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Cover: Cylindrical rim and "stalagmite" with drip tube, Geophyzicheskaja Cave, Turkmenia. See Klimchouk and others, page 31.

Peck, Stewart B., The Cave Fauna Of Alabama. Part II: The Insects: *NSS Bulletin* **57: 1-19.**

THE CAVE FAUNA OF ALABAMA. PART II: THE INSECTS

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Results are presented from a survey of the insects inhabiting about 250 caves in Alabama, at the southern end of the Appalachian Mountains. A rich fauna of over 200 species of insects is now known from aquatic and terrestrial cave habitats in Alabama. Sixty-nine of these species are judged to be cave-limited troglobites, 69 are troglophiles, and 18 are trogloxenes. The troglobitic species consist of 9 collembola, 5 diplurans, 21 carabid beetles, 20 pselaphid beetles, and 13 leiodid beetles.

INTRODUCTION

This is the second part of a summary of the cave-inhabiting faunas of Alabama. The non-insect terrestrial invertebrates were covered in Part I (Peck 1989). That work also presented background information on Alabama physiography, geology, and cave distribution. The third part of this series will unite the data of part I and II into a summary of faunal regions, geographic distributions and barriers to dispersal, and will present an overview on the origin, isolation, and evolution of the terrestrial invertebrate cave faunas.

Over 2000 caves are now known in Alabama. Most of them are in Madison, Morgan and Jackson Counties, in the northeastern corner of the state, in what is called the "Jackson County Mountains" (Fig. 1). Cave location is controlled by geology.

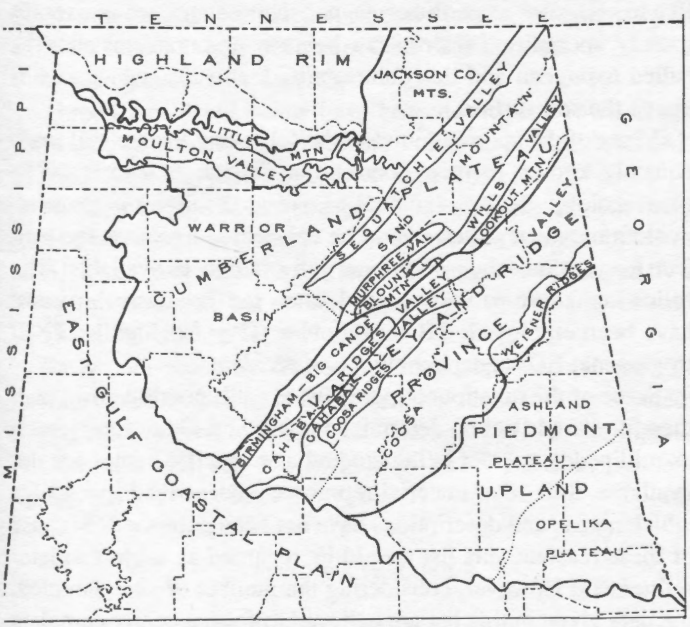

Figure 1. Physiographical divisions of northern Alabama (from Johnson 1930). Most Alabama caves occur here. Very few are developed in Cretaceous or Tertiary rocks on the east Gulf Coastal Plain of southern Alabama.

Figure 2. Counties in Alabama from which cave-inhabiting insects are known. Abbreviations are the first letters for the following counties: Blount, Butler, Calhoun, Clarke, Colbert, Conecuh, De Kalb, Franklin, Jackson, Jefferson, Lauderdale, Lawrence, Limestone, Madison, Marshall, Morgan, Shelby, St. Clair, and Talladega.

Counties in which caves have been studied for invertebrates are shown in Figure 2. Other cave regions are the Highland Rim, Moulton Valley, Sequatchie Valley, and Wills Valley. Data on cave locations and descriptions can be found in Jones and Varnedoe (1968, 1980), Varnedoe (1973, 1975, 1981), and the publications of the Huntsville Grotto. Persons interested in studying Alabama caves should contact the Huntsville Grotto of the NSS or the National Speleological Society, 2813 Cave Avenue, Huntsville, Alabama, 35810.

CAVE FAUNAS

One of the most fascinating aspects of cave faunas is their evolutionary adaptation to life in rigorous subterranean environments. General background information on the evolution and ecology of cave animals can be found in Barr (1968), Barr and Holsinger (1985), Culver (1982), Holsinger (1988), and Howarth (1983).

Regional cave faunal surveys have been made for much of the southeastern United States. Examples are: Florida (Peck 1970), Georgia (Holsinger and Peck, 1971), and Tennessee and Virginia (Holsinger and Culver, 1988). The present report is a contribution to an understanding of the cave-inhabiting insects of Alabama, at the junction of the southern Appalachians and the Gulf Coastal Plain.

The purpose is to give a list of the species of insects found in caves, and to present data on their distribution.

FIELD STUDY

Collecting efforts in Alabama caves have been as extensive and as intensive as possible. In addition to direct visual searching I have used Tullgren funnel extraction of arthropods from organic debris and have extensively used dung and carrion baits.

Since 1963 I have devoted some 50 weeks of full-time field work to Alabama cave faunas. A total of 543 research visits has been made to 213 caves in 14 Alabama counties. Collecting by others brings the total to about 250 caves that have received some biological study. Faunas of the dark zone of the caves received the most emphasis. Entrance and twilight zone faunas are under-represented in this study as are cave litter and soil faunas and parietal (wall-inhabiting) faunas. The latter have been emphasized in studies of cave faunas in other areas (Peck 1988; Peck and Christiansen 1989). A general introduction to the study of cave biology is that by Cooper and Poulson (1968).

ANNOTATED FAUNAL LIST

The following list uses the same conventions as in Part I of this series (Peck 1989). Cave-inhabiting animals can usually be easily placed into one of the four ecological-evolutionary categories often used in cave biology (Barr 1968). (1) *Troglobites* (TB) are obligatory cave species that are morphologically specialized for, and restricted to, cave habitats and are unable to live in non-cave habitats. They always display some degree of troglomorphy (morphological specialization for subterranean life). (2) *Troglophiles* (TP) are facultative cave species, which frequently inhabit caves and complete their entire life cycles there, but many occupy ecologically similar (cool, moist, and dark) habitats outside of caves. They often display some degree of troglomorphy. (3) *Trogloxenes* (TX) are species that often occur in caves but are incapable of completing their entire life cycle in caves. They must at some time leave the cave, usually for feeding purposes. They only rarely display any troglomorphy. (4) *Accidentals* (AC) are species that accidentally wash, wander, or fall into caves and can exist there only temporarily. Although these may serve as food sources for regular cave inhabitants, the accidentals are of no importance in distributional or evolutionary analysis of cave faunas. I have listed most species judged to be accidentals (but excluded obvious herbivores such as leaf hoppers), even though this category could potentially, through time, come to embrace much of the fauna in the area containing the cave. In many cases, it is still too early to judge the relative degree of cave association of many species. I think it better to include the species than to lose the information. By so doing, patterns of cave association that are not yet apparent may emerge through the compilation of additional data (as was found for cantharid beetle larvae, Peck, 1975b), and the category to which the species is assigned may be changed.

The ecological term *endogean* (EN) or *edaphobite* (ED) may also be used for cave animals. There are species that normally live in soil, such as earthworms, and their occurrence in caves is usually sporadic. Subterranean habitats or organisms may be called *hypogean* and this contrasts with *epigean,* which means above the soil surface.

Many of the species found in the following list are still inadequately known in their distribution outside Alabama and in their ecology; their assignment to one of the above ecological-evolutionary categories should be considered tentative and subject to revision when additional information is available. The following abbreviations, placed after the organisms' names, have been employed: TB = troglobite; TP = troglophile; TX = trogloxene; ED = edaphobite; AC = accidental.

Some of the taxa found in this list are still poorly known and, therefore, could not be determined to species. Other forms, such as millipedes, are not being studied and specific names are not available. Still other material represents undescribed species for which names and descriptions have not been published. Because of these reasons, this list should be regarded as subject to later refinement. However, considering the number of sites sampled, the data given in this list are believed to form a nearly complete picture of the invertebrate fauna of the caves of the region.

Because of space limitations, I do not give supporting data for species records presented here, such as date of collection, collector's name or collection containing the specimens. Records not found in the references listed for each species should generally be assumed to be new records made by me or provided by the specialists acknowledged at the end of the paper. Unpublished records made by other collectors are followed by the initials of the collector. These initiated collectors are listed in the acknowledgments.

Published cave names that do not agree with present usage are placed in parentheses following the currently accepted cave names. Sometimes there is more than one cave in a county with the same name. When this occurs, the Alabama cave survey number (e.g., AL 60) is used to indicate the identity of the cave. Some cave names used here are not known to the Alabama cave survey. They are included here as they are stated on the specimen label so that the data and record will not be lost.

Where species names and names of higher taxa do not correspond to those given in some of the older literature, it is because we have used names based on more recent revisional studies. Where more recent studies have shown older literature locality records to be based on inaccurate identifications, I have not listed the erroneous localities.

The higher taxa have been listed in generally accepted phylogenetic sequence. Genera within families and species within genera have been listed in alphabetical order. Localities are listed alphabetically by county within the state and by cave within the county.

Counties are useful geographical units under which caves can be grouped. They may or may not have natural physiographic boundaries that relate to cave faunas. The Alabama counties mentioned in the following faunal listing are shown in Figure 2. Some new records are given for poorly known invertebrates in adjacent states, to help document their distributions.

Notes on some cave localities.

Three caves listed below have been destroyed. Town Creek Cave (AL 40) has been flooded, and Toll Gate Natural Well (AL 61) and Sinks Cave (AL 102) have been filled in.

Nickajack Cave has its sole entrance in Tennessee, but it extends under Jackson County, Alabama, so has been included as an Alabama cave site. The entrance passage is now flooded by a TVA impoundment, but the terminal rooms, in Alabama, should be above the water level.

Early collections by Walter B. Jones were made in the following caves, which can no longer be identified or located; Spring AL 31; Terrill AL 32, Kelly Natural Well AL 49, Ingram AL 70, Clemons AL 73, Wolf Den AL 83, Dickey AL 84, Spring AL 85, Pack Rat AL 89 caves.

SUPERCLASS HEXAPODA

Class Parainsecta
Order Collembola

The springtails of North America have been summarized to species level by Christiansen and Bellinger (1980), and keys to genera are given by Christiansen (1990). Many species live in caves. Cave colembola evolution and distribution are summarized by Christiansen (1961, 1965, 1982, 1985) and Christiansen and Culver (1987). The Alabama cave collembola fauna is probably richer in species that is indicated by the following records.

Family Entomobryidae

Pseudosinella argentea Folsom, TP. Jefferson County: McCluney (Crystal) Cave.

Pseudosinella collina Wray, TP. Blount County: Bryant Cave. Calhoun County: Weaver Cave. Jackson County: Tumbling Rock Cave. Jefferson County: Crystal (McCluney) Cave. This primarily surface species occurs in caves through most the southeastern states (Christiansen 1960a; Christiansen and Bellinger 1980).

Pseudosinella christianseni Salmon, TB. De Kalb County: Mose's Tomb and Talley Cave. Jackson County: Cornellison No. 2, Indian Rock, and Horseshoe caves. Morgan County: Wolf Cave. This species is also known, but only from caves, from Kentucky, Georgia, and Tennessee. It was once called *P. boneti* (Christiansen 1960a) and is a highly troglomorphic derivative of *P. hirsuta* (Salmon 1964; Christiansen and Bellinger 1980).

Pseudosinella folsomi Denise, TP. Blount County: Cedar Grove River Cave. The species ranges from Illinois and Arkansas to Louisiana and Texas and is known from a cave in Missouri (Christiansen 1960a; Christiansen and Bellinger 1980).

Pseudosinella hirsuta (Delamare Deboutteville), TB. Blount County: Bangor Cave, Bryant Cave, Horseshoe-Crump, and Randolph (JEC) caves. Calhoun County: Daugette Cave #1 and Wrights Cave (WBJ). Colbert County: Galleymore, Keeton, and Murrels caves. De Kalb County: Cemetary, Cherokee, Manitou, Section 26, Stanley-Carden, and Talley caves. Jackson County: Crossing, Edgefield, Greising, Horseskull, Kennamer, New Fern, Paint Rock, Pig Pen, Rainbow, Salt River, Sheldons, and Steele Saltpeter caves. Lauderdale County: Bone, Collier and Key (JEC) caves. Limestone County: Spence Cave. Madison County: Alladin, Burwell, and Hurricane caves. Marshall County: Bishop, Cathedral Caverns, Davidson, Guntersville Caverns, Kirkland, Lower Four Lane, McHardin, Merrill, Painted Bluff, and Porches Spring caves. Morgan County: Inge and Talucah caves. Shelby County: Anderson Cave. St. Clair County: McLendon Cave. The species is also known from Tennessee Kentucky, Virginia, and Georgia, but with one exception only from caves (Christiansen 1960a; Christiansen and Bellinger 1980; Delamare and Debouteville 1949). Geographic variation has been studied by Christiansen and Culver (1968).

Pseudosinella nata Christiansen and Bellinger, TB. Jefferson County: McCluney (Crystal Cave) (type locality). Known only from this cave (Christiansen and Bellinger 1980).

Pseudosinella pecki Christiansen and Bellinger, TB. Jackson County: Unspecified cave. Also known only from caves in Georgia (Decatur, Randolph, and Stewart counties) and Jackson County, Florida (Christiansen and Bellinger 1980).

Pseudosinella rolfsi Mills, TP. Blount County: Bryant Cave.

Pseudosinella spinosa (Delamare Debouteville), TB. Jackson County: Bucks Pocket, Engle Double Pit, Hambrick, Jesse Elliott, McFarland, Paint Rock, Rising, Scott, Sheldons, and Tumbling Rock caves. Madison County: Aladdin Cave (type locality!), Green Grotto, Chapman Cave Spring (A60), and Jacks caves. Marshall County: Guffey Cave. Morgan County: Wolf Cave in Newsome Sinks. Shelby County: Anderson Cave. The species is limited to caves and occurs in central Tennessee and northeastern Alabama and adjacent Georgia (Christiansen 1960a, Christiansen and Bellinger 1980).

Pseudosinella violenta (Folsom), TP. Blount County: Cedar Grove, River Cave.

Sinella barri Christiansen, TP. De Kalb County: Cook Cave. The species is distributed from Arkansas, through Kentucky, to Virginia, and south to Alabama. There are some records from non-cave habitats (Christiansen 1960a).

Sinella (Coecobrya) caeca (Schott), TP. Calhoun County: Weaver Cave. The species is widely distributed across the United States and is frequently found in caves (Christiansen and Bellinger 1980).

Tomocerus (Pogonognathellus) bidentatus Folsom, TP. Blount County: Bryant and Randolph caves. Colbert County: unspecified cave. De Kalb County: Cook Cave. Jackson County: Merrill Cave. Madison County: Barclay, Bishop, and Cold Spring caves. Marshall County: Guntersville Caverns and Porches Spring Cave. The species is widespread and is known from caves in California and seven eastern states (Christiansen 1964, Christiansen and Bellinger 1980).

Tomocerus (Pogonognathellus) dubius Christiansen, TP. De Kalb County: Cook and Kelly Girls caves. Jackson County: Paint Rock Cave. Madison County: Hurricane Cave. This species is spread over much of the United States, is common in epigean sites in Alabama, and is also known from caves in Kentucky and Tennessee (Christiansen 1964, Christiansen and Bellinger 1980).

Tomocerus (Pogonognathellus) flavescens (Tullberg), TP. Blount County: Bryant Cave. Jackson County: Horseshoe Cave. Marshall County: Cathedral Caverns. The species occurs commonly across the continent, and is known from caves in ten states (Christiansen 1964, Christiansen and Bellinger 1980).

