minerals (ca. 3000-2200 year ago), historic mining of calcium nitrate around the War of 1812, use of the cave as a tuberculosis sanatorium in the 1840s, and construction of various amenities for the tourist business throughout the 19th and 20th centuries. Beginning in 1993, we conducted a systematic inventory of archaeological resources along a three-mile section of upper Mammoth Cave. Using volunteers coordinated by Earthwatch Institute, we have recorded more than 9700 prehistoric and historic artifacts in the cave to date.

PICTURE CAVE: THE STUDY, DATING, GATING, AND SACRED MEANING OF A PREHISTORIC AMERICAN INDIAN SITE

Carol Diaz-Granados, James R. Duncan, Department of Anthropology, C.B. 1114, Washington University, St. Louis, MO 63130 USA

We described preliminary study and preservation efforts at Picture Cave in eastern Missouri. This cave is considered the most important site of its type in the Eastern Woodlands. Native Americans left drawings on the walls that appear to reflect Siouan oral traditions. In 1996, a grant was obtained to date the pigments in the drawings. Accelerator Mass Spectrometry radiocarbon dating was used on four samples. The weighted average date for these samples is A.D. 1025 (calibrated). The dates and the striking Mississippian graphics have generated considerable discussion among researchers concerned with the origins of the Southeastern Ceremonial Complex. Realistic portrayals of several important characters known from 19th and early 20th century Siouan oral traditions contribute a great deal to our understanding of Mississippian cosmology in the greater Cahokia area. A target of looters and vandals for over a century, the cave was finally gated in 1996.

KENTUCKY CAVE ARCHAEOLOGY - UNDERGROUND AND UNDER-REPORTED

Jim Fenton, 465 E. High St., Suite 100, Wilbur Smith Associates, Lexington, KY 40507 USA
Philip Mink, University of Kentucky, Lexington, KY 40506 USA
Susan Neumeyer, Kentucky Heritage Council, l300 Washington St., Frankfort, KY 40601 USA

We examined the Kentucky Office of State Archaeology site inventory to explore the state of documentation for those caves where prehistoric and historic peoples had left their marks. Some of these archaeological sites have been the focus of spectacular archaeological discoveries, but most cave sites are not recorded in the Kentucky Office of State Archaeology. Despite the potential for Kentucky caves to yield important information about a wide range of prehistoric and historic activities, no statewide inventory of archaeological sites in caves has been undertaken. Using the recently completed statewide GIS database of archaeological sites, we documented the extent of omissions from the inventory, and suggested some ways in which cave archaeology and caving could be mutually beneficial.

ARCHAEOLOGICAL INVESTIGATIONS OF HUBBARDS CAVE, WARREN COUNTY, TENNESSEE

Erin Pritchard, Anthropology Department, University of Tennessee, Knoxville, TN 37996 USA

Hubbards Cave, located in Warren County, Tennessee, contains evidence of a prehistoric gypsum mine. Archaeological investigations conducted thus far have focused on the systematic documentation of all prehistoric material found within the cave.

BIOLOGY

BIOLOGY OF SPRING CAVEFISH (*FORBESICHTHYS AGASSIZI*): NOTES ON DEMOGRAPHY, HABITAT USE, REPRODUCTION, AND EARLY LIFE HISTORY

Ginny L. Adams, S. Reid Adams, Amy L. Phillips, Brooks M. Burr
Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, Illinois 62901 USA, gadams@siu.edu

Spring cavefish, *Forbesichthys agassizi*, are locally abundant in surface springs at LaRue-Pine Hills Ecological Area, Illinois, that flow less than 100 m before entering a lowland swamp. We initiated a study of the Pine Hills populations and a state endangered population in Missouri to provide much needed information on their biology and status. Spatial and temporal variation in fish abundance, size-frequency distribution, condition, and habitat use in five surface springs were examined by sampling fixed locations along a longitudinal gradient on a seasonal basis. In all five springs, cavefish abundance was highest during the spring season and in upstream stations near the resurgence. Large adults were not present in samples during summer and fall, suggesting mortality or movement underground. Cavefish remaining on the surface during daytime used a variety of cover items, including large boulders, logs, and leaf litter. Gravid females with mature ova were found during winter in two surface springs and in the cave. Larval cavefish with yolk appeared in the surface springs during late winter and were susceptible to capture by drift nets and light traps. Additional data and observations on reproduction and early life history will be presented.

DIFFERENCES IN BEHAVIORS, PHYSIOLOGICAL RESPONSES AND NEURAL STRUCTURE OF CAVE CRAYFISH TO THOSE OF EPIGEAN SPECIES

R.L. Cooper, H. Li, L.R. Listerman, S.P. Kellie, J. Greer, J.L. Cole, H.L. Hopper, .School of Biological Sciences, University of Kentucky, Lexington, KY 40506-0225 USA, RLCOOP@ pop.uky.edu

Cave crayfish serve as a good model organism to investigate cave adaptations since much is known about epigean species in their social behaviors, physiological responses and neural anatomical features for comparisons. We

compared the repertoire of social behaviors of cave crayfish to those previously reported with interacting sighted crayfish. The blind crayfish did not exhibit behaviors usually associated with visual displays and posturing. Additional investigations were conducted to determine how cave-adapted blind crayfish responded to novel territories of various sizes. We also used the cave crayfish and to examine their responsiveness to stimuli while monitoring their heart rate as a measure of an internal state. Heart rate is a reasonable measure of the responsiveness of blind cave crayfish to given stimuli even in the absence of observable behavioral changes. This enables the observer to determine if an individual is responsive to and making an assessment of particular cues. Alterations in the crayfish internal physical state, such as when the animal autotomizes its chelipeds, will cause the larger sized animals to tail flip when before they would not. Comparing adult crayfish in an epigean species to a cave species revealed that the cave crayfish are more likely to tail flip to a given stimulus. Neural modifications in the cave crayfish visual and chemosensory structures were also examined. Troglobitic crayfish have a disorganized neuronal ganglion within the eye stalk. In addition, neurons associated with olfaction that arise in the central brain are more numerous in cave crayfish, suggesting that they have more neural processing devoted to olfaction, as an adaptation to cave life.

CAVE DIPLURA OF KENTUCKY

Lynn M. Ferguson, Department of Natural Sciences, Longwood College, Farmville, VA 23909 USA, caveman@longwood.lwc.edu

The world's first named cave campodeid dipluran, *Campodea cookei* [now placed in the genus *Litocampa*] was described from a specimen from Mammoth Cave in 1871 by A.S. Packard. This species is widespread in the caves of southern Kentucky, Tennessee, and southwestern Virginia. *Plusiocampa jonesi* [now also placed in the genus *Litocampa*], originally described by B. Condé in 1949 from a specimen collected in Dunbar Cave in northern Tennessee, has also been found in neighboring Christian County, Kentucky. In eastern Kentucky there is an undescribed species that is closely related to *L. cookei*. This new species is known from caves in Pulaski and Rockcastle counties. Another new species of *Litocampa* has been found in the extreme eastern Letcher County, Kentucky. These specimens appear to be the same as a species first discovered in Rye Cove in Scott County, Virginia. This currently presents a zoogeographic range that is difficult to explain. In all, 64 collections of campodeid diplurans from 44 Kentucky caves were examined. As for the japygid diplurans, *Japyx subterraneus* [now placed in the genus *Metajapyx*] was described by A. S. Packard from Little White Cave [White's Cave, Jr.], near Mammoth Cave, in 1874. The only other record of a japygid from a cave in Kentucky is an unidentified species from Barnes Smith Cave in Hart County.

NEW GENUS AND SPECIES OF CAMPODEID DIPLURAN FROM CAVES IN EASTERN TENNESSEE

Lynn M. Ferguson, Department of Natural Sciences, Longwood College, Farmville, VA 23909 USA, caveman@longwood.lwc.edu

A new genus and species of campodeid dipluran has been identified from Tuckaleechee Caverns and four neighboring caves in Blount County in eastern Tennessee. The new species displays troglomorphic characters indicating a highly adapted cavernicole, with possible affinities to the *henroti* species group of the cave-inhabiting *Litocampa* of Tennessee, Georgia, and Alabama. Morphologically the new genus is somewhat intermediate to the *Plusiocampa* of the Mediterranean region and the *Litocampa* of North America and elsewhere. However, its affinity appears to be closer to the *Litocampa*, from which it is possibly derived. Since the *Plusiocampa* may have evolved from ancestral *Litocampa* as well, the similarity of the new genus to *Plusiocampa* is believed to be an example of parallel evolution.

ANALYSIS OF RRNA GENE SEQUENCES TO STUDY DIVERSITY OF MICROORGANISMS IN MAMMOTH CAVE

Rick Fowler, Chris Groves, Shivendra Sahi, Biotechnology Center, Western Kentucky University, Bowling Green, KY 42101 USA, Rick.Fowler@wku.edu

Geochemical factors in streambeds inside Mammoth Cave cannot account fully for the observed rates of limestone dissolution. Microbial effects such as production of acids and acid-forming gases are implicated, but attempts to culture cave bacteria for their identification have had limited success. In this study we use 16S rRNA gene sequences as a means for identifying bacteria in cave sediment without the need to culture environmental bacterial strains. DNA was extracted directly from cave sediments and bacterial 16S rRNA genes were selectively amplified by PCR. PCT products were ligated into the pGEM cloning and sequencing vector and circular molecules, thus produced were used to transform *E. coli* cells to create a cave clone library. Plasmid DNAs carrying 16S rRNA gene sequences from cave bacteria were isolated and used as templates for automated DNA sequencing. Sequences were compared to online databases and closest genetic matches to the cave bacteria were tabulated. Genetic matches to the cave bacteria include most notably soil inhabitants associated with the atmospheric and aqueous nitrogen cycle, plus some exotic strains and ecological red flags. Clues to the mechanisms by which bacteria promote cave formation are emerging, and applications of biotechnology as a tool for cave research are becoming apparent.

REEVALUATION OF THE TAXONOMIC STATUS OF AN "ALBINO" SCULPIN (ACTINOPTERYGII: COTTIDAE) FROM SUBTERRANEAN WATERS OF THE GREENBRIER RIVER DRAINAGE OF WEST VIRGINIA.

David A. Neely, R. L. Mayden, Biodiversity and Systematics, Box 870345, University of Alabama, Tuscaloosa AL 35487-0345 USA

We reexamined the single known specimen of a depigmented sculpin from Buckeye Creek Cave in the Greenbrier River drainage of West Virginia. This specimen has previously been considered to represent an aberrent albino individual of the banded sculpin, *Cottus carolinae*. The specimen differs from all known species of *Cottus* in the possession of a frenum. In addition, the specimen differs from epigean mottled sculpin (*Cottus bairdi*), as well as both epigean and troglophilic populations of Kanawha sculpin (*Cottus* sp. cf. *carolinae*) in meristic counts, body shape, prickling, development of the cephalic lateralis system, and other characters. This suite of character differentiation is inconsistent with the hypothesis that the specimen is an albino displaying pleiotropically induced anomalies associated with albinism. We urge cavers in the New River drainage, and especially the Greenbrier Valley, to be alert for additional specimens of this unique member of the Appalachian ichthyofauna.