Tomocerus (Tomocerina) lamelliferus (Mills), TP. Jackson County: Paint Rock Cave. Madison County: Burwell Cave. The species ranges from Oregon and Ontario southward to North Carolina and Alabama. It is occasionally found in caves (Christiansen 1964; Christiansen and Bellinger 1980).

Family Hypogastruridae

Hypogastrura (Ceratophysella) denticulata group, TP. Jackson County: Doug Green and Limrock Blowing caves.

Hypogastrura essa Christiansen and Bellinger, AC. Madison County: Cave Spring Cave (A 60).

Hypogastrura sparta Christiansen and Bellinger, AC. Madison County: Cave Spring Cave (A 60).

Schaefferia (Typhlogastrura) alabamensis Thibaud, TB. Blount County: Bryant Cave (type locality). Jackson County: Swain Cave. Known only from specimens from the stomachs of *Eurycea lucifuga* salamanders caught in these caves (Peck and Richardson 1976; Thibaud 1975).

Schaefferia (Typhlogastrura) christianseni Thibaud, TB. Morgan County: Cave Spring Cave (type locality). Known only from this cave (Christiansen and Bellinger 1980, Thibaud 1975).

Family Isotomidae

Folsomia candida Willem, TP. Colbert County: McKinney Cave.

Folsomia penicula Bagnall, AC. Madison County: Aladdin and Simmons Caves.

Folsomia sp., TP. Blount County: Bryant Cave. Jackson County: Sheldons Cave (Christiansen 1960c).

Family Onychiuridae

Onychiurus sp., TP. Madison County: Hurricane Cave (Christiansen 1960c).

Onychiurus (Onychiurus) paro Christiansen and Bellinger, TB. Marshall County: Dunham Cave (type locality). Known only from this cave (Christiansen and Bellinger 1980).

Onychiurus (Onychiurus) janus Christiansen and Bellinger, TB. Calhoun County: Weaver Cave (type locality). Known only from this cave and a cave in Greenbrier County, West Virginia (Christiansen and Bellinger 1980).

Family Sminthuridae

Arrhopalites pygmaeus (Wankel), TP. Blount County: Bangor Cave. Jackson County: Crossing Cave. Madison County: Barclay, Burwell, Cold Spring, and Sinks caves. Marshall County: Cathedral Caverns. Widely distributed in epigean sites from Alaska to Connecticut and south to Louisiana and Florida and in caves in nine southeastern states (Christiansen 1960c, 1966, Christiansen and Bellinger 1980).

Arrhopalites whitesidei Jacot, TP. Talladega County: DeSoto Caverns (Kymulga Cave). The species is reported from epigean sites from California to New York, and in caves from Wisconsin, Missouri, Iowa, and Indiana (Christiansen 1966; Christiansen and Bellinger 1980).

CLASS INSECTA

Order Diplura

Diplurans are frequent inhabitants of soil and cave habitats. The United States cave fauna has been reviewed by Ferguson (1981), and the US fauna in general by Ferguson (1990a).

Family Campodeidae

Litocampa cookei (Packard) TB. Jackson County: Nickajack Cave. The species ranges through Tennessee (Cave 5 km (3.5 mi) SSW Bradyville, Cannon County: Burke Cave, Coffee County) into caves in Warren, Greene, Hardin, and Edmonson Counties, Kentucky.

Litocampa (Tychocampa) henroti (Condé) TB. Madison County: Green Grotto, Matthews, and Shelta (type locality) caves. The species seems restricted to caves in western outliers of the Cumberland Plateau in Madison County, Alabama (Condé 1949).

Litocampa (Cocytocampa) valentinei (Condé) TB. De Kalb County: Stanley-Carden Cave. Jackson County: Bouldin (RCG), Crossing, Crow Creek (RCG), Edgefield, Fern (RCG), Indian Rock (RCG & WT), Larkin, Limrock Blowing (RCG), Pigpen, Roadside, Russell, Sheldons, Valhalla (WT), and Gary Self Pit (Rousseau entrance) caves. Madison County: Aladdin, Grayson Spring (RCG), Hering (Cave Spring) (type locality), and Styles Spring caves. Marshall County: Cathedral Caverns, Kellers, Kristys (WT), Ledbetter (RCG) and Roaring River (RCG) caves. The species also occurs in caves in Franklin and Grundy counties, Tennessee. It is distributed in caves of the southern Cumberland Plateau.

Litocampa n. sp. C, TB. Colbert County: McKinney Pit. De Kalb County: Cherokee Cave. Jefferson County: Cedar Pole Cave. The species is also known from caves in Dade and Walker counties, Georgia.

Plusiocampa n. sp. D, TB. Blount County: Bryant and Catfish caves. De Kalb County: Goat House Cave (T. Iles). Jackson County: Salt River Cave. The species is also known from Dade and Walker counties, Georgia, and Bedford and Warren counties, Tennessee.

Plusiocampa spp. TB. Calhoun County: Millers Cave (WBJ), Wrights Cave (LGC). De Kalb County: Kelly Girls Cave (WBJ). Jackson County: Bell, Driftwood, Guess Creek, McFarland, Paint Rock, Tate, and Wynne Caves. These represent observed populations which were not collected, which most probably are *P. valentinei* Condé.

Family Japygidae

"Japyx" sp., TP-ED. Jefferson County: McCluney (Crystal Caverns) Cave (TCB). Japygids are soil inhabitants that are occasionally found in caves (Reddell 1983).

ORDER ARCHEOGNATHA

Family Machilidae

Machilus sp., AC. Franklin County: Ezell Cave (F. Shires). These jumping silverfish are sometimes found inside of cave entrances.

Order Thysanura

Family Nicoletiidae

Nicoletia sp., TP-ED. De Kalb County: Cemetary Cave. Jackson County: Talley Ditch Cave. Madison County: Shelta Cave. This is an eyeless and unpigmented soil-inhabiting silverfish. Keys for the identification of silverfish are in Ferguson (1990b).

Order Orthoptera

Family Rhaphidophoridae; the cave-crickets

Cave crickets may be the most conspicuous and common animals in most caves. The fauna in Alabama is quite rich, with 11 species known from Alabama caves. Positive identification can only be made with adult male specimens. A question mark indicates that only immatures (nymphs) or females were collected.

Ceuthophilus gracilipes (Haldeman), TX. Figure 3. Blount County: ?Catfish, ?Cedar Grove River, ?Horseshoe-Crump, ?Ingram (WBJ), and ?Pass caves (WBJ, OP, JMV). Butler County: Hinson (WBJ), and Rock caves (WBJ). Calhoun County: Daugette, Erby, Weaver (Lady) (WBJ), ?Wilson, and Wrights caves. Clarke County: Broadenax (WBJ), ?Elam Church (WBJ), and McVay caves (WBJ). Colbert County: ?Dickey (WBJ), ?Galleymore (WBJ), ?Gist (WBJ), McCluskey, McKinney Pit, ?Spring (WBJ), and ?Wolf Den caves (WBJ). Conecuh County: Sanders (=Turks) Cave (WBJ, L.G. Sanford). De Kalb County: ?Cherokee, ?Manitou (=Fort Payne) (WBJ), and ?Section 26 caves. Jackson County: Horseskull, and Schiffman caves. Jefferson County: McCluney (=Alabama or Crystal) Caverns and Pinson (=Hickman) Cave (OP, WBJ, JMV). Lauderdale County: ?Gravelly Springs Cave (WBJ). Lawrence County: ?Bradford (WBJ), ?Cave Spring (WBJ, IR), ?Check (WBJ, IR), ?Indian

Figure 3. The cave cricket *Centhophilus gracilipes*. This is the most conspicuous insect in Alabama caves. It may occur in large numbers in the daytime just inside of cave entrances. These crickets leave their caves at night to feed in forests.

(WBJ), ?Ivey Hollow (WBJ), ?Thomas (WBJ, IR), Thrasher, (WBJ, IR), Whitlow (WBJ, IR), and ?Unnamed caves in Black Warrior National Forest (WBJ). Madison County: Barclay, Ellis, ?Lott (WBJ), Matthews, Shelta, and Spook caves. Marshall County: ?Dunham, ?Jackson (WBJ), ?Painted Bluff, and Terrill caves. Morgan County: ?Barrell (WBJ, IR), ?Bat (WBJ), Cave Spring (WBJ), Echols (WBJ, IR), ?Hughes (WBJ), ?Inge (WBJ, IR), Lipscomb (WBJ), ?Lost Mule (WBJ, IR), ?Painted Room (WBJ, IR), ?Roper (WBJ, IR French), ?Royer, Sans Souci (WBJ, W.H. Baker), Trinity (WBJ), Whitlow Hole (WBJ, IR), and ?Winchester caves (WBJ, IR). Shelby County: Lous Crawl Cave. St. Clair County: ?McLendon Cave (WBJ). Talladega County: ?DeSoto (Kymulga) Cave (WBJ). Wilcox County: ?Mt. Moriah Cave (WBJ). This camel-cricket species occurs in forests and other epigean habitats and ranges from the New England states southward along the Appalachians, through most of Alabama, to the Florida panhandle and then northwestward to the Ozarks. The range does not overlap with that of the very close species *C. stygius* except perhaps in Madison and Jackson counties, Alabama. *C. gracilipes* occurs in caves and frequently in forest habitats in Arkansas, Florida, Georgia, Illinois, Missouri, New York, North Carolina, Ohio, Oklahoma, Tennessee, Virginia and West Virginia (Hubbell 1936 and Hubbell unpubl.).

Ceuthophilus stygius (Scudder), TX. Jackson County: ?Clemens, (WBJ), House of Happiness, ?McFarlen (WBJ), ? McFarlen Spring (WBJ), Gross-Skeleton (=Mink, Out), ?Pack Rat (=Mink, Out) (WBJ), Williams Saltpeter and Unnamed caves (1 mi E Scottsboro, W.H. Baker). Madison County: Cave Spring Cave #60, Jacks, Morring Spring, ?Natural Well (WBJ), and ?Scott caves (WBJ). The species is not frequently found outside of caves. It is distributed in the Interior Low Plateaus from southern Ohio and Indiana southward to Madison and Jackson counties, Alabama, where it comes in close geographic contact with *C. gracilipes. C. stygius* occurs in caves in Indiana, Kentucky, and Tennessee. The following localities in Jackson County are known to have either *C. gracilipes or C. stygius* but mature males have not been collected from the sites to make definite determinations in this area of geographic contiguity of the two species: Santa (=Blowing), Boxes Cove, Doug Green, Tony, and Swaim caves.

Ceuthophilus ensifer ensifer Packard, TX. Nickajack Cave, Marion County, Tennessee is the type locality for this subspecies. It has been found in Alabama in Jackson County, 7 mi N Flat Rock, but is not yet known from Alabama caves. It is known from caves to the east in Dade County, Georgia.

Ceuthophilus ensifer n. ssp. *ap* Hubbell MS, TX. Jackson County: Buds, Clemens (WBJ), ?Coon Creek (WBJ), Crossing, ?Devils Stair Step (WBJ), Doug Green, Gary Self Pit (Rousseau entrance), ?Gross Skeleton (=Mink, Out), ?Hambrick (WBJ), House of Happiness, Isbell Spring, Kennamer, McFarland, McFarland Blowing, McFarland Spring (WBJ), Nat, Sauta (=Saltpeter Cave #50), Schiffman, Sheldons, Slippery Pole, Small, Swaim, Tony, ?Tony Sinks, and Unnamed caves, 1 mi E Scottsboro (W.H. Baker). Madison County: Aladdin, (WBJ), Herin (Cave Spring), Cold Spring, Grayson Spring, Candlestand (=Goat) (WBJ, OP), Hurricane, Hutton (WBJ), Moon (WBJ), St. Clair (AFA), and Scott caves. The species is distributed from Smith and Overton counties, Tennessee to Madison County, Alabama and Dade County, Georgia. It is found in the outer parts of caves as well as forested talus slopes and rocky ravines. These above two subspecies represent two of the four species. Note: The Cold Spring Cave locality overlaps with the range of *C. dioxyurus* n.sp. and det. should be checked.

Ceuthophilus n. sp. *ph* MS Hubbell, TX. Marshall County: ?Dunham, Guffey (WBJ), Honeycomb (WBJ), Jackson (WBJ), Kellers, ?Kirkland, ?MacHardin (WBJ), Merrill, Town Creek (Cave Ms 2, WBJ), King School (=Cave Ms-2a of Hubbell, WBJ), Bluff (Cave Ms-3, WBJ), Honeycomb School (Cave Ms-4, WBJ), Bishop (Cave Ms-5, WBJ), Hambrick (Cave Ms-6, WBJ), Painted Bluff, and ?Walnut caves. The species is closely related to *ensifer* and n. sp. *(dioxyurus)*, and it has a range limited to Marshall County, on both sides of the Tennessee River. The ranges of these three species do not overlap.

Ceuthophilus n. sp. *di* MS Hubbell, TX. Colbert County: Wolf Den Cave (WBJ). Lauderdale County: Basket (WBJ), ?Coffee (WBJ), ?Collier (WBJ), and Key caves. Limestone County: Rockhouse Cave. Madison County: Barclay, Burwell, Byrd Spring, Cave Spring #60, ?Clark Bluff, Cold Spring, Ellis, ?Kelly Natural Well (WBJ), ?Lott Spring (WBJ), Morring, Sadler Spring (WBJ), ?Sinks (WBJ), Spook, and Toll Gate Natural Well (WBJ) caves.

Ceuthophilus n.sp. *di* n. ssp. *sp* MS Hubbell, TX. Blount County: Bangor, ?Bryant, Catfish, Cedar Grove River, Dixon, Frenchs (=Saltpeter) (WBJ, OP), Pass (WBJ, OP, JMV), Posey Spring, (WBJ, OP, JMV), and Randolph caves. Colbert County: Georgetown (WBJ), McKinney (WBJ), and McKinney #2 caves. Marshall County: Davidson, Eudy (WBJ), Griffith (WBJ), ?Guffey (WBJ), Halbrook (T.H. and S.P. Hubbell), Light (WBJ) (=Eudy Cave, AL107), Lime Point (WBJ), Rockhouse (WBJ), ?Saltpeter #37 (WBJ), ?Spring (WBJ), and Warrenton caves (WBJ). Morgan County: Bartee, Blowing #48 (WBJ), Cave Spring (WBJ), ?Houston (WBJ, IR), Hughes, Intreken, ?Lipscomb (WBJ), Skidmore, Talucah (WBJ), and Vandiver Cave #824. The species is known mostly from caves. It has a fairly linear range along and near the Tennessee River from Marshall County westwards to Colbert County. It is divisible into two subspecies, one mostly north of the river in Madison, Lauderdale and (far western) Colbert counties, and the other south of the river in central Colbert, Morgan, Marshall, and Blount counties.

Ceuthophilus latens Scudder, TX. Comments. This species is known from caves in Alabama only in Saltpeter (Guntersville Cavern) Cave, Marshall County (WBJ). It is known from epigean sites in northern Alabama, and in caves in Illinois, Kentucky, and Tennessee.

Euhadenoecus puteanus (Scudder), TX. De Kalb County: Bartlett, Cherokee, Manitou (=Fort Payne), and Section 26 caves. Jackson County: Coon Creek Saltpeter Cave. The species is distributed from southern New York southwestward along the Appalachians to northeastern Alabama. It occurs in wet to mesic forests, especially where it is rocky, and often in cave entrances, but rarely deep inside caves. It is also known from caves in Georgia, Kentucky, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia (Hubbell and Norton 1978).