EXPERIMENTAL ANALYSIS OF METABOLIC ADAPTATION OF *COTTUS CAROLINAE* IN RESPONSE TO PHOTOPERIOD AND FOOD AVAILABILITY

Linda L. Roman, Ginny L. Adams, Department of Zoology, Southern Illinois University, Carbondale, IL 62901 USA, linnie1998@yahoo.com

Variation commonly exists between organisms inhabiting epigean (surface) and hypogean (cave) environments due to the differences between the two habitats. As organisms move from surface to cave environments, they adapt to cave conditions: constant darkness, relatively constant temperatures year-round, low food availability, and high humidity. Fish adapted to cave life often experience reductions in pigmentation, eye size, pelvic fin ray count, and metabolic rate. The focus of this study was to understand metabolic changes in cave-adapted *Cottus carolinae* (banded sculpin) in response to photoperiod and food availability. Metabolic rates of sculpin were measured after brief acclimation to laboratory aquaria. Soon after initial metabolic measurement, sculpin were placed into one of four treatments for a period of eight weeks before final metabolic tests were run. Treatments included: 1) 24 hours dark, low food availability, 2) 24 hours dark, high food availability, 3) 12 hours light; 12 hours dark; low food availability; and 4) 12 hours light: 12 hours dark, high food availability. Results indicated no statistically significant differences existed in fish as a result of photoperiod, food availability, or the interaction of the two. Also, no significant differences existed between laboratory measurements and field measurements from cave and surface environments. However, many variables were identified that may have influenced fish metabolism in the laboratory. Further study is necessary to determine the influences of photoperiod and food availability on metabolism of banded sculpin.

UNPARALLELED EVOLUTION: BLINDNESS, DEPIGMENTATION, AND SCALELESSNESS DO NOT RUN HAND IN HAND AMONG TROGLOMORPHIC FISHES

Aldemaro Romero, Kelly M. Paulson, Environmental Studies Program and Department of Biology, Macalester College, 1600 Grand Ave., St. Paul, MN 55105 USA, romero@macalester.edu

Anecdotal evidence have suggested in the past that blindness, depigmentation, and simplification or loss of scales may be an example of parallel evolution among troglomorphic hypogean fishes. We investigated the level of blindness, depigmentation, and scalelessness among 423 families of fishes. Among those with troglomorphic features, blindness was categorized as eyes

present, eyes sunken, microphthalmic, and eyes not visible; pigmentation level was categorized as fully pigmented, mostly pigmented, mostly depigmented, and totally depigmented/albino. For all families of fishes, scalelessness was categorized as "have scales," "do not have scales," or "mixed" (some species have scales, some do not). We could not find reliable information on the scales for 22 of them, usually small, little known families, none of them with hypogean representatives. Of the rest, 257 (64.0%) have scales, 117 (29.2%) do not have scales, and 27 (6.7%) were mixed. There are 18 families of fish with troglomorphic representatives. Of those, seven (38.8%) families have scales, seven (38.8%) do not, and four (22.2%) contain both scaled and scaleless species. Our results suggest that levels of blindness, depigmentation, and scalelessness is different even among species of the same family and that simplification and/or loss of scales are common features among troglomorphic fishes, but that the lack of scales in the family as a whole cannot be considered a preadaptive feature. Different phylogenetic histories, selective pressures, and genetic independence governing these features account for the explanation of these results.

ONE EYE BUT NO VISION: TROGLOMORPHIC *ASTYANAX FASCIATUS* (PISCES: CHARACIDAE) WITH REGENERATED EYES DO NOT RESPOND TO LIGHT

Aldemaro Romero, Andrea Romero, Meghan N. Lelonek, Katy C. Stropnicky Environmental Studies Program and Department of Biology, Macalester College, 1600 Grand Ave., St. Paul, MN 55105-1899 USA
Steven M. Green, Department of Biology, University of Miami, Coral Gables, FL 33124 USA
William R. Jeffery, Yoshiyuri Yammoto, Department of Biology, University of Maryland, College Park, MD 20742 USA

One of the most intriguing questions in evolutionary biology is the degree to which behavior can be viewed as a consequence of morphology. We explore this issue by examining behavior associated with the loss of phenotypic structure and its presence, using responses to light by characid blind cave fish, *Astyanax fasciatus*, that are eyed and eyeless. Our experiments examine subjects that are epigean (eyed surface) and troglomorphic (blind cave) forms. We compare their photoresponsiveness with blind cave fish with restored eyes. These are produced transplanting the lens from an epigean fish into the optic cup of a blind cave form. The lens from the surface fish stimulates growth and development of the eye, restoring optic tissues lost during cave fish evolution. Fish were placed an aquarium with one half illuminated with dim or bright white light or infrared light, the other half dark. Their photoresponsiveness was examined by scoring their presence in the illuminated or dark half. Our results strongly suggest that both the blind subjects and those with restored eyes are indifferent to the illumination whereas the surface forms are not. Deactivation of the genes responsible for scotophilic behavior and/or lack of appropriate neurological connection may account for these results.

DIFFERENCES IN FEEDING BEHAVIOR, PREY SIZE, AND DIETARY COMPOSITION AMONG BANDED SCULPIN POPULATIONS IN PERRY COUNTY, MISSOURI

Kelly L. Smith, Ginny L. Adams, Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, IL 62901 USA

In the early 1990s, unique populations of banded sculpin *(Cottus carolinae)* were discovered in Missouri, showing troglomorphic adaptations typical of many cave species. Banded sculpin are traditionally crepuscular feeders. We were interested in investigating the differences in feeding behavior of these unique cave sculpin populations from typical surface populations. Stomachs were removed from samples collected for a previous study and analyzed for content. At the study sites, contents were flushed, using a non-lethal method, from the stomachs of fish found and taken to the laboratory for analysis. Initially, results indicated surface sculpin had an average stomach content weight ~6x that of the cave populations, while there was not a significant difference (ANOVA, $p < .05$) in total body weights. Surface sculpin total body weight was only 1.1 times the weight of the cave sculpin. Surface sculpin stomachs contained an average of 21% Diptera and 72% digested material. Organic debris (5%) was also found in the surface sculpin stomachs. In the cave sculpin, the stomachs contained 55% partially digested invertebrate material, 10% Amphipoda, and a higher percent (11%) of organic debris compared to surface sculpin. The cave sculpin stomachs also contained 70% acanthocephalon parasites occurrence, which were not found in the surface populations.

FRESHWATER OLIGOCHAETES (ANNELIDA) IN FINE SEDIMENTS OF CAVE STREAMS AND SEDIMENT CHEMICAL COMPOSITION

Steven J. Taylor, Mark J. Wetzel, Donald W. Webb, Center for Biodiversity, Illinois Natural History Survey, 607 E. Peabody Dr., Champaign, IL 61820-6917 USA, sjtaylor@inhs.uiuc.edu

We report on quantitative collections of aquatic oligochaetes from fine sediments of 8 cave streams in Illinois and Missouri, USA. Four of these streams were sampled monthly for one year. Eight annelid genera (*Haplotaxis*, *Dero*, *Pristina*, *Pristinella*, *Limnodrilus*, *Rhyacodrilus*, *Tubifex*, *Varichaetadrilus*) were collected. Some of the species identified are associated with more pristine conditions and others with organic enrichment. Measuring slide mounted specimens, we estimate the minimum volume of worms per unit volume of fine sediment in the cave streams. Examination of monthly samples did not reveal any statistically significant seasonal patterns in worm density or diversity. Sediment samples were analyzed for a variety of chemical constituents. We expected these would be positively correlated with the same constituents in water samples, but no such trend was detected for calcium, magnesium, sodium, and potassium. Metals in sediment samples showed some tendency to co-vary. For example, elevated iron levels in sediment samples were typically associated with increased lead and nickel levels in the sediments. Mercury was detected twice as often (6 of 12 monthly samples) in sediment samples from one wild cave that experiences heavy visitation as it was in three less frequented caves (3 of 12 monthly samples each). Lead was present in most sediment samples but only a few water samples, while Atrazine was detected in few sediment samples, but was more common in water samples.

STUDY OF A CONVERGENT CAVE BEETLE/CAVE CRICKET PREDATOR PREY SYSTEM

Molly Jean White, Department of Biological Sciences, University of Cincinnati, P.O. Box 210006, Cincinnati, OH 45221 USA

Darlingtonea kentuckensis is a cave dwelling trechine beetle found in caves of the Cumberland Plateau (MP-II) (Barr 1985) that has evolved specialized foraging behavior that allows it to prey upon the eggs of the cave cricket, *Hadenoecus cumberlandicus*. *Neaphaenops tellkampfi*, a trechine beetle found in caves of the Pennyroyal Plateau (MP-I) in west-central Kentucky (Kane & Poulson 1976; Kane & Ryan 1983; Griffith & Poulson 1993), has also evolved similar specialized foraging behavior that allows it to prey upon the eggs of *Hadenoecus subterraneus*. The predator-prey interaction between *N. tellkampfi* and *H. subterraneus* has been previously studied (Kane and Poulson 1976; Griffith and Poulson 1993). Unlike the *N. tellkampfi*/ *H. subterraneus* system, the dynamics of the *D. kentuckensis*/*H. cumberlandicus* system are unknown. Due to the fact that caves are similar in selective pressures but discontinuous in space, the comparison of *D. kentuckensis*/*H. cumberlandicus* to *N. tellkampfi*/*H. subterraneus* may give evidence for convergent evolution.

COMMUNICATIONS AND ELECTRONICS

CAVING LIGHT USING 24 SERIES/PARALLEL WHITE LEDS

Ray Cole, 3410 Austin Ct, Alexandria, VA 22310 USA, k4gaa@arrl.net

A caving light design using four parallel strings of six Nichia White LEDs in series does not need as many LEDs to match the strings as when they are all wired in parallel. The circuitry is based on the MAXIM 1698 integrated circuit, which has provisions for efficient dimming and switch mode operation using an external MOSFET. By carefully selecting the inductor and other components for low loss, it is possible to achieve efficiencies greater than 90% using surface mount components. The electronics and 24 LEDs are mounted on a 1.25 x 1.75 inch printed circuit board.

SIMPLE WHITE LED LAMPS FOR PRIMARY AND EMERGENCY LIGHTING

Brian Pease, 567 Fire St., Oakdale, CT 06370 USA, bpease@99main.com

An array of 24 (or more) LEDs can be mounted in a red "Easter Seals" headpiece along with a simple adjustable linear current source that can be powered from any 4-6 volt battery pack. The result is a waterproof lamp, using 4 AA alkaline batteries, which can be adjusted from very dim (25mA current, 100 hours life) to very bright (440mA, 3-4 hours life). The light pattern, with 20° half-beam width LEDs, is similar to a carbide cap lamp (with a large polished reflector), with a large bright area and plenty of side-light. The "rings" and sharp cutoff of halogen lamps are absent. In a 2-week test, the white, even

light made caving easy and the light remains white even at the dimmest settings, while the efficiency rises! Cavers can dim the lamp to suit conditions, greatly lengthening battery life. I could usually get away with 200mA when moving, and much less when stationary (surveying, resting, eating), getting 10 hours from 4 AA batteries.

The small, waterproof white LED flashlights are great backup lights, but the LEDs are grossly overdriven because they are directly connected to the 3 AA cells. This makes for a bright light (initially), but greatly reduces both LED and battery life. I wired a 1.5V/25mA bulb (Radio Shack 272-1139) in series with each of the 3 LEDs in a flashlight to regulate the current. The initial current dropped from 120 to 60mA, falling to 20mA with .08V across the bulbs near the end.