Euhadenoecus insolitus Hubbell, TX. De Kalb County: Bartlett and Cathcart caves (the location of this cave is not known to the ALA survey). Marshall County: King School (Cave Ms-2a of Hubbell, WBJ), Jackson (= Fort Deposit) (now submerged), Terrill, and Town Creek caves. Jefferson County: Cedar Pole and McCluney (=Alabama or Crystal) Caverns (type locality). St. Clair County: McLendon Cave. The species also occurs in caves in central Tennessee and perhaps in Barren County, Kentucky. The range is remarkably discontinuous (Hubbell and Norton 1978), and some populations are parthenogenetic.

Hadenoecus jonesi Hubbell, TX. Figure 4. Jackson County: Bouldin, Boxes, Tony Sinks (=Cox), Devils Stair Steps, Doug Green, Engle Double, Fern, Gary Self (Rousseau and Cave Stand entrances), Gross-Skeleton (=Mink, Out), Hambrick, Horseshoe, Keel, Kennamer, Limrock Blowing (type locality), McFarland, McFarland Blowing, McFarland Spring, Montague, Orgy Cave System (an entrance to Kennamer Cave (L. McLennon), Paint Rock, Pig Pen, Ridley, Saltpeter, AL74, Saltriver, Schiffman Cove, Tally Ditch, and Williams Saltpeter caves. Madison County: Aladdin, Cave Spring (Hering), Cold Spring, Grayson Spring, Hutton, Scott Cave, and Walnut Bottom caves. Marshall County: Bishop (Cave Ms-5), Cathedral Caverns (= Bat Cave), Dunham, Gross Skeleton, Guffey, Hambrick (Cave Ms-6), Honeycomb, Kellers, Kirkland, MacHardin, and Merrill caves.

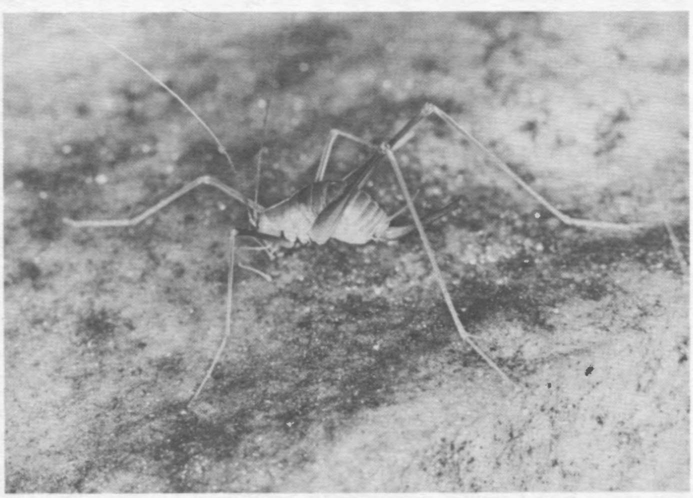

Figure 4. The cave cricket *Hadenoecus jonesi*. This is the second most conspicuous cave insect in Alabama.

The species is known from the above records and two sites in Franklin and Lincoln Counties, Tennessee. This is a distribution encompassing the caves at the edge of the Cumberland Plateau, north of the Tennessee River, which seems to represent a barrier. To the northeast is a distribution gap before encountering *H. barri* Hubbell (in Hubbell and Norton 1978) (in the same species group) in caves at the edge of the Cumberland escarpment in Grundy and Warren Counties. Collecting between known sites in Grundy and Franklin Counties would be interesting to see how closely the species come to each other (Hubbell and Norton 1978).

Tachycines asynamorus Adelung, AC. Lawrence County: Indian Cave (WBJ, 1961). Madison County: Barclay Cave (at cave mouth, T.H. & S.P. Hubbell). This introduced Asiatic species has rapidly spread in the United States in both natural and manmade environments. It may replace native cave crickets. The occurrence, as known in 1944 is recorded by Rehn (1944). The only other cave record I know of for this species is Cave-in-Rock, Illinois.

Order Dermaptera
Family Carcinophoridae

Euborellia annulipes (Lucas), AC, TP?. Marshall County: Hambrick Cave (in bat guano). This is a predator on other insects.

Order Hemiptera
Family Dipsocorida

Dipsocorus sp., AC. Jackson County: Indian Rocks Cave (2 adults, 1 immature; which suggests that these reproduce in the cave); they are normally soil inhabitants.

Order Psocoptera
Family Psocidae

Episocus (Berthauia) orosbyanus Chapman, AC. Lauderdale County: Basket Cave. This species is widespread in the eastern U.S. in forest litter. This record was taken from the stomach of the salamander *Eurycea lucifuga*. The salamander may have captured the insect outside the cave (Peck and Richardson 1976).

Liposcelis sp. AC?. Jackson County: Tumbling Rock Cave (on dry human feces, one female).

Psyllipsocus ramburii Selys-Longchamps, TP. Blount County: Catfish and Horseshoe caves. Calhoun County: Weaver Cave. Colbert County: McKinney and Murrells caves. De Kalb County: Lois Killian and Sequoyah caves. Limestone County: Indian and Rockhouse (WBJ) caves. Jackson County: Cornellison no. 2, Sauta, Larkin, and Tumbling Rock (on dry human feces) caves. Madison County: Byrd Spring Cave. Marshall

County: Cave Mountain (*Neotoma* nest), Dunham, Terrill, and Quarry caves. St. Clair County: McLendon Cave. This species is also known from Europe, and is often in human habitations. In North America it ranges from Mexico to Michigan. It is recorded from caves in Texas and Tennessee (Barr 1961), Gurney (1943), Mockford (1950), Reddell (1965)). The species prefers dry habitats in caves and feeds on organic materials. The populations are usually all female and parthenogenetic, and adults may or may not have fully developed wings.

Order Coleoptera
Family Carabidae

Alabama lies at the southern end of the rich carabid beetle fauna of the Appalachians. This beetle fauna, especially the cave carabids, has been well summarized by Barr (1969, 1981a, 1985).

Agonum (Circinalia) punctiforme (Say), AC. Jackson County: Upper Rainbow (=Happy Hollow) Cave. Madison County: Barclay and Ellis caves. The species is widespread from California to Massachusetts to Florida.

Amara (Celia) cf. *muscula* Say, AC. Madison County: Barclay Cave.

Anillinus spp., TP-ED. Blount County: Horseshoe Cave (HRS & TCB). Colbert County: Gist Cave. De Kalb County: Cemetary and Cherokee caves. Jackson County: Gary Self, Cornelison, Crossing (HRS), Paint Rock, Reece, and Tupelo caves. Marshall County: Cathedral Caverns, Cave Mountain, Creek Cave near Grant (TCB) (not in AL survey), and Guffey (TCB) caves. Madison County: Aladdin (TCB, HRS) and Herin caves. St. Clair County: McLendon Cave. These are small, pale, eyeless beetles that live in soil. These collections represent several undescribed species. Several are undoubtedly troglophiles since they also occur outside the caves. *A. longiceps* Jeannel, TB, is known from Crystal Cave, Marion County, Tennessee (Jeannel 1963, Loding 1945).

Anisotarsus terminatus (?), AC. Madison County: Barclay Cave.

Atranus pubescens (Dejean), TP. Calhoun County: Weaver Cave. De Kalb County: Talley Cave. Jackson County: Dripping Spring, Gross-Skeleton, and Indian Rock caves. Madison County: Ellis, Hawkins, and Shelta caves. This species occurs throughout caves in the eastern United States, the Ozarks, and Texas. It is distributed across Alabama (Barr 1964, Loding 1945, Reddell 1966).

Bembidion affine Say, AC. Madison County: Barclay Cave.

Bembidion (Notaphus) nigripes Kirby, AC. Madison County: Ellis Cave.

Bembidion lacunarium Zimmerman, AC. Madison County: Barclay Cave.

Brachinus sp., AC. Madison County: Ellis Cave.

Dischirius sp., AC. Madison County: Sinks Cave.

Evarthrus sp., AC. Madison County: Ellis Cave.

Galerita sp., AC. Marshall County: Keller Cave.

Harpalus sp., AC. Jackson County: Upper Rainbow (=Happy Hollow) Cave.

Harpalus (Pseudophonus) pennsylvanicus DeGeer, AC. Madison County: Barclay Cave.

Harpalus (Pseudophonus) erythropus Dejean (?), AC. Madison County: Ellis Cave.

Loxandrus sp., AC. Madison County: Barclay Cave.

Patrobus longicornis, AC. Jackson County: Rousseau entrance of Gary Self Cave.

Progaleritina lecontei, AC. Madison County: Cave Spring, and Cold Spring caves.

Lebia ornata Say, AC. Madison County: Barclay Cave. A single specimen, recorded as possibly hibernating (Barr 1964).

Platynus tenuicollis LeConte, TP. Blount County: Bangor Cave. Calhoun County: Weaver Cave. Jackson County: Boxes and Russell caves. Madison County: Cold Spring Cave and Green Grotto. Marshall County: Honeycomb and Keller caves. This species, also listed as *Agonum reflexum*, occurs commonly in caves in the eastern United States (Barr 1964, Lindroth 1966: 641). It can be found along wooded creeks throughout eastern North America and all populations are fully winged.

Pseudanophthalmus, the cave carabid beetles. This genus of beetles contains more eyeless cave-inhabiting species than any other in the United States. Additionally, there are more species in this genus than in any other beetle genus in the USA. Only a few species live outside of caves in the mountains of Kentucky or West Virginia. There are many species groups and each group represents the descendents from a single ancestral species. These beetles are still under study by Dr. T.C. Barr, Jr.

The alabamae *species group*

Pseudanophthalmus alabamae Valentine, TB. De Kalb County: Bartlett, Cherokee, Kelly Girls, Lykes, Manitou (type locality), Section 26, Stanley-Carden, and Talley caves. Limited to caves on the east side of Little Wills Valley (Barr 1965, 1981b; Jeannel 1949; Valentine 1932). The group otherwise contains only *P. georgiae* from Chatooga and Walker counties, Georgia.

The cumberlandus *species group*

Pseudanophthalmus n. sp. C, TB. Limestone County: Gaston, Indian and Pope caves. The group also occurs to the north in Tennessee.

The englehardti *species group*

This group contains species in caves in the Appalachian Valley from Lee County, Virginia to northwest Georgia and the lower Tennessee River Valley in Alabama.

Pseudanophthalmus alladini Valentine, TB. Jackson County: Bucky, Cagle, Cave Stand, Doodlebug, Dripping Springs, Engle Double Pit, Gary Self, Horseshoe, Keepout (?), McFarland, Moon Spring, Roadside, Rover, and Stiles Spring Caves. Madison County: Alladin, and Scott caves.

Pseudanophthalmus distinguens Valentine, TB. Morgan County: Anvil, Horseback, Inge (type locality), and Roper caves. This species has previously been considered a subspecies of *P. loedingi* (Jeannel 1949, Valentine 1948).

Pseudanophthalmus fluviatilis Valentine, TB. Marshall County: Rock House cave (type locality). Morgan County: Hughes, Laughlin Spring, Lamons, Mill Bluff, Shine, Talucah, Turtle, and Wolf caves (JEC) (Jeannel 1949, Valentine 1948).

Pseudanophthalmus humeralis Valentine, TB. Tennessee. Franklin County: Caroline Cove and Dry caves. Grundy County: Crystal, and Wonder caves. This species could occur to the south in Jackson County, Alabama.

Pseudanophthalmus loedingi Valentine, TB. Madison County: Barclay, Canoe, Ellis, Glover Sink (?), Goat (?), Hoopers Well, Huntsville Spring, Jacks, Kelly Natural Well, Matthews, Shelta, Spook and Sinks caves.

Pseudanophthalmus meridionalis Valentine, TB. Marshall County: Beech Spring, Bishop, Davidson, Guntersville (Saltpeter, Nyman) Caverns, Hampton (?), Old Blowing and Warrenton caves. This species has previously been considered a subspecies of *P. loedingi.*

Pseudanophthalmus profundus Valentine, TB. (= *P. aquaticus* Val.) Jackson County: Crossings (= Stewart), Gary Self (Cave Stand and Rousseau entrances) (?), Nat, and Paint Rock, caves. Madison County: Cave Spring (Herrin), Chapman Mt. Cave Spring (A60) (?), Graham Spring, Grayson Spring, Natural Well (?), Water (caves on Monte Sano where drainage is *east* to Flint River).

Pseudanophthalmus steevesi Barr, TB. Blount County: Bryant, Horse, Randolph (type locality), and Rickwood Caverns caves (Barr 1981).

Pseudanophthalmus n. sp. E, TB. Lauderdale County: Collier Cave.

Pseudanophthalmus n. sp. D, TB. Colbert County: Cobbs Bear Pit, McKinney Pit, McKinney #2.

Pseudanophthalmus n. sp. K, TB. Lawrence County: Tingling Hole.

Pseudanophthalmus n. sp. G. TB. Morgan County: Cave Spring Cave.

Pseudanophthalmus n. sp. H. TB. Jackson County: Jess Elliott Cave.

Pseudanophthalmus n. sp. J. TB. Marshall County: Cathedral, Guffey, Keller (?), Kelly Ridge, Lim Rock Blowing ?, McAllister (A 275), Saltpeter (near Grant), and Walnut caves. Jackson County: Beanfield Hall, Henshaw Spring, House of Happiness, Larkin, Little Sink (A 657), Pig Pen, and Roadside caves.

Pseudanophthalmus n. sp. L, TB. Jackson County: Driftwood Cave.

The fulleri *species group*

Pseudanophthalmus nickajackensis Barr, TB. Jackson County: Nickajack Cave (type locality). Known only from this cave, whose now-flooded entrance is in Marion County, Tennessee (Barr 1981b).

Pseudanophthalmus fulleri Valentine, TB. This species is recorded from caves in Hamilton County, Tennessee and Dade County, Georgia. The species may occur in adjacent De Kalb County, Alabama (Barr 1965, 1981b; Jeannel 1949; Valentine 1932, 1948).

The hirsutus *species group*

Pseudanophthalmus assimilis Barr, TB. De Kalb County: Ellis (Sequoyah) (type locality) and Kudzu caves (Barr 1981b). This is the only Alabama member of the species group, which occurs from southwest Virginia through Tennessee to northwest Georgia and adjacent Alabama.

The intermedius *species group*

Pseudanophthalmus n. sp. A, TB. Jackson County: Bell Spring (?), Cagle, Guess Creek, Indian Rocks, Kyles Spring (?) (Barr and Peck 1965), Limrock Blowing and Loki's (Crow Creek area) caves. The species also occurs in adjacent Tennessee.

Pseudanophthalmus n. sp. B. TB. Jackson County: Horseskull (?), McFarland (?), Russell (Montague Entrance), Salt River, Talley Ditch, Tate, Tumbling Rock Upper Rainbow (= Happy Hollow) caves.

Pterostichus (Euferonia) relictus Newman, AC. Blount County: Banger Cave.

Pterostichus (Lagarus) lecontianus Lutshnik, AC. Madison County: Ellis Cave. This is the first Alabama record for this species.

Rhadine caudata LeConte, TP. Blount County: Catfish Cave. Colbert County: McKinney Cave. De Kalb County: Talley Cave. Jackson County: Isbell Spring Cave. Jefferson County: McCluney (=Crystal) Cave. Limestone County: Rockhouse Cave. Marshall County: Dunham, Eudy, Merrill, and Painted Bluff caves. Alabama cave localities are mentioned for this species by Barr (1964) but are not named. The species is distributed from Arkansas to Wisconsin to Pennsylvania to Georgia and is frequently found in caves.

Rhadine larvalis LeConte, TP. Conecuh County: Sanders (Turks) Cave (type locality)! (Barr 1964) (described as *Rhadine jonesi* Barr). The species is otherwise known in Arkansas, Missouri, Mississippi, and Florida (Choate and Rogers 1976).

Stenolophus sp., AC. Madison County: Barclay Cave.