EXPLORATION-INTERNATIONAL

BONES BENEATH THE DUNES

Mahmoud Al-Shanti, Saudi Geological Survey, P O Box 54141, Jeddah 21514 SAUDI ARABIA

Dahl Murubbeh, located in the desert 200 km north of Riyadh, was the first place cavers found thousands of well-preserved animal bones from camels, gazelles, porcupines, gerboas, etc., apparently carried in by hyenas. These bones were found to be around a thousand years old and provide valuable information on animals inhabiting this area in the past. In recent years, human skulls and artifacts were also discovered and are thought to be just as old. Other parts of this cave contain beautiful boxwork and delicate calcite-frosted feathers.

During the last few months, Saudi geologists have been trained in horizontal and vertical caving techniques and a project is now underway to locate and study caves all over the country. One of the first results has been the discovery of new caves in northern Saudi Arabia that contain large caches of animal bones and naturally mummified foxes and bats. In these caves, it appears that modern-day wolves are continuing a process that was begun by hyenas centuries ago. Serdab Al Aqrab Al Aswad (Black Scorpion Cave) is an example. This cave also contains eroded, stratified piles of bat guano that might be extremely old, as well as small but attractive gypsum formations resembling swords, needles, spaghetti and wood shavings.

Vigorously blowing holes were recently discovered in this area, suggesting that there may be many more cave passages awaiting exploration in the limestone hard pan located north of the Nafud Desert.

PROYECTO CERRO RABÓN 2001

T. Evan Anderson, Suzette Kane, PO Box 613, Glenwood Springs, CO 81602

The Cerro Rabón is a limestone massif located in the southeastern margin of the Sierra Madres in a region called the Sierra Mazateca and is well known for its potential for deep caves. It is situated in the northern region of the state of Oaxaca, 300 km ESE of Mexico City, and rises 2000 m above the tropical lowlands of the Gulf of Mexico.

Systematic speleological research on a semi-annual basis began in 1985. This heavily karstified uplift of limestone has since yielded hundreds of kilometers of caves. The Kijahe Xontjoa system has been pushed to a depth of –1209 m, well below one of its speculated resurgences, the Nacimiento del Río Oropan. An unexplored region on the southeast corner named Terra Incognita is now thought to be part of the catchment area for the Río Oropan. Its rather high flow rate of 20 m³/sec may be an indication of a large and deep cave system.

In February 2001, a team of 13 cavers from America and Germany, led by Cerro Rabón veteran Mike Frazier, ventured into Terra Incognita to search for insurgences to the Río Oropan. Despite some harassment from local authorities, the team was able to perform an initial evaluation of the Terra Incognita landscape. Several caves were discovered and mapped and the team retreated with a valuable amount of knowledge to assist further expeditions.

YUCATAN 2000

Hazel A. Barton, 6920 Canyon Drive, Park City, UT 84098 USA

The Yucatan 2000 Expedition took place in the town of Mucuyche, Yucatan, Mexico, bringing together an international group of cavers and cave divers. The primary goal of the project was exploration of some of the 2400 described cave entrances in the Northern Yucatan Peninsula. Exploration was aimed at developing a database of these caves to help geologists determine the influence of the Chicxulub impact on cave development and hydrology in the area. Additional studies to monitor the impact of local farming on pollution within the caves were also carried out.

The majority of the caves in the State of Yucatan are underwater, with depths averaging 60 m and maximum explored depths exceeding 160 m. These depths require technical cave diving techniques and equipment. In order to make such exploration possible, a base camp was established with an elaborate air mixing station for the blending of specialized dive gasses (including nitrox and trimix) on site. Several caves were explored and mapped during the expedition, including Sabak Ha, Dzonot Nohoch, E-Babuel and Yaal Utzil.

Whilst the majority of caves surrounding Merida are submerged, the Tekax area (150 km south of Merida), contains over 100 dry caves. Members of the expedition traveled to this area to offer geologic suggestions to the local government about why these caves are dry. The majority of caves in this area are formed in an uplift, corresponding with a sudden dip (>30 m) of the water table, allowing depths of now dry cave development in the area to approach 200 m.

CUBAN-AMERICAN EXPEDITION TO CENTRAL CUBA

Kevin Downey, 21 Massasoit Street, Northampton, MA 01060 USA
Dave Bunnell, P.O. Box 879, Angels Camp, CA 95222 USA

Six Americans and 1 Swiss caver spent two weeks in Cuba working with 2 Cuban caving groups. Our first 2 projects were in cooperation with members of SAMA, based in Sancti Spiritus, and were centered in the Escambray Mountains. Survey and photography was begun in the Boqueron system, which contains a large river passage and extensive fossil levels accessed through a spectacular collapsed borehole. One segment contained large numbers of shields, including unusual curtain-like forms. A second project was undertaken at Cueva de la Guira, the resurgence of the multi-drop Caja de Agua system, Cuba's deepest at over 400 m. A scaling pole was used to access upper levels seen near an upstream sump, but unfortunately these did not afford a bypass.

A third project was to begin a detailed survey of Cueva de Santa Catalina, near Matanzas, in conjunction with the Comité Espeleologico de Matanzas. Located near the coast, the cave hosts unusual speleothems thought to be a mixing-zone phenomenon. These include "hongos piedras," or mushroom-shaped formations, in association with folia, some of it on a macro scale observed in few other caves. Other sections of the cave where folia are absent contain long clusters of snake-dancer helictites. While none of the surveys were completed on this trip, groundwork was laid for future cooperation with the congenial cavers of these 2 groups.

CAVES OF THE WADI DEGLA PROTECTED AREA, CAIRO GOVERNATE, EGYPT: INITIAL RECONNAISSANCE

William R. Halliday, 6530 Cornwall Court, Nashville, TN 37205 USA

The Egyptian Environmental Affairs Agency (EEAA) is beginning a systematic survey of significant caves throughout Egypt. Its "Protected Areas" are essentially the equivalent of national monuments in the USA. In April 2001, I accompanied a staff geologist to 6 caves in the new Wadi Degla Protected Area in the outskirts of Cairo. Others exist nearby. To date all are small, but because EEAA so far has absolutely no caving equipment, we had to stop at a 8 m pit in 1 of the 5 we mapped. In still another, we ran out of time after 35 m in a tight, seemingly endless phreatic tube floored with fragments of broken rock. We also visited a much larger cave in the Wadi Sannur Protected Area in the Eastern Desert. Other caves are mentioned in various publications and several visits are scheduled in the next 12 months.

GUNUNG NGALU SERIBU: THE MOUNTAIN OF 1000 CAVES, SUMATRA, INDONESIA

John Lane, P.O. Box 385, Forest Ranch, CA 95942 USA
Matt Covington, 2899 Brookbury Xing, Fayetteville, AR 72703 USA

In July 2000, a reconnaissance to the Gunung Ngalau Seribu (Mountain of 1000 Caves) region of West Sumatra was conducted. The focus consisted of exploration for caves in a 90 km² limestone massif bordered on the north by Sungai (river) Sangkiamo and on the west by Sungai Kuantan and sampling of water for characterization analyses. During the trip, 1488 m of cave passage were surveyed and mapped in four separate caves. The longest cave, Ngalu Moeko Moeko, yielded 988 m of river passage. A number of cave leads remain to be explored. Significant caves were discovered in the Sungai Kuantan valley. Routes to insurgences and resurgences have been located. Depth potential is ~400 m for caves found near the top of the massif. Five water samples were collected and analyzed for calcium, total hardness, total akalinity, chloride,

sulfate, nitrate, phosphorus, temperature, pH, and conductivity.

MULTIYEAR PROJECT TO MAP CAVES FOR THE DEPARTMENT OF ARCHEOLOGY OF BELIZE

David Larson, Eleanor Burns Larson, 4346 Via Presada, Santa Barbara, CA 93110 USA, delarson@aol.com

In March 2001, a group of 10 US cavers spent 2 weeks in Barton Creek Cave in the Cayo District, Belize. This was the third mapping trip to the cave, which had been used by the Maya 1000 years ago and which is used today as a popular show cave. Archeologists under the direction of Jaime Awe excavated in the cave last summer and will be tying their highly detailed maps into our map when it is complete. The first 940 m of stream passage, shown to tourists in canoes, is beautifully decorated. The cave was reputed to be a simple stream passage that continued for a distance of as much as ~10 km. Our exploration showed that it is much more complex than previously thought. Instead of being a simple stream passage it is a complex cave. During the last days of the trip many leads were discovered which will have to wait for next year.

A SHORT TOUR OF SAUDI ARABIA'S DESERT CAVES

John J. Pint, Mahmoud Alshanti, Saudi Geological Survey, Cave Exploration Unit, PO Box 54141, Jeddah 21514, SAUDI ARABIA, ThePints@saudi-caves.com

In 1983, cavers discovered a small hole on a hard-pan plateau alongside Saudi Arabia's Dahna Desert. Warm, moist air blowing out of this hole encouraged them to widen the opening until they could just fit through. The labyrinth of decorated passages below is now called Dahl Sultan and it was just the first of many outstanding caves discovered and explored over nearly 20 years. These caves include:

- The Whistling Teapot, named for a mysterious wailing sound that baffled its first visitors.
- UPM Cave, which boasts three levels, cave pearls, and a small rimstone dam growing beneath the desert. This cave was discovered by speleologists from the Austrian Academy of Sciences and the University of Petroleum and Minerals, in Dhahran.
- Dahl Abulhol, which means Father of Fear, a large, single chamber at the bottom of a 75 m drop.
- Surprise Cave: Home of the most beautiful formations found so far, with passages still going.

Most of these caves were found while investigating only a small fraction of countless holes dotting the Summan Plateau. The exploration of Saudi Arabia's desert caves may be only in its infancy.

EXPLORATION – U.S.

SURVEY AND EXPLORATION OF THE FARMERS CAVE SYSTEM, KENTUCKY

Steve Aspery, 264 Crandall Drive, Worthington, OH 43085-4006 USA
Darrell Adkins, 1427 Club Drive, Mount Vernon, OH 43050-4761 USA

The Farmer Cave System of Pulaski County, KY, has been an ongoing project of the Central Ohio Grotto of the NSS since 1989. This is a long-term project in a system that has yielded over 21 km of surveyed passage.

The system is contained within a single valley with no passages yet discovered that pass through the ridges. There are 21 entrances within the valley, 12 connected to substantial passage. Many of these required significant digging to gain access. The history of the project involves numerous connections between these entrances, creating a substantial system that continues to yield exciting discoveries. Recent efforts have centered on several connections in the center of the system. All efforts within the system are limited by the pool level of Lake Cumberland, with many passages accessible only during low winter pools.

The Farmer System may be a classic long term project with the challenges of personnel, leadership, data management, landowner relations, and enough new discoveries to keep us interested and coming back.

GOING WEST FROM NW NORTHTOWN RIDGE IN FISHER RIDGE CAVE SYSTEM

Suzanne DeBlois, 150 Essex Ct., Athens, GA 30605 USA

The survey in Fisher Ridge Cave System in Hart Co., KY, was 159 km long in April 2001. Some of the most remote areas from the entrances on Fisher Ridge are in the northwest reaches of Northtown ridge, the northernmost point in the cave. On five trips in 1993, 1994, and 1995, 2.9 km of passages called the Other World, the Chasm, and the Chasm Drain were surveyed in this section of ridge. In 1998 members of the Detroit Urban Grotto completed the construction of the Quick Exit, an artificial vertical entrance on Northtown ridge, which facilitated access to the cave under Northtown ridge, including the northwest corner containing the Other World area and another significant passage. Fourteen more survey trips taken from December 1999 to the spring of 2001 turned up an additional 4.4 km of passage in this area. Of this survey 1400 m came from loops and piracies from the southwest-northeast-trending Other World trunk to the Chasm and the Chasm Drain. A wet, windy passage draining from the northwest, south to the Chasm Drain was not exhaustively explored. A dry phreatic infeeder to the Other World having good airflow meandered for 754 m before pinching. Since October 2000, 2233 m more were mapped after another portal into the northwest corner of the ridge was found near the junction where the Other World took off from the main cave. Leads remain, 1.6 km apart on either end of what are known as the Rough Route and Pencil Sharpener passages.