Tachys (Tachyura) ferrugineus (Dejean), TP. Conecuh County: Sanders Cave. Marshall County: Eudy and Honeycomb caves. Morgan County: Bat and Royer caves. Though this species occurs rarely in caves in the east, it is common in caves in Texas (Barr 1964, Loding 1945, Reddell 1966).

Trichotichnus dichroas Dejean, AC. Madison County: Ellis Cave.

Troglanillus valentinei Jeannel, TB-ED. De Kalb County: Killian Cave (TWD), Manitou Cave (type locality). Jefferson County: McCluney (=Crystal) Cave (Jeannel 1963, Loding 1945).

Family Histeridae

Geocolus sp., TP-ED. Jackson County: Paint Rock Cave. Lauderdale County: Butler Cave (both records in *Plethodon glutinosus* salamander stomachs). This genus of eyeless, soil histerid beetle was previously known only from central Georgia.

Neosaprinus sp., TP?. Jackson County: Sauta Cave. This is an undescribed species, near *N. rubicola*, from under rocks with guano, at "Jack Rock."

Family Ptiliidae

Micridium sp., AC. Jackson County: Schiffman Cave. A forest-litter species taken on *Neotoma* dung.

Family Pselaphidae

This is a large family of small-sized beetles living in forest litter and soil. Many are known from caves and both cave and soil species can be eyeless. Chandler (1990) gives a key to the genera.

Arianops cavernensis Park, TB. Marshall County: Guntersville (=Nymans Saltpeter) Caverns (type locality). The species is known only from the type locality (Barr 1974; Park 1951, 1960). All species in this genus are eyeless. Five species are probably troglobites, and at least 26 species are edaphobites in the Appalachians (Barr 1974).

Arianops steevesi Barr, TB. Jackson County: Horseshoe and Williams Saltpeter caves. Another *Arianops* (*A. externa* Barr) is known from forest litter outside of Horseshoe Cave (Barr 1974).

Batrisodes (Babnormodes) jocuvestus Park, TB. Madison County: Aladdin Cave (type locality). The species is known only from the type locality. It may be a dimorphic minor male form of *B. specus* (H.R. Steeves, in litter) (Park 1960).

Batrisodes (Babnormodes) jonesi Park, TB. Colbert County: Dickey, Gallymore, Gist, Little Bear (type locality), McCluskey, McKinney, McKinney Pit, and Wolf Den caves (Park 1951, 1958, 1960).

Batrisodes (Babnormodes) profundus Park, TB. Conecuh County: Sanders (Turks) Cave (type locality). Known only from the type cave. The species has not been found in the cave in the past few years, and it is apparently being replaced by *B. globosus* which is abundant in the cave (Park 1956, 1958, 1960, Steeves, in litter).

Batrisodes (Babnormodes) specus Park, TB. Colbert County: Georgetown Cave. Jackson County: Cornellison and Indian Rock caves. Madison County: Aladdin (HRS), Cave Spring A60, Big (Huntsville) Spring, Hutton (type locality), Lott, Pitts, and Twin caves. Marshall County: Terrell Cave. This species is also known from Indian Cave, Jefferson County, Tennessee. It has been found only in caves (Park 1951, 1958, 1960).

Batrisodes (Babnormodes) subterraneus Park, TB. Marshall County: Griffith Cave (type locality). Known only from the type locality (Park 1951, 1958, 1960).

Batrisodes (Babnormodes) tumoris Park, TP. Colbert County: McCluskey Cave (type locality). Known only from the type locality (Park 1960).

Batrisodes (Babnormodes) valentinei Park, TB. Jackson County: Clemons and Gross-Skeleton (=Out) caves. Morgan County: Talucah Cave. Madison County: Candlestand (=Goat) (type locality), Hurricane, and Toll Gate Natural Well caves. The species is known only from caves. It is also recorded from Crystal Cave, Grundy County, Tennessee. Its ecology is discussed in (Park 1951, 1956, 1958, 1960).

Batrisodes (Babnormodes) sp., TB. This undescribed species is known only from Marshall County, Campbell Cave (H.R. Steeves, in litter) (not in AL survey).

Batrisodes (Excavodes) cavernosus Park, TB. Butler County: Hinson Cave (type locality). Clarke County: Chastain Cave, near Rockville (HRS). The species is known only from these cave collections (Park 1951, 1958, 1960).

Batrisodes (Excavodes) sp., TB. An undescribed species known only from Sanders (=Turks) Cave, Conecuh County (H.R. Steeves).

Batrisodes globosus (LeConte), TP. Calhoun County: Weaver (Lady) Cave (HRS). Conecuh County: Sanders Cave (=Turks). Species is widespread in the eastern United States. It is apparently replacing *B. profundus* in Sanders Cave (Park 1947: p.82).

Batrisodes sp., TB. Jackson County: Cave Stand entrance to Gary Self Cave (WBJ). Madison County: Chittonwood (WBJ), Jett (WBJ), and Sublett (WBJ) caves. These records are based upon females.

Batriasymmodes spelaeus Park, TP. Blount County: Bangor (type locality), Bryant (TK), Catfish, Dixon, Frenchs, Horseshoe, Ingram, Pass, and Posey (Spring) caves. De Kalb County: Manitou Cave. Jackson County: Coon Creek (Pisgah) Saltpeter (HRS) and Nickajack caves. Lauderdale County: Bat Cave. Lawrence County: Cave Spring (WBJ), Thomas, and Tingling Hole caves. Marshall County: Lime Point, Kelly Ridge, and Warrenton caves. Morgan County: Barrel, Cave Spring, Echols, Inge, Ladder, Lost Mule, Royer, and Winchester caves. St. Clair County: McGlendon Cave. Walker County: Devils Ladder (HRS). Winston County: Natural Bridge Rock Shelter. This species is also recorded from caves in Clay, Grainger, Van Buren, and White Counties, Tennessee. It was previously known only from caves. The Walker and Winston county records represent rockshelters that do not possess a dark zone. This toleration of twilight and the wide and abundant distribution suggests a recent if not present dispersal and invasion into caves.

Batriasymmodes troglodytes Park, TP. Butler County: Rock Cave (type locality). Known only from the type locality (Park 1951, 1956, 1960, 1965).

Batriasymmodes sp., TP. Jackson County: Rainbow Cave (1 female). Marshall County: Dunham Cave (1 female).

Batriasymmodes (Batriasymmodes) sp., TP. This apparently undescribed species has been collected in Colbert County: Gallymore Cave, and Winston County: Natural Bridge Rock Shelter, in the light and twilight zones of rockshelters as well as in the dark zone of caves (H.R. Steeves, in Litt.).

Batriasymmodes (Batriasymmodes) sp, TP. Jackson County: Coon Creek (Pisgah) Saltpeter Cave, and Marshall County: Guffey Cave. This is an apparently undescribed species.

Bythinopsis jonesi Park, TP. Colbert County: Wolf Den Cave (type locality). The species is known only from the type locality (Park 1951, 1953, 1960).

Speleochus croceus (Park), TB. Madison County: Lott Cave (type locality), Twin Cave (Park 1960). This and following species in the genera *Speleochus* and *Subterrochus* were once placed in the genus *Macherites. Macherites* is now understood to be limited to the Old World.

Speleochus stygicus (Park), TB. Madison County: Cave Spring Cave AL60, Big (=Huntsville) Spring, Kelly Natural Well, and Toll Gate Natural Well caves (Park 1951, 1953, 1960).

Speleochus synstygicus (Park), TB. Madison County: Barclay Cave (type locality). The species is known only from the type locality (Park 1956, 1960).

Subterrochus eurous (Park), TB. Jackson County: Jess Elliott Cave (type locality). The species is known only from the type locality (Park 1960).

Subterrochus ferus (Park), TB. Madison County: Aladdin Cave (type locality) and Hutton Cave. Jackson County: Devil Stair Step, Hambrick, and Keel Sinks caves (Park 1951, 1953, 1960).

Subterrochus steevesi (Park), TB. Marshall County: Guffey Cave (type locality). The species is known only from the type locality.

Speleobama vana Park, TB. Jefferson County: McCluney (=Crystal) Caverns. This species is known only from the type locality cave (Park 1951).

Tmesiphorus costalis LeConte, TP. Marshall County: Terrell Cave. Morgan County: Lost Mule Cave. This is a widespread species, usually associated with ants (Park 1951).

Undetermined Genera and species. De Kalb County: Bartlett, Lykes, and Talley caves. Jackson County: Driftwood (with dung) and Happy Hollow caves. Marshall County: Cave Mountain, Davidson, and Painted Bluff caves. Madison County: Hurricane Cave. Morgan County: Thomas Cave (ICR).

Family Agyrtidae

Necrophilus pettitii Horn, TP-ED?. Jackson County: Russell Cave (Pig Entrance). This wingless species occurs in much of the eastern United States through and near the Appalachians, and into Florida, Louisiana, and Missouri. It usually occurs at high elevations, or in soil and cave entrances at lower elevations (Peck 1981).

Family Leiodidae

This is a diverse family of small carrion beetles and small fungus beetles, living in forest litter, soil, caves, and animal burrows and nests (Peck 1990). Many hundreds of species in the tribe Leptodirini exist in Europe in caves.

Adelopsis appalachiana Peck, TP. Blount County: Bangor Cave. De Kalb County: Cherokee, Cook, Kelly Girls, Lykes, and Manitou (type locality) caves. Calhoun County: Wrights Cave. Morgan County: Inge Cave. Marshall County: Kelly Ridge Cave. The species is distributed south of the Tennessee River in north-central Alabama and into Georgia. It is also frequent in leaf-litter habitats (Peck 1978).

Adelopsis cumberlanda Peck, TP. Jackson County: Clemons, Keel, and Rousseau entrance to Gary Self caves. Marshall County: Creek (not in AL survey), Guffy, and Hampton Caves. The species is limited to cave and forest-litter habitats in the Cumberland Plateau of north eastern Alabama (Peck 1978).

Adelopsis jonesi Peck, TP. Colbert County: Gist, McClusky, and Wolf Den (type locality) caves. Known only from these caves and other Alabama soil-litter records (Peck 1978).

Catopocerus alabamae Peck, TP-ED. Madison County: Cave Spring Cave (A 60) (type locality) (in *Eurycea lucifuga* salamander stomach). Known only from this locality (Peck 1974a). All members of this genus are eyeless, soil inhabitants.

Catopocerus appalachianus Peck, TP-ED. Madison County: Barclay, Cave Spring, and Ellis caves. This species is distributed along the Appalachians from Madison County, Alabama, to Pocahantas County, West Virginia (Peck 1974a).

Catopocerus jonesi Peck, TP-ED. Marshall County: Eudy Cave (type locality). Morgan County: Shine and Vandiver caves. Jackson County: House of Happiness Cave. The species is known only from these caves (Peck 1974a).

Catops gratiosus Blanchard, TP. Colbert County: McCluskey (in *Neotoma* nest), and Wolf Den caves. De Kalb County: Killian (H&D) and Manitou (WBJ) caves. Jackson County: Cox entrance to Tony Sinks Cave (WBJ). Madison County: Scott and Sinks (WBJ) Caves. Marshall County: Griffith Cave (WBJ). Morgan County: Trinity Cave (WBJ). The species is frequent in caves in the southern Appalachians and occurs in forests in more northerly localities. It is found in caves on animal dung or carrion.

Nemadus horni Hatch, TP. Blount County: Bangor Cave. Calhoun County: Lady (WBJ) and Weaver (WBJ) caves. Colbert County: Wolf Den Cave (WBJ). Conecuh County: Sanders (=Turks) Cave. Deklab County: Bartlett (WBJ), Cook (WBJ), Lykes, and Manitou (WBJ) caves. Jackson County: Coon Creek Cave. Limestone County: Pope Cave (WBJ). Morgan County: Talucah Cave (WBJ). Talladega County: Dulaney Cave (WBJ). The species is distributed from northern Florida, northwards through much of the eastern United States. It occurs frequently in caves in the northern part of its range, often in large numbers in bat guano.

Prionochaeta opaca (Say), TP. Blount County: Catfish, Horseshoe-Crump, and Randolph caves. Calhoun County: Robertson and Weaver caves (WBJ). Conecuh County: Sanders (=Turks) Cave. De Kalb County: Cherokee and Lois Killian caves. Calhoun County: Weaver Cave (WBJ). Jackson County: House of Happiness and Rousseau entrance to Gary Self caves. Madison County: Burwell, Ellis, Hurricane, Matthews, and Scott caves. Marshall County: Eudy (WBJ), Honeycomb, Merrill, Painted Bluff, and Terrill caves. Morgan County: Lipscomb Cave (WBJ). The species ranges from northern Florida to southeastern Canada. It is frequent in caves in the southeastern states where it occurs on carrion, animal dung, and bat guano (Peck 1977).

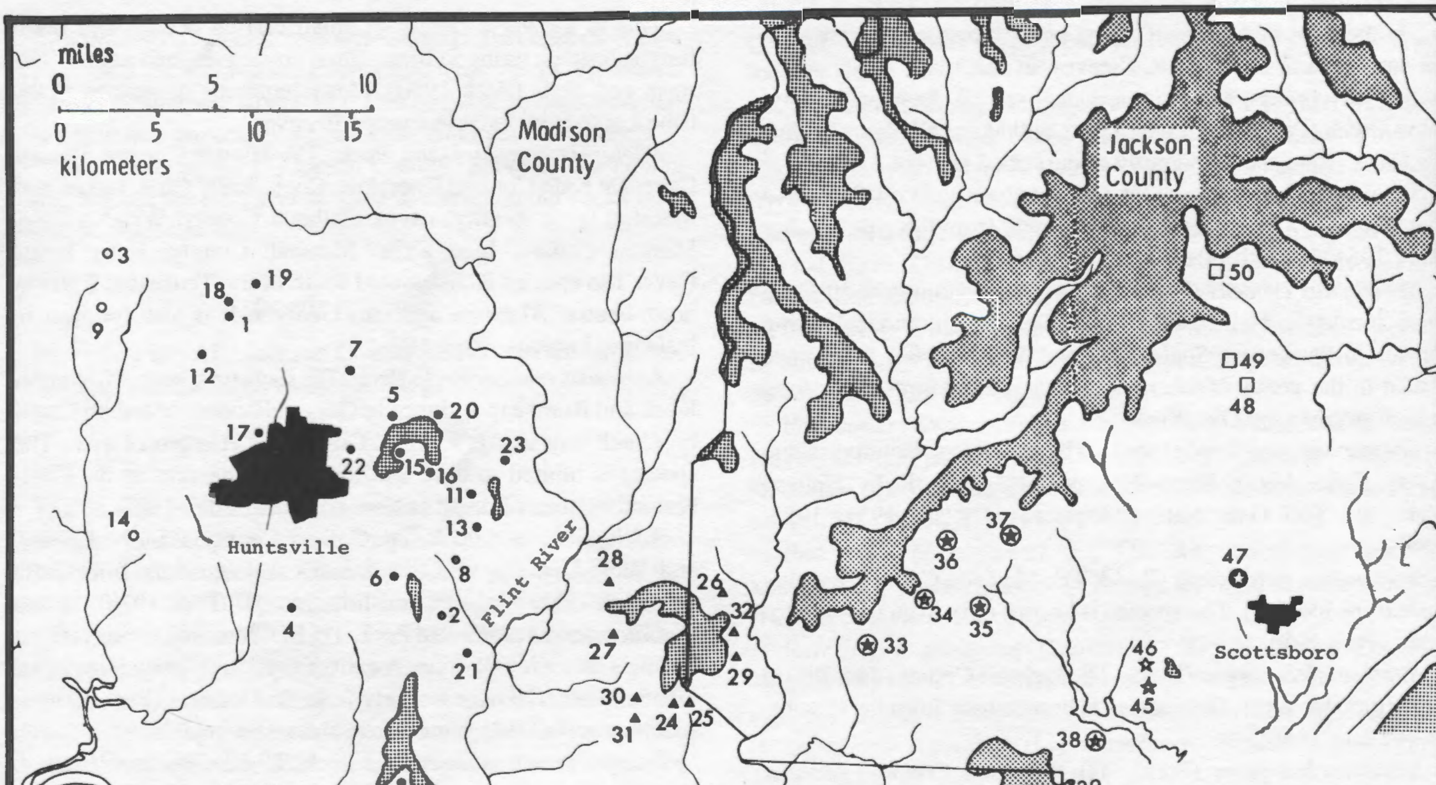

Figure 5. The distributions of some of the species of troglobitic *Ptomaphagus* in northeastern Alabama. The dark stipple represents the sandstone cap of the Cumberland Plateau. Caves occur in the limestones underlying the sandstone, but do not extend far under the sandstone itself. Subterranean movement of the beetles must be through air-filled caves and cracks in the limestones around and back from the edges of the Cumberland Plateau. The alluvial lowlands and rivers are also barriers to the present day subterranean dispersal of the species. The numbers refer to individual caves (from Peck 1984).