SURVEY AND EXPLORATION OF JUGORNOT CAVE, PULASKI COUNTY, KENTUCKY

Lee Florea, 108 Westwood Dr., Lexington, KY 40503 USA

Jugornot Cave in Pulaski County, Kentucky is a well-known cave used by locals and visitors since the 1800s. It was located along the primary route of travel connecting Cumberland Gap to Sublimity Station on the Rockcastle River and to Elihu just south of Somerset and points further west. At that time, the cave was known as Old Kentucky Cave. The first survey took place during 1974 by the Dayton Area Speleological Society. This survey mapped over 1400 m during one trip in one canyon passage. In January 2001, members of the Central Ohio Grotto, Blue Grass Grotto, and local cavers began a project survey of the cave. In one 8-hour trip, 1200 m had been re-surveyed in the canyon. This canyon trends linearly, with a flow direction southwest through the ridge separating Jugornot Hollow from Pumpkin Hollow. Other surveyed passages within Jugornot follow this trend and consist of breakdown strewn, highly decorated upper levels, and tall canyons in lower levels. The spatial location and orientation of passages in Jugornot continue the trend found in the Richardson Bore, Big Room, and Easter Passage sections of the Coral Cave System. Photographic, statistical, and geologic evidence gathered from within Jugornot Cave and from nearby surface features support the hypothesis that regional speleogenesis has been influenced by ancient Cambrian faulting propagated upward through Mississippian and Pennsylvanian strata as fracture swarming. To date, 3000 m of cave have been mapped with a cave depth of 73 m.

MARTIN RIDGE CAVE SYSTEM, EDMONSON COUNTY, KENTUCKY

Alan Glennon, Chris Groves, Don Coons, Hoffman Environmental Research Institute, Western Kentucky University, Bowling Green, Kentucky 42101

Southwest of Mammoth Cave, the Martin Ridge Cave System is composed of Whigpistle, Jackpot, and Martin Ridge Caves. Entrances are on private land and access is tightly controlled by the owners and respective projects.

Whigpistle Cave was discovered by Quinlan employee Rick Schwartz in 1976. Through the late 1970s and early 1980s, Quinlan's explorers mapped an extensive flood-prone cave between the Mill Hole and Cedar Sink karst windows. Beyond grueling entrance crawls and eardips, explorers found some of the most continuous trunk passage in the region. They also discovered the Big Womb (240m long, 35m wide, 18m tall), which is likely the largest underground chamber in Kentucky.

A digging project several kilometers to the east led to important discoveries in 1995. In Jackpot Cave, through a series of tight domes and drains, explorers found a beautiful, gypsum encrusted trunk, the Celestial Borehole. Smaller, wetter leads continued in the cave's lower reaches. Ridgewalking in April 1996 between Whigpistle and Jackpot, Alan Glennon discovered a swallet leading to numerous narrow canyons and stream passages. In several locations, these passageways intersected large trunks, and an extensive cave was revealed.

The connections of the three caves, which took the system length beyond 50 km, occurred in the summer of 1996 by Glennon, Jon Jasper, and Chris Groves. Since that time, exploration has continued with the goal of pushing northeasterly toward Mammoth Cave and discovering downstream sections of the underground river that flows from the Mill Hole karst window.

LECHUGUILLA CAVE CULVERT REPLACEMENT PROJECT

Jason M. Richards, 121 Nuchols Street, Apt. 7016, Goodfellow Air Force Base, Texas 76908-3335 USA

The Lechuguilla Cave breakthrough was in May 1986. During the first week of exploration, a 61 cm diameter road culvert with a locking gate was placed through the rubble to make entry into the cave safe and to add security. Due to the high velocity of winds entering and exiting the culvert, the locking gate was later replaced by the Sandia Grotto with a counter balanced lid with a seal. The interior of the culvert was alternatively wet or dry depending on whether the cave was exhaling or inhaling. This constant variation caused by changes in barometric pressure created a very hostile environment for the metal ladder and culvert. During the years, the mild steel ladder and the culvert was in a state of severe corrosion. For safety purposes, the management of Carlsbad Caverns National Park, Cave Resource Office, decided that the culvert needed to be replaced with a combined non-corrosive airlock and culvert. The project started in February 1999 with the combining of ideas and the writing of an environmental assessment. Along with combined long hours, frustration, and hard work, the construction phase of the project is complete and the restoration phase is in progress.

THE BLACK HOUSE MOUNTAIN CAVE SYSTEM, TENNESSEE

Lou Simpson, Steve Lugannani, Todd Rowland Bryan, 750 Avon Fields Ln., Cincinnati, OH 45229-1511 USA

Efforts since 1998 have focused on extending the numerous caves toward each other. Lugannani and others discovered a fourth entrance to the longest segment, 8.9 kilometers long Cornstarch. Todd Bryan and Nikki Woodward extended 0.8 kilometers long Little Jack to a sump that is likely the same as a sump in 3.2 kilometer long Red Bud. Bryan, Lugannani, and others repeatedly braved the grueling Water World crawl in Red Bud to map the long crawls beyond Viagra Dome and did a wet dig named "It Sucks" under "Offending Valley" where a connection to 2.4 kilometers long Temple Falls seems likely. Nashville technical digging experts helped get into Blowing Fern Cave right on top of this connection area, but the next dig looks grim. In 2001, we have dug into more cave in 300 m long Green Bottle Cave and hope to connect to the Viagra Dome area of Red Bud, thus avoiding the Water World crawl.

THE CAVES OF REDMOND CREEK, WAYNE COUNTY, KENTUCKY

Bill Walden, Katie Walden, 1672 S Galena Rd., Galena, OH 43021-9540 USA

Redmond Creek flows north out of Tennessee into a very large sinkhole where it disappears into the ground in southern Wayne County, KY. The largest known cave in the sinkhole is Redmond Creek Cave. The Central Ohio Grotto began examining the cave during the autumn of 1997 with the policy of surveying as it was explored. Surveying and exploration are limited to late summer, autumn and early winter because the cave is flooded during much of the year. The cave consists of a primary north-south stream passage, significant east-west canyons, and high, old phreatic passages that are rich in fossils. It is this east-west-trending part of the cave that has been most interesting and has received the most exploration and surveying. The Redmond Sinkhole is rimmed with waterfalls, cascades, and streams exiting from caves in the Bangor Limestone, all of which enter caves in the Kidder Limestone. We have many leads yet to explore and survey including the main stream passage, which should go for at least 2.4 km where Redmond Creek enters the cave.

GEOLOGY AND GEOGRAPHY

KARST EDUCATION AT WESTERN KENTUCKY UNIVERSITY: THE CENTER FOR CAVE AND KARST STUDIES

Nicholas C. Crawford, Center for Cave and Karst Studies, Department of Geography and Geology, Western Kentucky University, Bowling Green, KY USA, caveandkarst@wku.edu

The first international conference that dealt with environmental problems of karst regions was sponsored and hosted by the Department of Geography and Geology at Western Kentucky University in the spring of 1976. The Center for Cave and Karst Studies, established in 1978, was the first center in the United States to emphasize karst and its environment problems. Although the NSS and other organizations were concerned about cave conservation and protecting caves, the Center was the first organization to emphasize the hydrogeologic environmental problems associated with development upon karst terrain.

BI-MODAL CONDUIT DISTRIBUTION, WELLS CAVE, KENTUCKY: IMPLICATIONS ON REGIONAL HYDROGEOLOGY

Lee Florea, Kentucky Cabinet for Natural Resources, #2 Hudson Hollow, A-16, Frankfort, KY 40601, lee.florea@mail.state.ky.us

Wells Cave, contained within the Silvers Branch sub-drainage of Buck Creek in southeastern Pulaski County, Kentucky, is a diverse cave system with ~19 km of surveyed passage. The survey of the cave took place during the 1970s and 1980s by the Dayton Area Speleological Society. From in-cave and surface evidence, the geomorphology of Wells Cave can be shown to be the result of a significant hydrologic transition separating two phases of conduit development. Wells Cave began as a phreatic maze cave when Silvers Branch downcut into Mississippian carbonates. Following this period of development, the isthmus of a large meander of Buck Creek was truncated. This meander contained the outlet for Silvers Branch and the paleo-springs for Wells Cave. The isthmus truncation provided an increased hydraulic gradient and an extra 2.4 km of horizontal distance to a new discharge point along Buck Creek. During this transition period, floodwater pulses filled conduits depositing layers of sediment. As Buck Creek entered a phase of rapid downcutting, Wells Cave responded through the development of lower level vadose canyons, including the River Passage (a large trunk conduit reaching sizes of up to 30 m wide by 15 m high). These vadose passages reworked sediment from filled phreatic passages and utilized them as piracy routes. This pattern of cave development is common for caves along southern Buck Creek and may be related to a past change in regional hydrogeology. Understanding the Wells Cave karst aquifer is important as human demands on the aquifer increase.

WATER QUALITY THREATS FROM OIL PRODUCTION ADJACENT TO MAMMOTH CAVE NATIONAL PARK, KENTUCKY

Weldon Hawkins, Alan Glennon, Chris Groves, David Ek, Hoffman Environmental Research Institute, Western Kentucky University, Bowling Green, KY 42101 USA

Joe Meiman, Mammoth Cave National Park, Mammoth Cave, KY, 42259 USA

In the early 1990s, a small oil boom began in the Arthur Community along the southwestern edge of Mammoth Cave National Park. In January 1997, a spill occurred, dumping over 2,000 L of crude oil into the park. An emergency effort prevented the oil from sinking into the karst aquifer. However, the spill highlighted the threat posed by these wells, and demonstrated the need for a better understanding of the area's hydrogeology.

Much of the watershed exhibits alternating surface and karst (subsurface) water flow. However, results from dye tracing also show that subsurface water flow within the Glen Dean limestone karst aquifer is able to breach the Hardinsburg Sandstone in the subsurface, and flows into the underlying Haney limestone karst aquifer.

In order to prepare for potential threats, scientists and students of Western Kentucky University's Hoffman Environmental Research Institute and Mammoth Cave National Park are cooperating in the development of a geographic information system database that depicts the hydrogeology, oil well location, karst features, access roads, and water flow routes adjacent to these oil facilities. The resulting database and map will be distributed to various emergency response agencies, to speed planning and response in the event of future environmental emergencies.

HYDROGEOLOGY OF SPENCER MOUNTAIN, VAN BUREN COUNTY, TENNESSEE: INVESTIGATION UPDATE

John Hoffelt, 208 Cheatham Road, Smyrna, TN 37167 USA

W. Stephen Anderson, P.O. Box 210485, Nashville, TN 37221 USA

Sid Jones, 640 E. Rock Quarry Road, Clarkrange, TN 38553 USA

A consortium of karst scientists conducted a hydrogeologic study of Spencer Mountain, Van Buren County, Tennessee. This study expands Crawford's research presented at the 1983 National Speleological Society convention. In 1999, the City of Spencer proposed to discharge sewage effluent into the karst system beneath Spencer Mountain. Dry Fork, the proposed stream to receive effluent discharge, is a High Quality Stream (Tier II). Issuance of an effluent discharge permit to Dry Fork required an exemption to Tennessee's Antidegradation Regulations, which was granted by the Tennessee Water Quality Control Board. The hydrogeologic study delineated and confirmed groundwater flowpaths and identified human and environmental targets susceptible to the proposed effluent discharge.

The study shows that the western edge of Spencer Mountain, including

Laurel Cove and Molloy Hollow, is in the Pennywinkle Spring groundwater drainage basin. The study delineated that McKeever Cave is in the Big Swamp Spring basin. The data confirm that groundwater from Dry Fork, Indian Camp Branch (Windy River Cave), Turkey Cot Cove, and Millstone Branch flows through caves under Spencer Mountain to Big Swamp Spring. Haston Spring and Thunder Run Cave are overflow conduits for Big Swamp Spring; however, the source of Haston Spring's base-flow is not established. The drainage from Green Monster Cave was not detected during the six-month study and will require additional investigation.

STREAM FLOW IN KAUMANA CAVE

Patricia Kambesis, Hoffman Environmental Research Institute, Western Kentucky University, Bowling Green, Kentucky 42101 USA

Kaumana Cave is a lava tube located within the 1881 lava flow originating from Mauna Loa. Situated in the lowermost reaches of the flow, Kaumana Cave typifies the morphology of Mauna Loa tubes within long, linear flows. However, it does display one unusual character for a lava tube: during medium to heavy rains, it carries a stream that floods some of the middle sections of the tube.

Stream flow in Hawaiian lava tubes is highly unusual because of the high permeability of basaltic rock which normally favors rapid infiltration. In Kaumana Cave, a combination of factors may contribute to the observed stream flow including:

- extremely high rainfall on the east side of the Big Island;
- floodwaters redirected via man-made drainages into the upper entrances of the tube;
- the 1881 flow, between the town of Kaumana and the western outskirts of Hilo, is underlain with an impermeable ash deposit that perches the stream through most of the cave.

The high stream flow during heavy rains moves floodwaters through the system extremely quickly (within a couple of hours). Waters exiting the lowermost entrance are redirected to a storm sewer located 60 m away. The exact course of the floodwaters once they exit the lava tube is not known. However, it is probable that the water eventually resurges in fresh water springs in Hilo Bay.

PACKRAT URINE PATHWAYS: AN UNUSUAL BIOSPELEOTHEM IDENTIFIED AT FAIRY CAVE-GLENWOOD CAVERNS, GLENWOOD SPRINGS, COLORADO USA

Fred G. Luiszer, University of Colorado, Department of Geological Sciences, Boulder, CO 80309 USA

Packrat urine pathways, which are found in both Fairy Cave and Glenwood Caverns, are linear deposits of indurated calcite that are along the top edges of bedrock breakdown and flowstone. The deposits are up to 4 cm high and 2 cm wide. The pathways are generally subparallel to cave passages and are level. However they can form bumps several centimeters long, called "Mickey Mouse" ears because of their uncanny resemblance to said mouse's famous ears (E. Anderson, pers. comm.). Petrographic examination of thin sections indicate that the pathways consist of very thin layers of microcrystalline calcite. Modern dried packrat urine, which was along the sides and top of a pathway, was identified as a mixture of calcite and monohydrocalcite by XRD. SEM microphotographs of the dried urine showed grain sizes of 0.1 to 3 microns. Fresh packrat urine is a viscous, milky liquid, which contains dissolved urea and calcite crystals. The elevated nitrate content (a byproduct of urea breakdown) of pools in Fairy Cave and Glenwood Caverns indicates that the urea is leaching away, leaving behind the calcite crystals, which with time become indurated. Packrats are apparently marking their trails with urine as an aid for locating their nests and water.

CAVE AND KARST DEVELOPMENT ON SAIPAN

John Mylroie, Joan Mylroie, Mississippi State University, Mississippi State, MS 3976 USA, Mylroie@Geosci.MsState.edu

John Jenson, Curt Wexel, Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao, Guam 96923, jjenson@uog9.uog.edu

Saipan, part of the Commonwealth of the Northern Mariana Islands (CNMI) in the western Pacific Ocean, is a 125 km² island made up of a core of Eocene and Oligocene volcanic and volcanic-derived sedimentary rocks mantled and surrounded by interlayered limestones ranging from Late Eocene to Pleistocene. Significant deformation, mostly as high angle normal faults, has created a complex landscape and outcrop pattern. As a result, Saipan falls into the Composite Island classification of the Carbonate Island Karst Model (CIKM), as both allogenic and autogenic recharge control cave and karst development.

In the island center, streams rising on volcanic and volcanic-derivative rocks sink upon reaching the limestones, in cases forming stream caves of appreciable length. Flank margin caves are found on interior and coastal scarps, their elevation above modern sea level caused by the interplay of tectonic uplift and glacio-eustasy. In the east-central area, faulting has placed limestone blocks against volcanic units such that paleo-recharge was confined and formed large lift tubes to create Vauclusian springs. The northeastern end of the island contains many caves that appear to be progradational collapse features, where dissolutional voids formed at the limestone/volcanic contact stoped upwards, similar to what is observed in Bermuda. Permeability in this northeastern area is sufficient that the fresh-water lens is thin to non-existent.

ELEVATION CONTROL OF CAVE MORPHOLOGY ON TROPICAL ISLANDS

Lars Mylroie, 617 Sherwood RD, Starkville, MS 39759 USA

The Carbonate Island Karst Model proposes that, in a simple carbonate island, the caves near past sea levels are horizontal in shape and the caves significantly above past sea levels are vertical. To test this model, an area on San Salvador Island near Flamingo Pond was examined to discover new caves and see how they fit the model, as part of an overall GIS program for the island. Using a machete, the ridge was walked at certain past sea levels to try to find caves. Once found, a cave was located using GPS. Caves were then surveyed using a Suunto compass, a Suunto inclinometer, and a metric fiberglass tape measure. The data were reduced and maps drawn.

Two caves close to past sea levels were surveyed and were more horizontal in shape than vertical. This was due to the ocean coming in against the land and making a fresh water table at the sea level, and the caves formed in that water table. The caves significantly above sea level had a mostly vertical profile. This is the case because the vertical caves formed by water flowing from the surface to the water table. The results would be more conclusive if more caves had been found.

TEMPERATURE VARIATION OF TROPICAL ISLAND CAVES

Leif Mylroie, 617 Sherwood Rd, Starkville, MS 39759 USA

Majors Cave, San Salvador, Bahamas, was studied to see if the temperature in a tropical cave changed dramatically with the weather or day/night cycle. Hobo temperature data loggers were placed in vertical profiles in the back, middle, and front of the cave, with a control placed outside of the cave. In the back of the cave, data loggers were placed in a tidally fluctuating pool of water at depths of up to 1.5 m; one data logger was placed at a depth of 4 m in a pool just inside an entrance at the front of the cave. The data loggers were set to take the temperature once every minute of the day. They were left in the cave for three days, removed on the fourth day and downloaded onto a laptop computer.

During the experiment a series of cold fronts from the North American continent passed over San Salvador Island, creating temperatures below the average temperature for the island. As a result this cool air entered the cave entrances and flowed over the cave floor to the low spots containing the tidal water. The data loggers on the ceiling recorded warm temperatures but the ones on the floor recorded cooler temperatures. The data loggers in the tidal pools showed progressively warmer temperatures with increasing depth and therefore distance away from the cool air. The shallow data loggers recorded the tidal cycle as cool at low tide and warmer at high tide.

GROUNDWATER TRACING RESULTS AT A NEW PUBLIC SCHOOL AND AN INVENTORY OF CLASS V INJECTION WELLS (SINKHOLES) IN PARTS OF RUTHERFORD COUNTY, TENNESSEE

Albert E. Ogden, Laura R. Ogden, Brook E. Powell, Department of Geography and Geology, Middle Tennessee State University, Murfreesboro, TN 37132 USA, karst@mindspring.com

Dye tracing was conducted around a new Rutherford County middle school site to determine the fate of runoff water planned for diversion to a very large sinkhole called Hooper Bottom. Two traces established that drainage into Hooper Bottom will move nearly 4 km in a northwest direction to a stream in the bottom of a karst window. From there, the subterranean stream moves through a series of karst windows to emerge at Nice Mill Spring along the

West Fork of the Stones River. The estimated size of the Nice Mill Spring groundwater basin, which includes the Middle School, is 17 km². Two other traces were conducted to different springs to help delineate the divides of the Nice Mill Spring basin.

A pilot study of sinkholes that have been modified to accept storm water runoff was conducted throughout a 72 km² area with high sinkhole density. A total of 125 Class V injection "wells" (sinkholes) were located by utilizing 2-foot contour maps provided by Murfreesboro and Smyrna. The locations of the sinkholes were placed in a GIS database. In addition to locating the 125 sinkholes, a broad type of drainage to each was designated. These included: 1) street/major highway; 2) rural road and/or agricultural; 3) industrial; and 4) subdivision/parking lot. Nearly all of the designated sinkholes drain streets, roads, and parking lots where the expected contaminants would be primarily grease and oils from cars or possibly fertilizers and pesticides from lawn and field application.

ORIGIN AND REGENERATION OF NITRATES IN MAMMOTH CAVE SEDIMENT

Rick Olson, Division of Science and Resources Management, Mammoth Cave National Park, Mammoth Cave, KY 42259 USA
Ivan G. Krapac, Illinois State Geological Survey, 615 East Peabody Drive, Champaign, IL 61820 USA

Few subjects have been the source of more confusion than the origin of nitrates in cave sediment and regeneration reported in the literature over the past three centuries. The purpose of our investigation was to determine the mechanism/s by which nitrate accumulates/regenerates in Mammoth Cave sediments.

Sediment samples were collected from a leach vat (LV) at Booths Amphitheater, leached sediment piled across the trail from this vat, and undisturbed sediment near Bunker Hill. Nitrate concentrations were determined, and samples were leached with deionized water to remove nitrates. The leached sediments were subsampled and replaced in the cave such that the samples were in contact with sediment, bedrock, or cave air. Samples were then periodically collected during the past six years and nitrate concentrations determined.

After six years in the cave, all of the samples (except LV bedrock) had nitrate concentrations less than 10% of original concentrations. Temporal changes in nitrate concentrations were extremely variable and in many instances no trend was apparent. These results suggest that proposed mechanisms such as transport/deposition of nitrates via percolating groundwater, and mineralization of atmospheric nitrogen through biotic or abiotic mechanisms are likely not responsible for regeneration of nitrates in these sediments.

Recent investigations indicate that former bat, woodrat, and raccoon populations in the cave were highly significant. With this realization, and the failure of our samples to significantly accumulate nitrate during the project period in the absence of these populations, the most likely dominant source of nitrate was guano.