Ptomaphagus, the cave carrion beetles. The cave inhabiting *Ptomaphagus* beetles of Alabama have had a rich history of taxonomic study (Barr 1963; Jeannel 1933, 1936, 1949; Peck 1973, 1983, 1984). Their name changes will not be given in detail below. Their ecology, evolution, and life cycles have been only partially studied (Peck 1975c, 1976, 1984, 1986). The complex geographic distributions of some of the Alabama species, and the limited distributions of some of these species are shown in Figure 5.

Ptomaphagus cavernicola Schwarz, TP. Morgan County: Talucah Cave. Known in Alabama only from this locality. The species otherwise occurs in caves from north Florida to Iowa, Texas, and Mexico, and in forests in north Florida and Georgia (Peck 1982).

Ptomaphagus chromolithus Peck, TB. Jackson County: Beanfield, Doodlebug Hole, Doug Green, Fortyeight Ten, Horseshoe, Little Sink, Moon Spring, Section 20 (not in AL survey), and Williams Saltpeter caves. The species also occurs in Franklin County, Tennessee. All caves are located in the upper Paint Rock River Valley. The species distribution is not continuous, for some caves in this valley are instead occupied by *P. hatchi* Jeannel (Peck 1984).

Ptomaphagus consobrinus LeConte, AC. De Kalb County: Manitou Cave (WBJ). Madison County: Aladdin Cave (Jeannel 1949). Morgan County: Inge Cave (TCB). This is a widespread southeastern forest litter species (Peck 1973).

Ptomaphagus episcopus Peck, TB. Marshall County: McHardin (type locality) and Honeycomb caves. The species is known only from these caves in Bishop Mountain, an isolated remnant of the Cumberland Plateau (Peck 1973).

Ptomaphagus hatchi Jeannel, TB. Jackson County: Borderline, Bouldin, Buds, Cagle, Clemons, Cornellison no. 2, Crowson, Devils Stairstep, Dripping Spring, Dry, Fourth of July, Gary Self (Cave Stand and Rousseau entrances), Guess Creek, Haddon Spring, Hambrick, Honey Hollow Saltpeter, Hurricane, Indian Rocks, Jess Elliott, Kennamer, McFarland, McFarland Blowing, McFarland Spring, Morgue entrance to Fern, Nat, Upper Rainbow, Roadside, Russell (Pig Entrance), Slippery Pole, Swaim, Talley Ditch, Tate, and Trenton caves. Madison County: Aladdin, Hutton, Jacks, and Scott caves. The species also occurs in caves in Franklin and Grundy counties, Tennessee (Peck 1973, 1984). It is the most widespread troglobitic *Ptomaphagus* at the southern end of the Cumberland Plateau.

Ptomaphagus hazelae Peck, TB. Jackson County: Driftwood, Ivey Bottom, and Tumbling Rock (type locality) caves. The species is known only from these caves, in the headwaters of Mud Creek (Peck 1973).

Ptomaphagus julius Peck, TB. Jackson County: House of Happiness (type locality) and Lindsay Spring caves. The species is limited to caves in July Mountain, an isolated outlier of the Cumberland Plateau (Peck 1973, 1984).

Ptomaphagus laticornis Jeannel, TB. Jackson County: Rousseau entrance to Gary Self Cave. Madison County: Hutton and Scott caves. The species is known only from these caves along the west flank of Bice and Bingham mountains, of the Cumberland Plateau (Peck 1984).

Ptomaphagus longicornis Jeannel, TB. Figure 6. Jackson County: Crossing, Greising, and Paint Rock caves. Madison County: Bee Sinkhole, Chittonwood, Candlestand (=Goat), Grayson Spring, Hering (Cave Spring) (type locality), Labyrinth, and Moon Sinkhole caves. The species is limited to caves in Keel Mountain, an isolated remnant of the Cumberland Plateau (Peck 1973, 1984).

Ptomaphagus loedingi Hatch, TB. Madison County: Barclay, Buford, Byrd Spring, Cold Spring, Canoe, Cave Spring (AL 60), Drake, Green Grotto, Jett, Kelly Natural Well, Lott, Natural

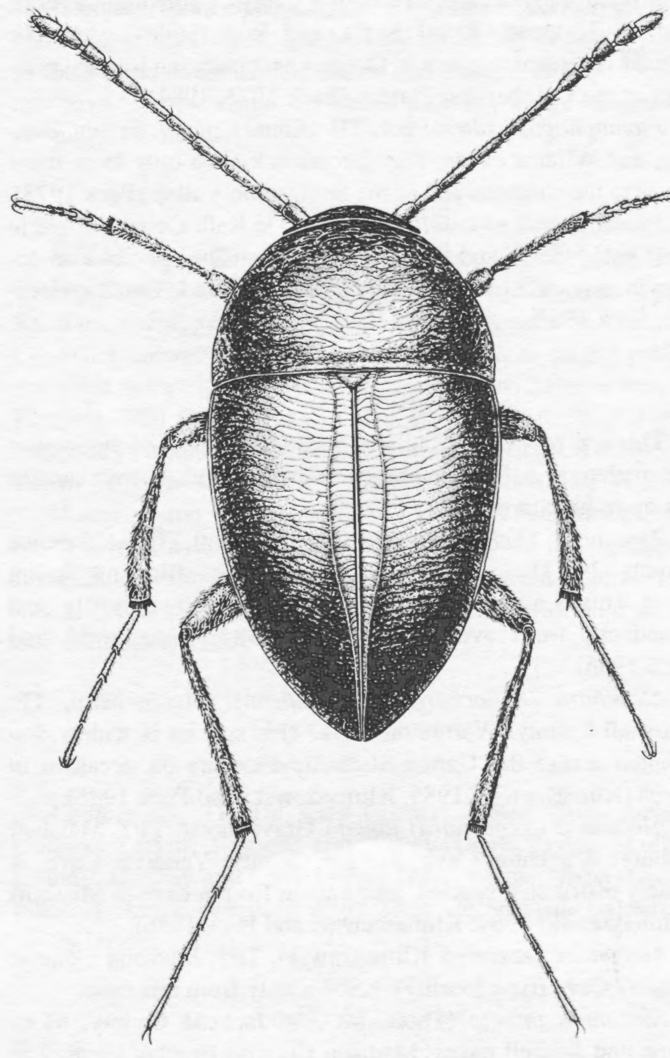

Figure 6. *Ptomaphagus longicornis,* probably the most cave-evolved species in the genus. Notice the long antennae and long legs which are typical of cave-evolved insects. This species is limited to caves in Keel Mountain, east of Huntsville, Alabama. Total body length is about 3 mm.

Well, Pitts Sinkhole, Sadler Spring, Shelta (type locality), Sinks (AL 102), Spook, The Sinks (AL121), Taploe, Toll Gate Natural Well, and Twin caves. The species occurs only in caves in western outliers of the Cumberland Plateau west of Flint River.

Ptomaphagus solanum Peck, TB. Jackson County: Sheldons Cave (type locality). The species is limited to caves in Tater Knob, a remnant of the Cumberland Plateau, at Scottsboro (Peck 1984).

Ptomaphagus torodei Peck, TB. Jackson County: Two Way (type locality) and Hall caves. The species is known only from these caves in Boxes Cove (Peck 1984).

Ptomaphagus valentinei Jeannel, TB. Jackson County: Larkin, Limrock Blowing, Lost, Mink, Pigpen, Sauta, and Schiffman Cave caves. Marshall County: Cathedral Caverns, Guffey, Kirkland, Royal Shaft, and War Eagle caves. The species is limited to caves in Gunters Mountain, an isolated remnant of the Cumberland Plateau (Peck 1973, 1984).

Ptomaphagus walteri Peck, TB. Blount County: Bryant, Bangor, and Wildcat caves. The species is known only from these caves in the southern end of the Sequatchie Valley (Peck 1973).

Ptomaphagus whiteselli Barr, TB. De Kalb County: Cave in Deer Head Cove, and Sequoyah Caverns. The species also occurs in caves in Lookout Valley in adjacent Dade County, Georgia (Peck 1973).

Family Staphylindae

This is a very large family of beetles, and most of the species are predators. A few are associated with caves, but no species are troglobitic in the United States.

Aleochara (Echochara) lucifuga (Casey), TP. Lawrence County: Ivy Hollow Cave. Morgan County: Blowing Spring Cave. This is a widespread eastern species, known mostly, and abundantly, from caves (Klimaszewski 1984; Klimaszewski and Peck 1986).

Aleochara (Xenochara) castaneipennis Mannerheim, TP. Marshall County: Warrenton Cave. This species is widely distributed across the United States, and occurs on occasion in caves (Klimaszewski 1984; Klimaszewski and Peck 1986).

Aleochara (Xenochara) fumata Gravenhorst, TP?. Marshall County: Warrenton Cave. Morgan County: Vandiver Cave. A widely distributed species, also known from a cave in Missouri (Klimaszewski 1984; Klimaszewski and Peck 1986).

Aloconota neospelea Klimaszewski, TP?. Madison County: Barclay Cave (type locality). Known only from this cave.

Aloconota insecta (Thomson), TP. Jackson County: Montague and Russell caves. Madison County: Barclay Cave. The species occurs in Europe and the eastern United States. It is known from caves from many states (Klimaszewski and Peck 1986).

Anotylus tetracarinatus, AC. Jackson County: Hall Cave.

Anotylus exiguus (Erichson), AC. DeKalb County: Lykes Cave.

Apocellus sp. AC. Madison County: Barclay Cave.

Atheta (Atheta) alabama Klimaszewski, TP?. Morgan County: Vandiver Cave (type locality). Known only from this cave.

Atheta (Atheta) annexa Casey, TP. Blount County: Horseshoe-Crump Cave. Calhoun County: Robertson Cave. Conecuh County: Sanders (=Turks) Cave. De Kalb County: Lykes, Lois Killan, and Manitou caves. Limestone County: Indian Cave. Madison County: Barclay, Burwell, Byrd Spring, Ellis, and Hurricane caves. Marshall County: Cathedral, Green Bar, Hampton, and Honeycomb caves. St. Clair County: McLendon Cave. Talladega County: Dulaney and Kymulga caves. The species is widespread in the eastern United States and is known mostly from caves (Klimaszewski and Peck 1986).

Atheta (Dimetrota) troglophila Klimaszewski, TP. Blount County: Bangor, Catfish, Bryant, Horseshoe-Crump, and Randolph caves. Calhoun County: Robertson Cave. Colbert County: McCluskey and McKinney caves. De Kalb County: Bartlett, Manitou, Lois Killian, Lykes, Sequoyah, and Section 26 caves. Jackson County: Coon Creek, Cornelison, Cox entrance to Tony Sinks, Doug Green, Edgefield, Rousseau, Horseshoe, McFarland, Montague, Nat, Schiffman, Rainbow, Swaim, Talley Ditch, Tumbling Rock, Twoway, and Williams Saltpeter caves. Limestone County: Pope Cave. Madison County: Aladdin, Barclay, Byrd Spring, Burwell, Ellis, Candlestand (=Goat), Hurricane, and Scott caves. Marshall County: Cathedral, Griffith, Dunham, Merrill, Keller, Porches Spring, Old Blowing, Painted Bluff, and Walnut caves. Morgan County: Blowing Spring, Horseback, and Royer caves. The species is widely distributed in eastern North America and is very common in caves in many states (Klimaszewski and Peck 1986).

Atheta (Dimetrota) lucifuga Klimaszewski, TP. Blount County: Horseshoe Crump Cave. Jackson County: Cornelison and Nat caves. Madison County: Barclay, Burwell, and Hurricane caves. Marshall County: Green Bar (type locality) and Painted Bluff caves. The species ranges from Missouri and Kentucky south to Florida and Texas. It is known only from caves (Klimaszewski and Peck 1986).

Belonuchus sp., AC. Jackson County: Nat Cave.

Blepharrhymenus illectus (Casey), TP. Jackson County: Paint Rock Cave. Limestone County: Duck, Gaston, and Spencer caves. The species is otherwise known only from Oregon and caves in Missouri and Tennessee (Klimaszewski and Peck 1986).

Brathinus nitidus Leconte, TP. De Kalb County: Manitou Cave. Limestone County: Spence Cave. Madison County: Cave Spring Cave. Marshall County: Kirkland and Natural Bridge caves. The species occurs along cave streams. It ranges from Alabama to eastern Canada. Most records from the south are from caves (Peck 1975a).

Carpelimus sp., AC. St. Clair County: McLendon Cave.

Cryptobium carolinum Erichson, AC. Jackson County: Iron Hoop entrance to Jess Elliot and Rousseau entrance to Gary Self caves.

Erichsonius patella (Horn), AC. St. Clair County: McLendon Cave.

Geodromicus brunneus Say, AC. Jackson County: Beanfield Cave.

Lesteva cribatulus Casey, AC. Jackson County: Grahams Pit. St. Clair County: McLendon Cave.

Lesteva pallipes Leconte, TP. Madison County: Barclay Cave. Marshall County: River Cave at Grant (HRS) (not in AL survey). Jackson County: Coon Creek (=Pisgah Saltpeter) (HRS) and Tumbling Rock caves (HRS). The species is found along rocky cave streams.

Omalium sp, AC. Jackson County: Cox entrance to Tony Sinks Cave.

Quedius erythrogaster Mannerheim, TP. Blount County: Randolph Cave. Colbert County: Wolf Den Cave. Jackson County: Cornellison No. 2, Hall, Upper Rainbow (=Happy Hollow), Horseshoe, House of Happiness, Indian Rock, Moody, Nat, Putman, Rainbow, Sheldons, Swaim, and Two Way caves. Madison County: Barclay, Burwell, Cave Spring AL60, Cold Spring, Ellis, Hering (Cave Spring), and Hurricane caves. Marshall County: Bishop, Dunham, Merrill, Painted Bluff, Steves, and Walnut caves. The species is distributed across the continent, and is frequently found in caves (Smetana 1971).

Quedius fulgidus Fabricius, TP. Calhoun County: Weaver Cave. This is the only Alabama record for this species that is spread across the United States. It occurs occasionally in caves (Smetana 1971).

Thinodromus sp. AC. Jackson County: Hall Cave.

Family Cantharidae

Cantharis ? sp., TX. Jackson County: Indian Rock and Trenton caves. Limestone County: Indian Cave. Madison County: Barclay, Cave Spring, and Morring caves. Marshall County: Warrenton Cave. Only larvae of these beetles have been found in caves. They are also known from caves in Georgia, Illinois, Kentucky, Tennessee, West Virginia and Ontario, Canada (Peck 1975b).

Family Chrysomelidae

Rhabteropterus sp., AC. Limestone County: Gaston Cave.