THE GEOLOGIC FRAMEWORK OF KARST IN THE OZARK PLATEAUS OF SOUTH-CENTRAL MISSOURI

Randall C. Orndorff, David J. Weary, U.S. Geological Survey, MS926A National Center, Reston, VA 20192 USA, rorndorf@usgs.gov
Stanka Sebela, Karst Research Institute, IZRK ZRC SAZU, Titov trg 2, 6230 Postojna, SLOVENIA

A regional geologic framework is required to understand the environmental impact of mining of lead and zinc proposed on large springs in the karst area of the Ozark Plateaus of south-central Missouri. Information about lithologies, faults, joints, and karst features (sinkholes, caves, and springs) contributes to the development of a conceptual model of karst hydrogeology of the Ozarks. Conduits and caves along bedding planes and joints provide avenues for groundwater recharge, movement, and discharge. The trend of joints was studied to determine if they controlled the orientation of cave passages and conduits. The data show that cave passages are curvilinear and do not correlate well with measured joint trends. Instead, stratigraphy, bedding-plane dip, and local base level affect conduit and cave development. The majority of caves in south-central Missouri have developed within stromatolitic dolomite horizons beneath sandstone beds. We hypothesize that the sandstone beds act as confining units allowing artesian conditions and mixing to occur beneath them, thus, enhancing dissolution. Additionally, joints and the high primary porosity of the stromatolitic dolomite beds form openings in the bedrock that initiate solution. Where a solution-widened joint intersects a bedding plane, lateral movement of groundwater is controlled by the bedding plane.

NOTCH MORPHOLOGY AS A PALEOHYDROLOGICAL INDICATOR

Matthew A. Reece, John E. Mylroie, Mississippi State University, Mississippi State, MS 39762 USA
John W. Jenson, Water and Environmental Research Institute, University of Guam, Mangilao, GU 96923

Distinctive "c-shaped" features known as notches exist on tropical rocky carbonate coasts, and are often interpreted as bioerosion notches. Inland notches have been interpreted as fossil bioerosion notches from a previous sea level highstand. However, many of these inland notches have morphologies similar to exposed flank margin caves, and contain speleothems, suggesting a speleogenetic origin. Fossil bioerosion notches contain important information on past sea level position, but fossil notches of speleogenetic origin offer important paleohydrological information.

Notches were examined on Guam, San Salvador, and Isla de Mona, both in and out of the modern intertidal. Linear notches with nearly horizontal roofs were observed in all of the modern intertidal settings and some inland settings. Notches that have undulating floors and ceilings are commonly observed outside of the intertidal in all three localities, and at rare locations within the intertidal. This latter morphology has been termed "beads-on-a-string" by previous workers, and is believed to be indicative of flank margin caves exposed by cliff retreat.

The degree of anisotropy in the flow of the fresh-water lens is presented by the degree of chamber enlargement. If flow is to specific discharge points along the lens margin, large separated dissolutional chambers are produced. Uniform, isotropic flow produces a low, continuous chamber. With sea level fall, the breaching of these chambers reveals the nature of the paleohydrology that produced them. The degree of anisotropy shown by these breached flank margin caves may reflect current anisotropy in island and coastal carbonate aquifers.

LOCATING AND MAPPING CAVES FROM THE GROUND SURFACE USING ELECTRICAL RESISTIVITY AND MICROGRAVITY

J. Richardson, L.A. Croft, J. Islas, S. Fryer, C.A. Caulkins, J. Ballard, C.A. Fogle, P.D. Littell, T.D. Oakes, M. Peveler, J.A. Tibbs, N.C. Crawford
Center for Cave and Karst Studies, Department of Geography and Geology, Western Kentucky University, Bowling Green, KY USA

The Center for Cave and Karst Studies has been using geophysical techniques to locate caves from the ground surface since 1985. Although several geophysical techniques have been employed, the best results have been obtained using microgravity and electrical resistivity. The general trend of the cave is estimated by using a combination of lineament analysis, dye traces and potentiometric surface mapping. Microgravity is then measured at a 10-ft interval along traverses established perpendicular to the hypothesized general trend of the cave. Electrical resistivity using the new Swift/Sting resistivity meter is also measured along the traverses using a dipole-dipole array. Once a low-gravity anomaly and/or a high resistivity anomaly has been confirmed to be a cave, usually by an exploratory boring, the general route of the cave passage can be determined by proceeding in a "leap frog" fashion with short parallel traverses. A spring or a known section of cave can also be used as the starting point for the "leap frog" traverses. This technique is particularly useful in well-developed karst, where the caves are relatively large and shallow. Use of this technique located the Lost River Cave under Bowling Green, KY.

A PROPOSED PROGRAM TO REGULATE GROUNDWATER WITHDRAWAL TO MINIMIZE THE IMPACT ON ENDANGERED SPECIES HABITAT DURING DROUGHT IN THE BALCONES FAULT ZONE PORTION OF THE EDWARDS AQUIFER OF SOUTH-CENTRAL TEXAS

Geary M. Schindel, Steve Johnson, Edwards Aquifer Authority, 1516 N. St. Mary's, San Antonio, TX 78216 USA
Andrew C. A. Donnelly, Charles W. Kreitler, LBG-Guyton Associates, 1101 S. Capitol of Texas Highway, Suite B-220,Austin, TX 78746-6437 USA

The Edwards Aquifer in south-central Texas is the primary source of water for over 1.7 million people. It is also the largest source of water for an irrigated agricultural economy as well as industrial demand in the region. Over 425,000 ac-ft/yr are withdrawn from the aquifer to meet these demands. The Edwards Aquifer is also the water source for the two largest springs in the southwest, providing critical habitat for a number of endangered species. In

May 2000, the Edwards Aquifer Authority's board of directors passed Emergency Drought Management Rules for 2000 (EDMR) to help reduce declining rates of springflow during the projected drought for the summer 2000. The EDMR specified reductions in pumping of groundwater based upon index wells in the region. Flow at Comal Springs reached "Jeopardy" levels for endangered species (as defined by the US Fish and Wildlife Service) for 3 days in September until relief was provided by cooler temperatures and moderate rainfall.

Hydrologic data from the 2000 drought along with other historical data on springflow and aquifer levels were used to develop a more technically based Critical Period Management Program (CPMP) with the goal to create an equitable method to allow reductions in pumping in the region. The plan is intended to optimize pumping from the aquifer while still providing sufficient springflow for endangered species habitat and downstream water users. The proposed CPMP is currently under committee review to determine if it will be proposed as a regulatory program to the Authority's board of directors.

AGRICULTURAL LAND USE AND PESTICIDES IN KENTUCKY KARST AQUIFER DRINKING WATER SOURCES

Katie Seadler, Chris Groves, Alan Glennon, Ritchie Taylor, Hoffman Environmental Research Institute, Center for Water Resource Studies, Western Kentucky University, Bowling Green, KY 42101USA

Western Kentucky University is working with the Environmental Protection Agency to investigate methods to improve source water quality for small, rural water systems. One year of monthly sampling from seven demonstration watersheds in Kentucky, including five from karst flow systems, shows that levels of several pesticides and herbicides, particularly atrazine and simazine, can occur in high levels. The highest levels found in raw water are from the Hawkins River, which drains 75 km² of the south-central KY karst and forms one of the major underground rivers of the Mammoth Cave System. Atrazine levels in *treated* water at Marion, KY, exceeded federally mandated Maximum Contaminant Levels (MCLs), in one case by a factor of 7. Data suggest that farmers applied atrazine during fall 2000 in several of the watersheds, which is prohibited by law.

A new, 1-year program is underway to understand how atrazine and simazine are transported through the watersheds and how geology, soils, and hydrology impact transport and storage of these chemicals. This is in cooperation with the state Department of Conservation, which is working with farmers to plan a "no-atrazine application" spring season in 2001. The goal of this research is to develop land use strategies that can improve water quality at these and other water supplies, to improve public health.

RADIOACTIVE AND STABLE ISOTOPES IN DEEP CAVES OF CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

H.J. Turin, Los Alamos National Laboratory, Los Alamos NM 87545 USA
M.A. Plummer, B.T Newton, F.M. Phillips & A.R. Campbell, New Mexico Institute of Mining and Technology, Socorro, NM 87801 USA

Lechuguilla Cave (-478 m) and Carlsbad Cavern (-316 m) are the two deepest known caves in Carlsbad Caverns National Park. While the two caves are nearby and of similar depth, host rock, and origin, they differ markedly in one respect. While Carlsbad has a large natural entrance, Lechuguilla has no known natural entrance, and the artificial entrance is equipped with an airlock to minimize atmospheric exchange. We have analyzed water samples from both caves for radioactive and stable isotopes. In Lechuguilla, we have found elevated Cl-36 levels associated with global nuclear fallout both in near-surface pools and in deeper pools located near mapped lineaments and surface catchments. These results indicate topographic and structural control on fast pathways for vadose-zone flow. Elevated fallout-associated H-3 occurs throughout the cave (including pools with no nuclear-era Cl-36 signal), suggesting a strong component of vapor-phase transport. Stable-isotope measurements in Lechuguilla are relatively homogeneous. There is some evidence for slightly heavier isotopes in deeper, presumably older pools, indicating a historic shift in recharge patterns, perhaps due to climate or land-use changes. Compared to Lechuguilla, the stable isotopes in Carlsbad Cavern vary widely, showing the increased impact of evaporation in that cave.

HYDRAULIC CHARACTERIZATION OF CARBONATE AQUIFERS FOCUSING ON WATER LEVEL DATA

Stephen R.H. Worthington, Worthington Groundwater, 55 Mayfair Avenue, Dundas, Ontario, L9H 3K9 CANADA
Geary M. Schindel, Edwards Aquifer Authority, 1615 N. St Mary's, San Antonio, TX 78861 USA
E. Calvin Alexander, Jr., Dept. of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455 USA

A major problem with understanding flow in carbonates is the lack of test methods to assess karstification. One useful approach is to compare hydraulic properties in a proven karst area to those in an area one wishes to understand. We use the Mammoth Cave area as the type area since there is abundant hydraulic data available and there is consensus that the area is karstified. Six specific testable properties that we use to differentiate karst aquifers from porous media aquifers are tributary flow to springs, turbulent flow in conduits, troughs in the potentiometric surface, downgradient decreases in hydraulic gradient and increases in hydraulic conductivity, and substantial scaling effects in hydraulic conductivity.

There are many carbonate aquifers where the role of the karstification and the presence of conduits has not been well addressed. Examples tested for the 6 above properties include the Edwards Aquifer in Texas, the Floridan aquifer in the Ocala area, the Yucatan aquifer in Mexico, and the dolostone aquifer in the Niagara Falls area. In each case, the data show that aquifer behavior is much more similar to the Mammoth Cave karst aquifer than to a porous medium. This accords with lab experiments and numerical modeling, which indicate that these aquifers should indeed behave as karstic rather than as porous media aquifers.

EVALUATION OF EQUATIONS ESTIMATING MASS OF DYE NEEDED FOR SINK TO SPRING TRACER TESTING IN KARST

Stephen R. H. Worthington, School of Geography and Geology, McMaster University, Hamilton, Ontario, L8S 4K1 CANADA
C.C. Smart, Department of Geography, University of Western Ontario, London, Ontario, N6A 5C2 CANADA

There are at least 17 published equations for estimating the quantity of dye needed for a successful groundwater trace in carbonate rocks. The pertinent variables in these equations are input discharge, spring discharge, distance, velocity, mass of dye injected, peak recovery, and time from injection to peak recovery. Surprisingly, there is a lack of empirical evaluation of these equations in the literature.