Family Melyridae

Collops sp., AC. Morgan County: Blowing Spring Cave.

Order Trichoptera

Caddis flies are often found in large numbers at springs flowing from caves. No careful study has been conducted on species associated with cave springs.

Family Hydroptilidae

Hydraptila sp., AC. Jackson County: Tumbling Rock Cave (in *Eurycea lucifuga* salamander stomach).

Ochrotrichia sp., AC. Jackson County: Doug Green Cave (in *Eurycea lucifuga* salamander stomach). Also known from Burk Hollow Cave, Rutheford County, Tennessee.

Order Lepidoptera

Family Noctuidae

Scoliopteryx libatrix Linnaeus, TX. Jackson County: Limrock Blowing, and Rousseau entrance to Gary Self caves. Madison County: Cave Spring, Clark Bluff, and Scott caves. This beautiful, multi-colored, and velvety appearing species is found in most parts of the United States and Europe. It may occur in any cave over the range. Caves are used for winter hibernation or summer estivation.

Family Tineidae

Amydria arizonella Dietz, TP. Blount County: Horseshoe Crump Cave. Jackson County: Cornellison, Crossing, Upper Rainbow (=Happy Hollow), Nat, and Pigpen caves. Marshall County: Dunham Cave. This clothes moth feeds on dry protein materials in caves, especially bat guano. I also have records for Henpeck Mill Cave, Franklin County, Tennessee; and Harrisburg and Pettijohn caves, Walker County, Georgia. The species occurs in Texas bat caves and Carlsbad Caverns, New Mexico.

Monopis, prob. *crocicapitella* (Clemens), TP. Calhoun County: Weaver Cave. Another record probably of this species is from Little Cedar Mountain Indian Cave, Marion County, Tennessee. This species seems to be nearly worldwide in distribution (Robinson 1980).

Order Hymenoptera

Family Braconidae

Aspilota sp., TP. De Kalb County: Talley Cave. Jackson County: Larkin, Russell, and Talley Ditch caves. Madison County: Barclay and Cave Spring (A60) caves. These were all taken in carrion-baited pit traps. They are probably parasitoids on fly larvae.

Family Formicidae

Prenolepis imperis Say, AC. Blount County: Cedar Grove River Cave, in a debris-filled fissure.

Order Siphonaptera

Fleas of bats and rodents in Alabama caves have not been studied.

Family Hystrichopsyllidae

Ctenophthalmus pseudagyrtes Baker, AC. Marshall County: Gamble Cave. The normal hosts of this flea are insectivores and small rodents.

Order Diptera

Flies have usually not received much attention in surveys of North American cave faunas. A large fauna of flies in caves is known from Ontario, Canada and Great Britain (Peck 1988, Jefferson 1981). They are most abundant on cave walls in the twilight zone or just inside the dark zone.

Family Anisopodidae

Anisopus sp., AC. Comments. One specimen was taken in a carrion-baited trap in Scott Cave, Madison County. The flies are normally found in moist areas containing decaying organic matter.

Family Chironomidae

Genus undetermined, TX. Jackson County: Nickajack Cave (abundant along mud bank at cave river), Sheldon Cave (in carrion traps), and Salt River Cave (in stomach of *Gyrinophilus palleucus* salamander).

Orthodadius (Orthocladius) sp., TX. Jackson County; Sheldons Cave (carrion bait traps). This is an undescribed species.

Polypedilum (Tripodura) sp., TX. Jackson County: Nickajack Cave (22 males, 1 female, from debris alongside cave stream).

Family Helomyzidae

Amoebaleria defessa, TX. Franklin County: Belgreen Cave. Jackson County: Paint Rock (*Eurycea* stomach) and Russell caves. Limestone County: Forked Stream Cave (JEC) (not in AL survey). These flies occur in almost every cave, and are far more numerous than this list of records indicates. Both adults and larvae frequent refuse in moist, dark areas. The adults are conspicuous on cave ceilings.

Aecothea sp., TX. Limestone County: Cave Spring (not in AL survey), Duck and Forked Stream (not in AL survey) caves.

Family Mycetophilidae

Undetermined genera and species, TX. These flies occur in decaying debris and guano in caves. They have been observed in a number of caves, and collected from Cold Spring, Madison County, and Eudy caves, Marshall County *(Exechia)*. They form swarms at cave entrances in the winter and are often mistaken for mosquitoes.

Leia cuneola (Adams), TX. Madison County: Cold Spring Cave. Also collected in Mountain Cove Farm Cave, Walker County, Georgia.

Rymosia triangularis Show, TX. Madison County: Cold Spring Cave.

Family Phoridae

Conicera pauxilla, AC. Marshall County: Honeycomb Cave.

Dorniphora cornuta, AC. Marshall County: Honeycomb Cave.

Dorniphora perplexa, AC. Jackson County: Crossing Cave (entrance zone).

Megascelia cavernicola Brues, TP. Conecuh County: Turks (Sanders) Cave. Jackson County: Crossing and Sheldon caves. Madison County: Barclay, Cold Spring, and Scott caves. Marshall County: Cathedral and Terrill caves. Georgia. Chatooga County: Blowing and Parker caves. Dade County: Johnson Crook Cave. Polk County: White River Caves. Walker County: Byers, Cave Spring, Horseshoe, Mountain Cove Farm, and Pettijohn caves. This species occurs widely in caves. It can be taken in large numbers at carrion baits (Peck 1976). Virtually nothing is known of the ecology of this cave-dwelling species (Robinson 1971). Over 1000 species worldwide are placed in this genus.

Puliciphora suavis, AC. Jackson County: Crossing Cave (entrance zone).

Spiniphora slossonae, AC. Jackson County: Crossing Cave (entrance zone).

Family Psychodidae

Psychoda sp., TP?. Jackson County: Sheldon Cave. Madison County: Aladdin and Scott caves. Marshall County: Eudy Cave. These flies are often associated with dung and sewage. Some have aquatic larvae (Quate 1954).

Family Sciaridae

Sciara sp., TP. Blount County: Bryant Cave. Franklin County; Belgreen Cave (*Pseudotriton* stomach). Marshall County; Cathedral Caverns and Painted Bluff caves (guano). The larvae of these flies feed on fungi and would be expected in many more caves around debris.

Family Sphaeroceridae

Spelobia tenebrarum (Aldrich), TB. Jackson County: Crossing, Nat, Horseshoe, and Schiffman caves. Madison County: Byrd Spring Cave. The species is widely distributed and very common in eastern North American caves (Marshall and Peck 1984, 1985). Its ecology in caves is poorly understood (Peck 1976). Sphaerocerid ecology has been studied in Hungary (Papp and Plachter 1976).

Telomerina cava Marshall and Rohacek, TP. Jackson County: Nickajack Cave. Marshall County: Merrill Cave (type locality). The species is known only from caves in Alabama, Tennessee, and Oklahoma (Marshall and Rohacek 1984).

FUTURE STUDIES

The insect and terrestrial invertebrate fauna of Alabama caves is still incompletely known. The taxonomy of several important groups, especially millipedes of the genus *Scoterpes*, has yet to be resolved. And the distributions of most of the troglobitic species have yet to be fully discovered and mapped. Only then will it be possible to understand fully the barriers that form the boundaries of the distributions of these species. Frequently, closely related species seem to be unable to co-exist. The distributions of the species of *Ceuthophilus* and *Euhadenoecus* crickets and some *Ptomaphagus* beetles suggest that they are mutually excluding other members of their genus from specific caves. How and why this happens is an interesting topic in evolutionary and population biology. Life history, population, and genetic studies have been made only on the *Ptomaphagus* beetles (Peck 1984, Peck 1986). And only for these and some Collembola has an evolutionary explanation been offered for the development of the present fauna (Christiansen and Culver 1987; Peck 1984). Only three ecological studies have been made in Alabama caves; one on the distribution of invertebrates around a cave entrance (Peck 1976), and two on salamanders that eat cave insects (Peck 1974b, Peck and Richardson 1976).

There is abundant opportunity to continue to understand the composition, the dynamics, and the origin of the fauna. Why are there not more southeastern biologists involved in such faunal, ecological, or evolutionary studies? After all, caves are excellent model laboratories for the study of the dynamics of ecological assemblages, and adaptation to extreme habitats (Christiansen 1992).

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NEW RECORDS OF FISHES WITHIN FLORIDA CAVES

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One hundred and thirty-eight subaerial and subaquatic Florida caves have been investigated over a 20-year period for fish faunas. A total of 29 fishes has been found in caves, of which 17 have been found in the cave dark zone and 12 in entrance twilight areas. Only six of these have been reported previously from Florida's cave habitats. None are troglobites or troglophiles, five are trogloxenes and the remainder are accidentals.

INTRODUCTION

Little published data exist on fishes occurring in Florida caves, and mostly those are based on observations made at cave entrances. Obviously, data collected from deeper within caves are needed in order to understand more fully the ecological relationships between caves and fishes. The main purpose of this paper is to try to fill part of that void by documenting all the species of fishes that the author has made in Florida caves from 1974 to 1994. Also collected in these investigations were such data as frequency of observations, relative abundances and numbers of individuals and level of sampling effort; these data are to be published in a subsequent paper.

METHODS

Data collection sites include freshwater spring (subaquatic) caves, upland subaerial and subaquatic caves, subaquatic swallets, and subaquatic karst windows. The geographic range covered in this study extends from Holmes County in the western Florida Panhandle southward to south-central Peninsular Florida. Horizontal, vertical, and cave diving techniques were used. Data were collected from a total of 353 logged subaqueous cave dives in Florida from 1983 to 1994, and over 200 unlogged subaerial caving trips from 1974 to 1994. Included are data from approximately 68 subaqueous and subaerial caves in Alachua, Citrus, Columbia, Gilchrist, Hamilton, Hernando, Holmes, Jackson, Lafayette, Leon, Levy, Madison, Marion, Orange, Pasco, Putnam, Suwannee, and Wakulla Counties, Florida. Precise cave locations have been withheld; this information may be obtained from the author or the Florida Speleological Society (Gainesville).

Identifications are based on in-cave observations, with the exceptions of *Gobiosoma bosci* and *Percina nigrofasciata* which were hand-caught and later identified by Dr. Carter Gilbert, Florida Museum of Natural History (Gainesville). Fish identifications and taxonomic nomenclature are based on Page and Burr (1991), McClane (1974a, b), and Lee *et al.* (1980).

For the purposes of this paper, accidentals are strays that have wandered into the cave (Peck, 1970) and are rarely encountered; trogloxenes cannot complete their life cycles in caves but regularly are encountered (Franz, *et al.*, 1994); facultative troglophiles may complete their life cycles in caves but do not show the extreme morphological adaptations that are usually reserved for troglobites (Franz, *et al.*, 1994); obligate troglophiles are restricted to caves and also do not possess the morphological characteristics of troglobites (Franz, *et al.*, 1994); and troglobites are restricted to caves and have obvious morphological adaptations for caves (Franz *et al.*, 1994).

RESULTS

Only nine species of fishes have been reported previously (Brockman and Bortone, 1977; Franz, *et al.*, 1994; Hale and Streever, 1994; Hobbs, 1942; Hobbs and Franz, 1992; Hubbs, 1956; Marshall, 1947; Pylka and Warren, 1958; and Relyea and Sutton, 1973; Streever, 1990) from Florida caves:

Scientific Name	Common Name
Ameiurus natalis	Yellow bullhead
Ameiurus nebulosus	Brown bullhead
Anguilla rostrata	American eel
Aphredoderus sayanus	Pirateperch
Awaous tajasica	River goby
Gambusia affinis	Mosquitofish
Ictalurus punctatus	Channel catfish
Morone saxatilis	Striped bass
Notropis harperi	Spring chub minnow

To these are added eight additional species reported in this study as having been found within the dark zones of caves:

Scientific Name	Common Name
Amia calva	Bowfin
Ameiurus catus	White catfish
Pylodictis olivaris	Flathead catfish
Lepomis gulosus	Warmouth
Lepomis macrochirus	Bluegill
Pomoxis nigromaculatis	Black crappie
Micropterus salmoides	Largemouth bass
Trinectes maculatus	Hogchoker

All but one (the warmouth) of these eight were discovered via cave diving. A total of 17 taxa has now been found in dark zones of Florida caves, which is almost double the previously known number. Those 17 and the following 12 have been observed in this study within twilight entrance areas of caves:

Scientific Name	Common Name
Ameiurus serracanthus	Spotted bullhead
Centrarchus macropterus	Flier
Cyprinus carpio	Common carp
Esox niger	Chain pickerel
Gobiosoma bosci	Naked goby
Lepomis auritus	Redbreast sunfish
Lepomis microlophus	Redear Sunfish
Lepomis punctatus	Spotted sunfish
Micropogonias undulatus	Croaker
Notemigonus chrysolucas	Golden shiner
Percina nigrofasciata	Blackbanded darter
Unidentified Cichlidae	

None of the latter 12 have previously been reported from cave habitats. A total of 29 species of fishes is now known to have been found in Florida cave habitats.

Systematic Listing Of Florida Cave-Inhabiting Fish

The following is an annotated list of the fishes observed in this study. The designation, "cavern," after a cave's name indicates the species was found only in the twilight zone of the indicated cave.

Order Amiiformes - Family Amiidae - Bowfins

Amia calva Linnaeus, Bowfin, accidental. Madison Co.: Baseline Cave (cavern). Leon Co.: Bird Sink Cave.

Order Anguilliformes - Family Anguillidae - Freshwater Eels

Anguilla rostrata (Lesueur), American eel, trogloxene. Columbia Co.: Jughole Spring Cave. Jackson Co.: Hole-in-the-Wall Spring Cave, Jackson Blue Spring Cave, Twin Spring Cave. Hernando Co.: Eagle's Nest. Holmes Co.: Cypress Spring Cave, Vortex Spring Cave. LaFayette Co.: LaFayette Blue Spring Cave. Marion Co.: Silver Spring/Mammoth Cave (cavern), Silver Glen Spring Cave. Madison Co.: Thunderhole Cave (cavern). Pasco Co.: Arch Sink Cave/Paradise Spring Cave. Leon Co.: Blue Sink Cave.

Order Clupeiformes - Family Clupeidae - Herrings

Order - Family Esocidae - Pikes

Esox niger Lesueur, Chain pickerel, accidental. Suwannee Co.: Luraville II entrance of Telford Spring Cave (cavern).

Order Cypriniformes - Family Cyprinidae - Minnows

Notropis harperi Fowler, Redeye chub, trogloxene. Alachua Co.: Bat Cave, Fern Cave (cavern), Rat Cave. Jackson Co.: Jackson Blue Spring Cave, Hole-in-the-Wall Spring Cave, Merritt's Millpond Dig Spring Cave, Madachalk Spring Cave, Twin Spring Cave. Leon Co.: Blue Sink Cave. Levy Co.: Batey's Signature Cave, Catfish Cave, Day-of-the-Fish Cave, Dolphin Cave, Eyebrow Cave, Gunpowder Cave (cavern), Hickory Cave (cavern), Indian Railroad Cave (cavern), Manatee Spring Cave, Williston Blue Cave, Williston Stadium Cave. Marion Co.: Silver Glen Spring Cave. Suwannee Co.: Azure Blue Cave, Bonnet Spring Cave, Charles Spring Cave, Dyke's Cave, Dyke's Calf Cave (cavern), Falmouth Cave, Peacock Spring Cave, Telford Spring Cave.

Cyprinus carpio Linnaeus, Common Carp, accidental. Suwannee Co.: Charles Spring Cave (cavern). Marion Co.: Silver Glen Spring Cave (cavern).

Notemigonus chrysolucas (Mitchell), Golden shiner, accidental. Hamilton Co.: Corbett Spring Cave (cavern). Madison Co.: Thunderhole Cave (cavern). Suwannee Co.: Charles Spring Cave (cavern), Peacock Spring Cave (cavern), Telford Spring Cave (cavern).

Order Siluriformes - Family Ictaluridae - Bullhead Catfishes

Ameiurus catus (Linnaeus), White catfish, accidental. Suwannee Co.: Cow Spring Cave, Telford Spring Cave (cavern).

Ameiurus natalis (Lesueur), Yellow bullhead, trogloxene. Alachua Co.: Bat Cave. Columbia Co.: Jughole Spring Cave. Gilchrist Co.: Devil's Eye Spring Cave. Hamilton Co.: Artifact Spring Cave, Corbett Spring Cave, Firecracker Cave, Natural Bridge Spring Cave, Overflow Spring Cave, Tanner Spring Cave. Hernando Co.: Eagle's Nest. Holmes Co.: Vortex Spring Cave (cavern). Jackson Co.: Hole-in-the-Wall Spring Cave, Jackson Blue Spring Cave, Madachalk Spring Cave, Merritt's Millpond Dig Spring Cave, Twin Spring Cave. LaFayette Co.: Allen's Millpond Spring Cave, Lafayette Blue Spring Cave, Perry Spring Cave (cavern). Leon Co.: Bird Sink Cave, Blue Sink Cave. Levy Co.: Catfish Cave, Catfish Strike Cave, Cave-That-Got-Away Cave (cavern), Collapsed Cave, Day-of-the-Fish Cave, Dessert Cave, Dolphin Cave, Floyd Collin's Memorial Cave, Four Cave, Gunpowder Cave, Hart Spring Cave, Hickory Cave (cavern), Indian Railroad Cave (cavern), Leotard Cave, Manatee Spring Cave (cavern); Octopus Cave, Peanut Cave, Possum Chimneys Cave, Romulus/Remus Cave, Williston Blue Grotto Cave. Madison Co.: Baseline Cave, M2 Blue Cave, Madison Blue Spring Cave, Thunderhole Cave. Marion Co.: Silver Springs Cave/Mammoth Cave. Pasco Co.: Arch Sink Cave/Paradise Spring Cave. Suwannee Co.: Artifact Spring Cave, Azure Blue Cave, Bonnet Spring Cave, Charles Spring Cave, Cow Spring Cave, Crazy Horse Cave, Dyke's Cave, Falmouth Cave, Line-eater Spring Cave, Little River Spring Cave, Oak's Cave, Peacock Spring Cave, Rock Bluff Spring Cave, Rubus Chimneys Cave, Suwannee Blue Spring Cave, Telford Spring Cave. Wakulla Co. (T.L. Morris, pers. comm.): Indian Spring Cave, Wakulla Spring Cave.

Ameiurus nebulosus (Lesueur), Brown bullhead, trogloxene. Hamilton Co.: Firecracker Cave. Leon Co.: Bird Sink Cave. Levy Co.: Catfish Cave. Madison Co.: Baseline Cave, Thunderhole Cave. Suwannee Co.: Bonnet Spring Cave, Charles Spring

Cave, Cow Spring Cave (cavern); Little River Spring Cave (cavern), Peacock Spring Cave, Telford Spring Cave.

Ameiurus serracanthus Yerger and Relyea, Spotted bullhead, accidental. Madison Co.: Madison Blue Spring Cave (cavern).

Ictalurus punctatus (Rafinesque), Channel catfish, trogloxene. Hamilton Co.: Tanner Spring Cave. Jackson Co.: Madachalk Spring Cave. Lafayette Co.: Lafayette Blue Spring Cave. Madison Co.: Madison Blue Spring Cave, Thunderhole Cave (cavern). Suwannee Co.: Cow Spring Cave.

Pylodictis olivaris (Rafinesque), Flathead catfish, accidental. Jackson Co.: Madachalk Spring Cave (this observation was reported to the author by T.L. Morris).

Order Percopsiformes - Aphredoderidae - Pirateperches

Aphredoderus sayanus (Gilliams), Pirateperch, accidental. Hamilton Co.: Overflow Spring Cave (cavern). Suwannee Co.: Bonnet Spring Cave, Charles Spring Cave, Telford Spring Cave.

Order - Atheriniformes - Family Poeciliidae - Livebearers

Gambusia affinis (Baird and Girard), Mosquitofish, accidental. LaFayette Co.: Allen's Millpond Spring Cave (cavern). Orange Co.: Apopka Blue Cave (cavern). Suwannee Co.: Peacock Spring Cave (cavern).

Order Perciformes - Family Percichthyidae - Temperate basses

Morone saxatilis (Walbaum), Striped bass, accidental. Marion Co.: Silver Glen Spring Cave (cavern).

Order Perciformes - Family Centrarchidae - Sunfishes

Centrarchus macropterus (Lacepede), Flier, accidental. Madison Co.: Baseline Cave (cavern). Marion Co.: Silver Springs Cave/Mammoth Cave (cavern). Suwannee Co.: Telford Spring Cave (cavern).

Lepomis auritus (Linnaeus), Redbreast sunfish, accidental. Hernando Co.: Diepolder III Cave. Marion Co.: Silver Springs Cave/Mammoth Cave (cavern). Suwannee Co.: Bonnet Spring Cave (cavern; introduced), Cow Spring Cave (cavern), Peacock Spring Cave (cavern).

Lepomis gulosus (Cuvier), Warmouth, accidental. Hernando Co.: Eagle's Nest Cave (cavern). Levy Co.: Catfish Cave. Suwannee Co.: Charles Spring Cave (cavern), Telford Spring Cave (cavern).

Lepomis macrochirus Rafinesque, Bluegill, accidental. Holmes Co.: Vortex Spring Cave (cavern). Madison Co.: Thunderhole Cave (cavern). Marion Co.: Silver Springs Cave/Mammoth Cave (cavern). Suwannee Co.: Peacock Spring Cave (cavern), Telford Spring Cave.

Lepomis microlophus (Gunther), Redear sunfish, accidental. Suwannee Co.: Peacock Spring Cave (cavern).

Lepomis punctatus (Valenciennes), Spotted sunfish, accidental. Suwannee Co.: Telford Spring Cave (cavern).

Micropterus salmoides (Lacepede), Largemouth bass, accidental. Jackson, Co.: Alligator Cave (cavern), Hole-in-the-Wall Spring Cave (cavern), Twin Spring Cave (cavern). Marion Co.: Silver Spring Cave/Mammoth Cave (cavern). Pasco Co.: Arch Sink Cave/Paradise Spring Cave. Suwannee Co.: Peacock Spring Cave (cavern), Charles Spring Cave (cavern).

Pomoxis nigromaculatus (Lesueur), Black crappie, accidental. Holmes Co.: Cypress Springs Cave (cavern), Vortex Spring Cave (cavern). Madison Co.: Thunderhole Cave. Suwannee Co.: Charles Spring Cave (cavern), Peacock Spring Cave (cavern), Telford Spring Cave (cavern).

Order Perciformes - Family Percidae - Perches

Percina nigrofasciata (Agassiz), Blackbanded darter, accidental. Madison Co.: Madison Blue Spring Cave (cavern). Suwannee Co.: Telford Spring Cave (cavern).

Order Perciformes - Family Sciaenidae - Drums

Micropogonias undulatus (Linnaeus), Atlantic croaker, accidental. Marion Co.: Silver Glen Spring Cave (cavern).

Order Perciformes - Family Cichlidae - Cichlids

Unidentified species, accidental. Marion Co.: Silver Glen Spring Cave (cavern).

Order Perciformes - Family Gobiidae - Gobies

Gobiosoma bosci (Lacepede), Naked goby, accidental. Marion Co.: Silver Glen Spring Cave (cavern).

Order Pleuronectiformes - Family Soleidae - Soles

Trinectes maculatus (Bloch and Schneider), Hogchoker, accidental. Suwannee Co.: Charles Spring Cave, Telford Spring Cave.

SUMMARY

Twenty-nine species of fishes are now known to occur in cave habitats in Florida, of which 17 are from within dark zone habitats and 12 within twilight lit cavern entrances to caves. Only eight species were known previously from cave dark zones and none of the cavern-dwelling 12 had been reported. This significant increase in the known checklist is due to the use of cave diving technology. The relatively large database reported in this study indicates that for Florida, no troglobitic or troglophilic fish is likely to be discovered and the number of trogloxenes is unlikely to increase much beyond five, but possibly many accidentals will be added.

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DIVING PROTOCOL FOR STERILE SAMPLING OF AQUIFER BACTERIA IN UNDERWATER CAVES

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Microflora of phreatic conduits are not accessible to ordinary environmental microbiology sampling techniques. Therefore, ecosystems found in underwater caves have received very little study. The combination of sterile technique for environmental sampling of microorganisms with technical cave diving procedures is required if aquifer bacteria in phreatic limestone conduits are to be sampled and studied. Groundwater bacteria in underwater caves have only recently been sampled by divers. Challenges such as sample container buoyancy, confined space, darkness, remoteness of sampling sites, and an aquatic environment were met by cave divers sampling bacterial colonies while hovering in the water column in underwater caves. A set of suggested instructions is provided for qualified cave divers to collect samples from visible natural colonies of aerobic and microaerophilic bacteria and other microorganisms in underwater cave environments while maintaining sterile technique. Sterile 50 ml tubes were used successfully to collect the bacteria. Collecting bacteria in underwater caves with sterile syringes was less successful. Bulk water samples collected from the vicinity of sampled bacteria colonies were autoclaved and used to improve isolation and culture of some fastidious aquatic bacteria such as Thiothrix *spp. A low pressure hose and air nozzle are used to purge outside non-cave water from these water sample jugs. Safety and conservation practices are important in this type of field work. Logistical details of preparation for the dive and handling of samples during and after the dive are described. Modifications for sampling anaerobic bacteria under N_2 gas are suggested. Study of underwater cave microflora may contribute substantially to a better understanding of groundwater biogeochemistry, carbonate geochemistry, speleogenesis, subsurface microbial ecology, paleo-ecology, the ecology of cave macrofauna, and global nutrient cycling.*

INTRODUCTION

Ecosystems found in underwater caves have received very little study (Streever, 1994). Cave divers have observed bacterial colonies large enough to be visible to the naked eye in springs and underwater limestone caves within the Floridan aquifer in Florida (Brigmon et al., 1994b; Martin, 1992; Martin and Brigmon, 1994), in underwater caves and meromictic sinkholes on the Yucatan peninsula in Mexico (Ervine, 1992; Morris, 1994; Wilson and Morris, 1994), and the phreatic brackish water caves in the Nullarbor karst plain in Australia (James and Rogers, 1994). Divers' observations of these colonies include thin white or gray mats or tufts on cave floors, filamentous masses in the water column, drooping threads or sheets of slime, and gelatinous masses attached to the cave floor. Underwater cave fungi have been observed in a Yucatan cenote (Brigmon et al., unpublished data). Underwater cave bacteria from Florida were identified with monoclonal antibodies and examined with electron microscopy (Brigmon et al., 1994a, 1994b, 1994c). Bacteria such as the sulfide oxidizing *Thiothrix* that are found in underwater caves can form aquatic biofilms which contribute to biofouling of municipal water storage tanks, sewage treatment facilities, private wells, and drip irrigation systems (Brigmon et al., 1995).

The bacteria collected in underwater caves may constitute a valuable genetic resource (Martin et al., 1994). Bacterial cultures from several deep non-carbonate aquifer sites have been collected by means of geotechnical drilling during groundwater and geology research sponsored by the U.S. Department of Energy (Fliermans and Hazen, 1990). These cultures, the Subsurface Microbial Culture Collection, and related computer data bases, have been made available for research and private industry (Balkwill, 1993). Vadose cave bacteria samples have yielded an anti-tumor compound (Mallory and Bigelow, 1994). At least one pharmaceutical company has begun aquifer bacteria sampling in underwater caves, yielding several new bioactive compounds (Dr. S. Sharples, Eli Lilly, Indianapolis, IN, personal communication).

The purpose of this paper is to describe a protocol that certified, experienced cave divers can use for grab sampling of aerobic and microaerophilic bacteria and other microorganisms in underwater caves.

MATERIALS AND METHODS

The logistics for sampling aquatic bacteria in underwater caves were worked out while conducting research on the sulfide oxidizing filamentous bacteria *Thiothrix* (Brigmon et al., 1994a, 1994b, 1994c; Martin and Brigmon, 1994). These methods were based on a combination of standard environmental microbiological sampling methods and those (methods) for sampling sediments (Martin and Harris, 1992) and macro-invertebrates (Morris, 1989; Morris and Butt, 1992; Streever, 1992; Yager, 1989) in underwater caves.

Research cave divers should learn as much as possible about the biological, microbiological, hydrological, and geological factors they are likely to encounter in the underwater cave. If possible, determine the limestone formation in which the cave to be sampled is found. The limestone formation can often be inferred from stratigraphy data in State Geological Survey publications on the region where the cave is located (Martin and Harris, 1992).

Diving Techniques and Equipment

Lighting the work area. A helmet-mounted light can greatly facilitate divers' sampling work in the cave. Kayaking and bicycling helmets have proved useful for cave diving. Normal caving helmets are not generally useful for diving due to their bulkiness and straps. Cave diving helmets should be able to fit over the diver's head with or without a neoprene hood. Light-mounting brackets can be purchased or made from schedule 40 PVC pipe. Lights for helmet mounting should be as bright and lightweight as possible and should be of the type that can be turned on and off with one hand. Ikelite's "Mini-C" light is easy to turn on and off but is heavy and can cause some neck strain for the diver. Underwater Kinetics's "Super Q" and similar lights are perfectly shaped, light-weight, and easy to wear on a helmet, but they require two hands to turn on and off so can be inconvenient at times. The head lamp of a primary cave diving light can be mounted on the helmet, providing plenty of light to the area where the diver's hands are working. It is, however, inconvenient for the diver to install or remove the primary light head on the helmet during the dive because this generally requires two hands.

The light is most effective during sampling if it is mounted on the helmet at a downward angle. The degree of this angle is a matter of personal preference of the diver. Since bacteria sampling requires use of both hands, hand-held lights, cameras, and diver propulsion vehicles must be set aside or passed to the safety diver or assisting diver before sampling at a site in the cave. This should be done carefully so as not to stir up bottom sediment. In order to accomplish this, the sampling cave diver needs to hover in the water column or crouch gently on the bottom downstream of the sampling site.

Water sample containers. We have found that the most useful water sample containers are 2 L plastic bottles with a built-in handle. Such bottles are apparently not available from laboratory ware suppliers. Thus we recycle half gallon (1.9 L) #2 HDPE plastic milk jugs by rinsing thoroughly with tap water after all milk is consumed. Acid washing and an additional rinse with deionized water would be useful for removing trace milk constituents and chlorine residue. Milk jugs are particularly useful because unlike standard laboratory plastic-ware, milk jugs have a built-in handle which is easy to hold while SCUBA diving, even while wearing gloves or when divers' hand are numb with cold. Use jugs with screw-on lids, not snap-on lids. Attach a brass dog-collar clip to the handle of each water jug with a cable tie.

Air for purging water sample containers. Install an air jet nozzle on a power inflator hose attached to one of the first stage SCUBA regulators. Two types of air jet nozzles are available, one with a flexible rubber nipple that is opened by bending and a metal one with a handle (Amflo, Inc., Santa Ana, CA). We have found the metal ones to be easier to use. These nozzles can be obtained from some full service dive shops. If the buoyancy control device or dry suit inflator hose is attached to the left first stage regulator, secure the nozzle hose to the right first stage regulator. Attach a brass dog-collar clip on the nozzle so the nozzle can be clipped off where it is convenient to the diver.