Data from more than 150 quantitative tracer tests were used to statistically evaluate the equations. The tests included a wide range of spring discharges (0.002-47 m³/s), distances (30 m – 30 km) and mass of dye used (2 mg – 250 kg). Tests with slow velocities often have poor tracer recoveries, so the few tests with peak velocities <0.005 m/s or recoveries <25% were rejected.

The most useful equation is

$$m = 17\,(LQc)^{0.93}$$

where m is the mass of dye, L is distance, Q is discharge, and c is concentration, using standard SI units. Use of the equation gives a high probability of successful sub-visual detection of dye in water samples, and thus addresses one of the major problems of tracer testing.

HISTORY

CAVES AS CURIOSITIES: THE LOCATION OF CULTURAL VALUES WITHIN AMERICA CAVES IN THE NINETEENTH CENTURY

Joseph C. Douglas, 645 Brookhollow Rd., Nashville, TN 37205 USA

During the 19th century, one way Americans conceived of caves was as natural curiosities, interesting spaces that were expressions of the sublime. Americans located spiritual, religious, romantic, and patriotic cultural values within caves, giving them an importance beyond their utilitarian and commercial worth. By attaching these values to caves, Americans created ambiguous and contradictory interactions with the cave environment, reflecting differing impulses towards the natural world. The tension between commercial and utilitarian exploitation of caves and the cultural values of caves was an important factor in the period's nascent efforts to conserve the cave environment.

NORWAY'S TORGHATTEN: THE CAVE AND THE LEGEND

Cato Holler, Jr., P.0. Box 100, Old Fort, N.C. 28762 USA, hollers@icu2.net

The natural history of Norway, including its caves, is steeped in fascinating tradition and folklore. Off the rugged northwest coast lies the island of Torghet, the Omarket hat. Rising from the center of the island is the granite peak of Torghatten, pierced completely through with a huge paleo-sea cave of

the same name. This historic natural tunnel measures 160 m long, 20 m wide, and over 35 m high. According to local folklore, the peak of Torghatten was pierced through by an arrow shot by the Horse Man, Hestmannen. The arrow was being aimed directly at the woman Lekamoya, but was blocked when King Somnafjellan intervened by throwing down his hat to distract the jealous archer. The woman was spared, the king's pierced hat fell upon the island just as the sun rose, and everything immediately turned to stone!

NUCLEAR FALLOUT SHELTERS IN MAMMOTH CAVE NATIONAL PARK

Colleen O'Connor Olson, Mammoth Cave National Park, PO Box 7, Mammoth Cave, KY 42127 USA

Between 1963 and 1978, Mammoth Cave National Park had four Civil Defense nuclear fallout shelters in the Mammoth Cave System and Great Onyx Cave. Supplies included food, water, a medical kit, sanitary supplies and devices to check radiation.

Though these spelean sites probably would have been as safe as other fallout shelters, usually basements in homes or public buildings, caves in general are not suitable for this use. Most caves are not in highly populated areas, do not have roads leading to them and lack easy access entrances. A well-ventilated cave could let fallout in, while a cave with little ventilation could be unsafe for large groups over long periods of time, and the cool temperature of most American caves would be uncomfortable for inactive people.

After 15 years in the cave, the shelter supplies were removed, not always with care. The water was poured out of the barrels before removing them from the caves, washing away sediment and leaving gullies in the floor in Mammoth Cave's Audubon Avenue. Workers destroyed gypsum flowers in Crystal Cave. Most of the supplies were disposed of, but the carbohydrate supplement candy, 15 years old and "hard as rocks", was given to National Park Service employees to eat.

The Office of Civil Defense has long been closed and fallout shelters are not now common. The Mammoth Cave fallout shelters are no longer a survival strategy, but an interesting chapter that covers extensive history.

SCIENTISTS PREFER THEM BLIND: A HISTORIOGRAPHY OF HYPOGEAN FISH RESEARCH

Aldemaro Romero, Environmental Studies Program, Macalester College, 1600 Grand Ave., St. Paul, MN 55105-1899, USA, romero@macalester.edu

The history of hypogean fish research has been strongly influenced by neo-Lamarckism (including orthogenesis) and typological thinking. Only in the last few decades has neo-Darwinism made any inroads in the research approach to this subject. The majority of the most distinguished and productive hypogean fish researchers have used their research subjects to confirm their own views on evolution rather than to use those subjects as a spring of knowledge to enrich mainstream biological thought. Of these views, the most perversive of all is the notion of evolutionary 'progress' that has led many researchers to envision hypogean fishes as prime examples of 'regressive' evolution. It is proposed that the utilization of hypogean fish for the study of convergent evolution should catapult these subjects of research into prime objects of evolutionary studies.

HISTORY: FLOYD COLLINS SYMPOSIUM

THE PRESENCE OF FLOYD COLLINS IN THE MAMMOTH CAVE AREA TODAY

John Benton, 208 West 19th Street, Huntingburg, IN 47542 USA

It has been over 75 years since the tragedy at Sand Cave that eventually claimed the life of Floyd Collins. Present day and recent times seem to have Floyd Collins embellished in the history and culture of the Mammoth Cave area. Probably the area's most "famous son," Collins' presence is still apparent today. Web sites about Collins on the Internet, a recent reenactment video about the ordeal targeted for sale and for cable TV markets, a Floyd Collins museum, and historical signs about Sand Cave marked by the National Park Service are all visible. The Floyd Collins story is often told to tourists throughout the Mammoth Cave region, and historical exhibits are displayed at the American Cave Conservation Association Museum in Horse Cave, Kentucky. Modern books about Floyd Collins by noted cavers such as Brucker and Halliday have added much insight into the story. A play about Collins has made the national rounds. The town of Cave City even sponsors "Floyd Collins Good Ole Day" annually as a community wide event. Some remnants of the Collins saga are slowly disappearing and need to be documented for future use and study.

THE EARLY FLOYD COLLINS BALLADS

David N. Brison, 8 rue d'Alsace Lorraine, 92100 Boulogne sur Seine, FRANCE

The tragic death of Floyd Collins touched the emotions of many people throughout the country, among them several ballad singers in the South. Shortly after the event, Andrew Jenkins was commissioned to write a ballad about the tragedy. Later he wrote at least one more and probably a third ballad commemorating Collins. Three other ballad writers, George Hunt, Al Eggers, and G.W. Blevens were moved to compose their own tributes.

UNCOVERING THE TRUTH ABOUT FLOYD COLLINS

Roger W. Brucker, 1635 Grange Hall Road, Beavercreek, OH 45432, USA

Between 1925 and 1979 no comprehensive investigation of the Floyd Collins entrapment story had been undertaken. Newspaper accounts, magazine articles, chapters in books, and reminiscences provided sometimes conflicting and fragmentary information about what really happened. Murray and Brucker investigated, resolved the conflicts, and filled in the details while writing the book *Trapped! The Story of Floyd Collins.* An examination of original source material, Sand Cave itself, was the primary key to resolving ambiguities and assessing the relevance of interviews with participants. Original source material remains the key to discovering additional details of the story.

THE ROLE OF MALCOLM BLACK IN THE FLOYD COLLINS SAGA

William R. Halliday, 6530 Cornwall Ct., Nashville, TN 37205 USA

Malcolm H. Black was born less than 8 km from Glasgow, Kentucky. As a boy, he knew many of the participants in the Floyd Collins rescue attempt. In January 1925, while attending high school, he was working nights in the Sports Department of the Louisville Herald-Post. Ultimately he spent 25 years as a journalist, four years in the U.S. Army during which he covered the invasion of Normandy, and 23 years in Kentucky state government, mostly as administrator of a state tuberculosis hospital in Glasgow. At the Herald-Post, he knew and worked briefly alongside Skeets Miller. Because of his local connections, that newspaper sent him to Sand Cave for five days when the story broke. Noted *Chicago Tribune* reporter Tom Killian befriended him and young Black accompanied Killian during the controversial Alma Clark interview and Killian's creation of the hoax about Floyd's dog. Black's reminiscences and his correspondence with Skeets Miller contributed significantly for Halliday's account of the Floyd Collins saga in *Depths of the Earth*.

VERNON DALHART AND "THE DEATH OF FLOYD COLLINS"

Dale Ibberson, 445 Hale Avenue, Harrisburg, PA 17104 USA

Many who have listened to this record probably regard Vernon Dalhart as a nasal hillbilly singer, but this is far from the truth. Born Marion Try Slaughter II in 1893, he received professional voice lessons at a young age and worked as a singer on Broadway before he ever made any records. Fame came quickly after he started recording and many of his records sold a million or more copies. During his career he was credited with over 3000 records on over 150 labels. His fame diminished in the 1930s and he was largely forgotten until he was posthumously elected to the Country Music Hall of Fame in 1991.

THE EDWARD POST FLOYD COLLINS NEWSREELS

Dean H. Snyder, 3213 Fairland Drive, Schnecksville, PA 18078

In January 1964, an article by Clarence Woodbury titled "The Death of Floyd Collins" appeared in the *American Legion Magazine*. Members of the Collins family objected to the article and sued. Louisville attorney Edward Post, who represented the plaintiffs, prepared a 16 mm film containing segments of 1925 newsreels and won a settlement against the magazine.

THE FLOYD COLLINS - SAND CAVE RESCUE POSTCARDS

Dean H.Snyder, 3213 Fairland Drive, Schnecksville, PA 18078 USA

Disasters have been a frequent topic seen on postcards during the first few decades of the 20th century. Despite being one of the most sensationalized news stories between the 2 world wars, and covered by dozens of photographers, relatively few postcards of the Floyd Collins tragedy were published. These cards can be divided into three categories: those published by Wade H. Highbaugh, a series of two cards published by the Auburn Post Card Manufacturing Company, and a small group of miscellaneous cards. All of them are difficult to find today and are highly prized by cave postcard collectors.

PALEONTOLOGY

THE EXTINCT MUSKOX *BOOTHERIUM BOMBIFRONS* FROM CAVES IN WEST VIRGINIA AND VIRGINIA

Frederick Grady, Department of Paleobiology, MRC 121 NHB, Smithsonian Institution, Washington, D.C. 20460 USA
David A. Hubbard, Jr., Virginia Division of Mineral Resources, P.O. Box 3667, Charlotteville, VA 22903 USA

Teeth of the extinct muskox *Bootherium bombifrons* have been found in three West Virginia caves, one Virginia cave, and provisionally identified from two other Virginia caves. A single upper premolar of *Bootherium bombifrons* was found in surficial deposits in New Trout Cave while a partial upper molar was found in Wormhole Cave, both in Pendleton County, WV. Three teeth, an upper molar, lower deciduous fourth premolar, and an upper third molar of *Bootherium bombifrons* was found while singular incomplete teeth provisionally identified to this species were found in Cedar Hill Cave, Rockingham County,VA and Winding Stair Cave, Scott County.

These finds of *Bootherium bombifrons* are the first for caves in both states and represent minor range extensions for the species. Most of the teeth show rodent gnawing and were likely brought into the caves by *Neotoma magister*. All the sites are believed to be late Pleistocene, mostly based on associated faunas except for the Bush Handline tooth.

THE LATE PLEISTOCENE FAUNA OF MELROSE CAVERNS, VIRGINIA

Frederick Grady, Department of Paleobiology, MRC 121 NHB, Smithsonian Institution, Washington, D.C. 20460 USA
David A. Hubbard, Jr., Virginia Division of Mineral Resources, P.O. Box 3667, Charlotteville, VA 22903 USA

A modest excavation in Melrose Caverns, Rockingham County, Virginia, has produced a fauna of >40 species of vertebrates. One species, *Mylohyus fossilis*, is extinct and several others are extirpated from Virginia including *Spermophilus tridecemlineatus, Phenacomys intermedius, Synaptomys borealis, Microtus ochrogaster, Geomys* sp., and *Cryptobranchus alleganiensis. Geomys* sp. and *Cryptobranchus alleganiensis* represent first records for Virginia.

Geomys now lives as separate species to the south and west. The only other fossil locality for *Geomys* in the Central Appalachians is in the lower levels of New Trout Cave, Pendleton County, WV. The lower levels of New Trout are below a C-14 date of >29 ka and also contain *Cryptobranchus*. The Melrose Fauna lacks the large microtine, *Microtus xanthognathus*, a species characteristic of Late Wisconsinan sites in the area. Thus, it seems likely that the Melrose Caverns Fauna dates to the Early Wisconsinan or, possibly, even the Sangamon Interglacial.

PHOTOGRAPHY

CAVE PHOTOGRAPHY AND ART

Ann Bosted, 2301 Sharon Road, Menlo Park, CA 94025 USA

In order to succeed in reaching the non-caver audience through publications, the cave photographer must understand and accept the non-caver perspective. Before creating a cave image, the photographer should decide who his audience will be and what response that audience will have to the image. Four ways to make cave images more artistic are 1) interpret the subject through use of the model(s), lighting and camera angle; 2) visualize an image and then go into a cave and create it; 3) use special effect techniques such as filters, prisms, color gels and "trick" photography; 4) edit the image through cropping, re-shooting and selection.

SURVEY AND CARTOGRAPHY

CURRENT STATUS OF MESHING OF THE WAKULLA SPRING POINT CLOUD

Barbara Anne am Ende, Javier Bernal, Christoph Witzgall, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899 USA, baamende@cam.nist.gov

A point cloud of 10 million wall points (thinned to 3 million) was gathered in 1998-1999 during the Wakulla 2 Expedition. The data was collected in the water-filled cave by a custom-designed sonar Digital Wall Mapper (DWM). Meshing the point cloud into a polygonalized surface remains a challenge. Problems to be overcome include: 1) the point cloud is unstructured data rather than data collected in grids; 2) branching passages are challenging to write algorithms to interpret; 3) real data contains noise that must be ignored; 4) the multiple data sets required registration. The automated portion of the registration was nearly perfect, but the manual registration was not as good giving a "thickness" to the wall positions. The current process of meshing begins by figuratively placing the point cloud in a box. The outside of the cave point cloud is meshed from points on the box, while the inside of the cave is meshed from the original DWM position within the cave. Parameters such as the length of "legal" polygons are used to refine the meshing. Where the data are thin, such as where the mapper's "viewing" of distant walls or the floor was blocked by obstructions, a longer length must be used to create the proper mesh. However, too short an acceptable length results in erroneous polygons forming at branches in the passage. We envisage that the current technique will solve the meshing problem, but requires extensive experimentation to achieve total success.

HANDHELD LASER RANGEFINDER FOR CAVE SURVEY DISTANCE MEASUREMENTS

Roger V. Bartholomew, 910 Laurel St., Rome, NY 13440-2526 USA, RVictor43@aol.com

The Leica Disto Classic handheld laser rangefinder sends out a continuous red laser beam when turned on. This is directed to any surface or diffuse (not mirror) reflection target plate and the measurement key is pressed. A pulsed laser signal is sent out and, if enough laser light is reflected back, the distance reading appears on a LCD display in either meters (to 0.001 m), decimal feet (to 0.01 feet) or feet and inches (to 1/16"). Specifications claim an accuracy of ±3 mm. The Disto Classic mounted on a tripod gave a reading of 98.35 feet as compared with a reading of 98.36 feet from a K&E Whiteface Steel Tape. The steel tape has been heavily used and could be stretched and could be further elongated by the 85° F. temperature during the measurement. Ordinary range is from 0.3 m to over 100 m. The Disto Classic is good enough to do station to station distances with a precisely positioned target plate. It can be used to do up/down/left/right distances at a station or do precise cross sections by pointing at the cave walls with a clinometer at each station. For surface surveying, a long strip of SCOTCHLITE Reflective trim and a target plate ringed with SCOTCHLITE enables one to see the continuous red laser spot for targeting.

CAVE ILLUSTRATOR – AN ADOBE ILLUSTRATOR PLUG-IN FOR CAVE CARTOGRAPHY

Jim Olsen, 6920 Canyon Drive, Park City, UT 84098 USA, jolsen@novonyx.com

While first learning to create digital maps, the author noticed the complexity in transferring survey data to the art program used to draw the map. It involved entering the data into Compass, or some other cave survey program, then exporting a bitmap or DXF file. This file was then scaled and aligned with the current drawing. Every time a new survey trip returned, a new file would need to be exported from the cave survey program, scaled, and aligned. There had to be an easier way! This led to the idea of a project that allows the direct importation of Compass format data into the popular Adobe Illustrator drawing program. This simplifies the creation of maps, since the plot is updated without exportation and subsequent alignment. Further, it has advanced features and capabilities that are only possible from within the art program. The survey data can be viewed as raw data, in a standard Adobe dialog, while simultaneously being highlighted within the artwork itself. Station labels, line color, etc., can also be manipulated and selected. Further, features such as 'undo', 'select', etc., all work seamlessly between Adobe and the plug-in. The overall result of the effort has been a dramatic increase in the ease and speed at which 'up to the minute' maps can be created.

INDEX TO VOLUME 63 OF THE JOURNAL OF CAVE AND KARST STUDIES

IRA D. SASOWSKY AND ELAINE SINKOVICH
Department of Geology, University of Akron, Akron, OH 44325-4101 USA
KEITH D. WHEELAND
2191 Mountain View Ave., State College, PA 16801 USA

This index covers all articles and abstracts published in volume 63 numbers 1, 2, and 3. Selected abstracts from the 2001 Society meeting in Mount Vernon, Kentucky are included.

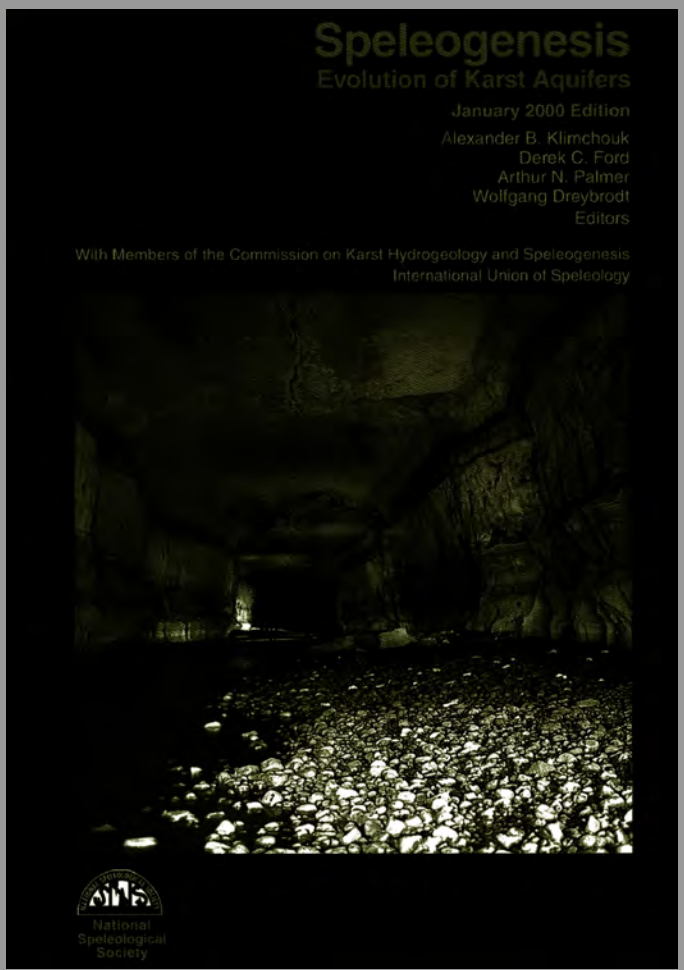
The index has three sections. The first is a **Keyword** index, containing general and specific terms from the title and body of an article. This includes cave names, geographic names, etc. Numerical keywords (such as 1814) are indexed according to alphabetic spelling (Eighteen fourteen). The second section is a **Biologic** names index. These terms are Latin names of organisms discussed in articles. For articles containing extensive lists of organisms indexing was conducted at least to the level of Order. The third section is an alphabetical **Author** index. Articles with multiple authors are indexed for each author, and each author's name was cited as given.

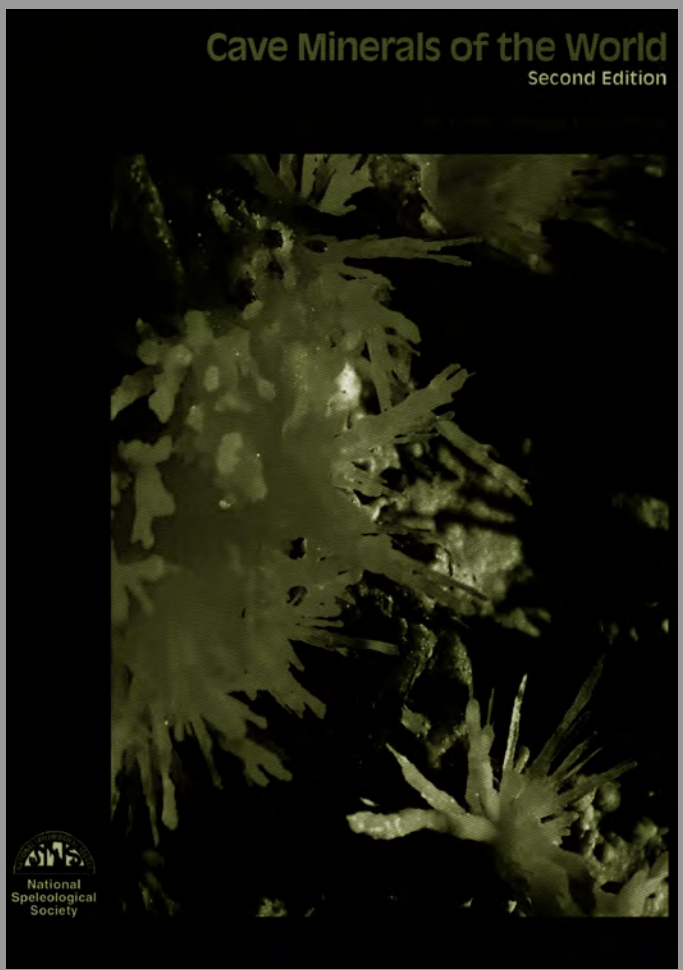
Citations include only the name of the author, followed by the page numbers. Within an index listing, such as "Bats", the earliest article is cited first.

KEYWORD INDEX

BIOLOGIC NAMES INDEX

AUTHOR INDEX





Speleogenesis: Evolution of Karst Aquifers
Klimchouk, Ford, Palmer, Dreybrodt, Editors
496 p. Hardback.....$60

Cave Minerals of the World
Hill and Forti
464 p. Hardback.....$70

Credit cards and Email welcomed. For shipping in U.S., add $5 for one book, $8 for two. International orders-Credit card and Email preferred. Inquire by Email for shipping cost: **manager@caves.org**

National Speleological Society
2813 Cave Avenue
Huntsville, Alabama 35810-4431