Miscellaneous dive gear. Take an accurate and rugged underwater thermometer. Standard small thermometers encased in protective cases are difficult to read accurately while cave diving. The best thermometer we have found for cave diving is one that is built into a digital diving watch. There are several brands available. They appear to be precise but we are not aware of any testing of their precision or accuracy. The precision and accuracy of digital thermometers built-in to diving watches should be tested in future research. Divers should have an accurate depth gauge. Diving computers are very helpful when sampling in underwater caves.

Sampling divers and assisting divers should carry at least one extra underwater writing slate each. These slates should be formatted before the sampling dive with spaces for information that will be needed to fill out a sample log sheet or field data notebook.

In order to collect *in situ* water chemistry data, divers can deploy battery powered remote water chemistry analysis sondes. Remote sondes such as Hydrolab's Datasonde and Yellow Springs Instrument's YSI 6000 are available commercially. At pre-selected intervals, sondes can determine and record *in situ* water pH, salinity, O_2 concentration, oxidation-reduction potential, depth, and temperature. Unfortunately, however, they are not currently equipped to determine alkalinity, hardness, total dissolved solids, or concentrations of mineral elements, CO_2, or H_2S. A remote underwater chemical analysis sonde was recently deployed in Warm Mineral Springs near Venice, Florida to a depth of 65 m (Brigmon et al., unpublished data).

Handling sample containers underwater.

Sampling containers can be stowed by divers in strapped-on pouch-pockets, wet suit or buoyancy control vest pockets, or in water-filled "dry" boxes with handles that are clipped off to a "D" ring. Pouch pockets and "dry" boxes can be purchased at full-service dive shops. The "dry" box should have a brass dog-collar clip attached to its handle with a cable tie.

Sterile sampling tubes and polyethylene sample bottles and their caps are positively buoyant under water, so the sampling diver must not let go of the container or cap. This is why one of the authors prefers pouch pockets to "dry" boxes for stowing sample containers. When a flooded "dry" box is opened under water, even flooded polyethylene sample containers will all tend to float out of the box, so great care must be taken when opening and closing the box. The advantage of a "dry" box over a pouch is that sample containers in the box are cushioned by the flood-water in the box from being knocked about. The entire box can be put on ice after the dive and not opened until arrival at the microbiology laboratory. If loss of container caps during sampling is considered likely, velcro can be glued onto each cap and onto some area of the container (Dr. Jill Yager, Antioch College, personal communication). The ideal bacteria sample container for use in underwater caves, would be one that is slightly negatively buoyant underwater, water-filled, sterile, and easy to manipulate even with gloved or cold hands.

Safety

For technical and safety details of cave diving practices, see Prosser and Grey (1992) and Balcombe et al. (1990) and older works by Exley and Young (1982), Lavaur (1956), and Mount (1973). If you read Rumanian, see Lascu and Sârbu (1987). For general information on research diving, consult Flemming and Max (1990) and Miller (1979). For specific recommendations on research cave diving, consult Balcombe et al. (1990), Bozanic (1985, 1992), Horne (1990), Flemming and Max (1990), Gliedt (1991), Lascu and Sârbu (1987), Murphey (1985), Skiles (1987), and Wood (1990). None of these works, however, addresses methods for microbiological sampling with SCUBA in underwater caves or other underwater settings. Bottrell et al. (1991) used cave divers to collect water samples in Bahamian blue holes but did not describe how samples were taken.

Adhere to safe cave diving practices at all times. Safety of divers takes precedence over all scientific objectives (Flemming and Max, 1990). Only experienced, "full cave"-certified divers should engage in research cave diving. Research cave divers should have diver's accident insurance including air-ambulance coverage.

Conservation

The biogeochemical ecosystems created by these bacteria are unusual, delicate, and easily disrupted by careless movement, thoughtless exploration (Balcombe et al., 1990; Bozanic, 1992; More and Poskey, 1990; Saltsman, 1991; Yager, 1986), or over-collecting of biological specimens (Daunt-Mergens, 1981; Smith, 1991). Cave conservation policies have been adopted by the (U.S.) National Speleological Society, the Cave Research Foundation, and the (British) Cave Diving Group. Underwater cave researchers should be aware of these policies. Sampling should be done with care, causing minimal disturbance to cave features and cave life.

Pre-Dive Logistics

Bring a packet of sterile 50 ml tubes, clean water (milk) jugs, an ice chest, and ice to the dive site. Label all sampling containers with secure markings. Include in labels: sample number, date, initials of sampling diver, and cave name. Indelible markers are best for writing on plastic containers. Using tape for labeling sample containers should be avoided because tape can fall off under water. We found this to be so in the early stages of our bacteria field work. Record sample label information on a sample log sheet or directly in a field notebook before the dive.

Just before the dive, break the seal on the packet of sterile air-filled tubes so individual tubes can be stowed by the divers. The entire sterile air-filled pack is too large and buoyant to take under water. Do not open the tubes except at the site and time of sampling. Each diver can easily manage three or four air-filled tubes. Our experience sampling in Florida caves has shown that each diver will not have time to collect more than four samples if required decompression is to be kept to a reasonable duration. In shallow caves such as those found in the Yucatan in Mexico, more than four samples per diver can be taken (Dr. Jill Yager, Antioch College, personal communication). If the cave is not deep, i.e., greater than 30 m, tubes should not implode. We have observed no implosion of sterile 50-ml polypropylene centrifuge tubes at depths of 30 m (100 ft) or less. We have observed, however, that at depths approaching 30 m, it was difficult to remove lids from sterile air-filled tubes due to elevated pressure. For deep sampling (> 30 m), sterile tubes can be filled with autoclaved water in a sterile laminar flow hood in the laboratory.

Fill water jugs with deionized water prior to the dive or fill with clean springwater in the spring-bowl or diver entrance area and clip on to divers at or below the water surface. Filling the jugs with sterile deionized water may be required for some sampling plans.

Before conducting final safety checks ("S" drill), go over the dive plan. There are various ways to arrange the tasks of members of the dive team depending on the size of the team and size and nature of the cave. The number of cave divers in a research team is a function of the size of the cave, the sampling tasks required, and the need for minimal environmental disturbance. While we cannot recommend solo cave diving, there are some very tight cave areas of scientific interest which can only be accessed by a single diver using a side-mount SCUBA tank configuration. In caves that are a little roomier, a two-diver team is desirable. In larger caves a three-diver team is desirable, especially if photography or video work is planned. Where there is room for more than one diver, one diver should be the primary sampling diver. The second diver should record data and assist the sampling diver. If a third diver is present, he or she should act as a safety diver and/or carry out photography, video, *in situ* drawings, or chemical analysis sonde deployment. The cave diving setting requires unique photographic (Fiorell, 1990; Priddy, 1992) and video (Brown, 1992) techniques.

Sampling Technique

General considerations. If the diving safety protocol permits, water and bacteriological sampling should be done on the way into or on the way down to the most distant/deepest sampling point during the dive (Horne, 1990). Careful region-by-region sampling, temperature measurements, and other operations should be done during the inbound part of the journey. In some caves, this is necessary to maintain the integrity of the water-column stratigraphy and chemistry which may otherwise be disrupted and/or contaminated by divers' movements and the upwelling of deeper, sometimes colder water by divers' air exhaust bubbles (Horne, 1990). In-bound sampling is particularly important in sinkholes, where most of Horne's (1990) methods were developed. Siphon caves present a unique sampling challenge. Whether it is best to sample bacteria in a siphon cave on the way in or on the way out depends on the penetration distance and the rate of cave water flow.

The collection of microbiological samples has been found to be a slow process even with the most efficient methods, thus shallow sampling sites are desirable. If samples are to be collected at deep (> 30 m) sites, be sure to consider the time-consuming nature of collecting samples in the dive plan.

Maintain sterile technique as much as practically possible when collecting cave microorganisms. Water samples for laboratory culturing, however, do not have to be sterile because they will be autoclaved prior to use in the lab. For some microbiological specimens, filtering the water may be preferable to autoclaving because autoclaving will likely denature some proteins that may serve as growth factors.

At some bacterial colonies, it is useful to collect one sample with and one without adjacent sediment. If the bacteria colony is growing on limestone, collection of a piece of substrate or adjacent limestone may be valuable. Store rock samples in labeled sterile whirl-pack bags. Weirich and Schweisfurth (1985) developed methods for the culturing of microorganisms found in rock matrices.

Water samples for culturing should be collected in the same area where the bacterial colony is located. The *in situ* water in these water samples is necessary for effective laboratory isolation and culture of some aquifer bacteria. Some underwater cave bacteria are hard to culture in the laboratory without springwater or other groundwater from the same sight or similar sights being added to the culture media (Brigmon, 1992; Brigmon et al., 1994a, 1994b, 1994c). Specificity of bacterial isolates for water sources is likely due to a combination of overall water chemistry and some unknown growth factors (Brigmon et al., 1994a).

Sampling with a syringe. Sampling with sterile syringes was attempted but found to be less practical than sterile tubes. One or two syringes could be carried to the sampling site in their sterile air-filled packets. Once the syringe is removed from the packet, the wrapping must be stowed by the diver. Once filled with bacteria and matrix water, the syringe contents can be emptied on-site (in-cave) into a sterile plastic whirl-pack bag. Several syringe-fulls of sample can be emptied into one bag.

Sampling with syringes was found to be substantially more time-consuming than sampling with tubes. Sampling bacteria colonies growing on cave floor sediments with a syringe was hampered by fouling of the syringe orifice by large sediment particles such as sand grains. Cutting off the end of the tip of a large syringe (50 cc) created a larger orifice which allowed easier sampling. This modification compromises sterility, however, unless the syringe is re-autoclaved and re-packaged.

An open syringe with plunger extended was awkward to handle for the cave diver. It is possible that a syringe with a capability for locking the plunger in the open position could be used. If, however, the syringe is large enough to collect an adequate sized sample, it likely will be too long, once extended, to be stowed conveniently by the diver. It is possible, however, that the syringe method could be refined to make it more practical for sampling in underwater caves.

A sterile slurp gun should be tried if a slurp gun can be autoclaved. Slurp guns are plastic suction devices designed for live collecting of fish and invertebrates in aquatic and marine settings. Methods for sterile stowing of the slurp gun would have to be worked out.

Sampling with sterile tubes. We have found sterile 50 cc tubes to be the best container for sampling bacteria in underwater caves. The following procedures have been successful:

1. Uncap the tube directly at the bacteria colony. Try to get as much bacteria as possible into the sample tube. Sample different-looking bacteria colonies in separate containers. Be careful not to lose tube caps.

Our experience has been that the best way to collect bacteria occurring as films on surfaces such as rock, clay, or iron oxide deposits, is to scrape the bacteria off with the mouth of the tube, orienting the tube so the bacteria (with a specific gravity slightly greater than water) sink into the tube. Flocculent bacteria, usually found in cave areas of little flow, can be collected by gently pushing the tube through the colony and if necessary, prodding the sample into the tube with the cap.

2. Replace the cap on the tube and secure tubes in a pouch, pocket, or box.

3. Collect bulk *in situ* water samples as close to the sampled bacteria colony as possible. To collect the water samples for culture media preparation, purge outside water from the jug with the air nozzle while holding the jug upside down. This is much more efficient than purging with an octopus regulator. Do this two or three times (filling the jug with *in situ* water in between) to insure the integrity of the sample (Horne, 1990). Where cave water flow is substantial, this can be done without stirring up cave floor or ceiling sediment or contaminating *in situ* water samples with water of a different chemistry. Where cave water flow is limited, care should be taken to minimize disturbance of cave ceiling sediment and contamination of *in situ* water samples with water of a different chemistry. Be careful not to lose jug caps. Other methods for water sampling by SCUBA divers described by Miller (1979) are not generally practical in the underwater cave setting.

4. Replace the cap on the jug and clip the jug to the diver.

On-Site Observations.

Record on an underwater slate, observations about the sampling site. Include water temperature, depth, distance from cave entrance, water current by method of Wilson (1991), and any other pertinent data. If diving a Ghyben-Herzberg lens cave such as those in the Yucatan and Bahamas (Brigmon et al., unpublished data), indicate if samples were taken in the fresh or salt water layer and the vertical distance from the halocline if one is present. These data are usually most conveniently recorded by the safety or support diver while the sampling diver is collecting bacteria.

Describe the color, shape, and position of the bacteria colony. Is it attached to the bottom or some other substrate? Is it stringy, fluffy, or slimy in appearance? If time allows, draw a picture of the colony, particularly if photography is not part of the dive plan.

Exiting the Cave

From the sampling site, the diver must swim all the way out of the cave, possibly picking up stage bottles and negotiating low or narrow restrictions where gear can be knocked about. Careful stowing of samples is critical. We have lost some bacteria and sediment samples on the way out of the cave.

Before exiting the cave, the diver must often decompress for as long as an hour or more. During this time, samples will be at the temperature of the ground water in the area where decompression is conducted. If the samples must be delivered to the surface quickly, support divers can enter the cave and retrieve the samples from the decompressing divers and deliver them to surface staff. Finally the diver climbs out of the water, exposing gear and samples to more jostling. Carefully passing samples to surface-staff at the water surface can minimize jostling of samples.

After the Dive

Upon exiting the cave, place bacteria sample tubes, water sample jugs, and rock sample bags in the iced cooler as soon as possible. Some samples may need to be treated with fixatives or concentrated acid if sampling for protozoans, sulfide, or soluble minerals. Procedures for sample preservation should be worked out with laboratory staff.

After gearing-down from the dive, but before leaving the dive site, record sample information on the sample log sheet or in a field data book. Transcribe all notes from underwater writing slates. If a map of the cave is available, mark sampling sites on the map. Keep samples on ice until processing at the microbiology laboratory.

Sampling anaerobic bacteria

We have not sampled anaerobes but propose the following modifications for sampling anaerobic bacteria in underwater caves: 1) Sterile sampling tubes should be configured for sampling of anaerobes. Gas in sterile tubes should be N_2, not air. If tubes are filled with sterile water, that water must also be O_2-free. 2) Do not use air from the SCUBA tank to purge the water sample jug. Fill a "pony bottle" (tank with 25 or less cubic feet capacity) with pure nitrogen gas. The nitrogen gas can be obtained from a welding shop. If the tank is not a SCUBA cylinder, the valve will have to be modified with a fitting that allows attachment of SCUBA fittings. These fittings are available at some full-service dive shops, particularly those catering to cave divers. Do not put a second stage regulator on this tank since breathing this gas could be fatal. To the first stage regulator on this tank, attach only a low pressure hose with an air jet nozzle and a pressure gauge. Attach the N_2 bottle to the doubles or wherever convenient to the diver and secure the N_2 hose and nozzle where the diver can get to it and will not confuse it with an air nozzle secured elsewhere on the diver. 3) When collecting the sample, open and close the sample container only in the anaerobic zone. 4) After the dive and after putting anaerobe samples in the cooler, purge the air from the cooler with N_2 gas from the nitrogen tank. A separate cooler for anaerobic samples may be useful. Conduct all sample transfers "under" N_2 gas to the extent possible under field conditions.

DISCUSSION AND CONCLUSIONS

While conducting research on the sulfide oxidizing aquifer bacteria *Thiothrix* (Brigmon, 1992, Brigmon et al., 1994a, 1994b, 1994c; Martin and Brigmon, 1994), the authors have worked out these techniques for sampling aerobes and have found them to be reliable and convenient. These methods can be adapted with some modifications for sampling protozoa, zooplankton, nematodes, and fungi in underwater caves. Sterile core tube sampling of phreatic cave sediment bacteria has not been attempted. Developing sterile techniques for core sampling of sediment bacteria in underwater caves will require creative attention to logistics including sterile stowing and transport of cores out of the cave. Sterile core-holding boxes or tubes would have to be constructed.

Many phreatic voids of biogeochemical interest may be inaccessible to the science cave diver because they are too deep, too small, or unconnected to any opening. It is likely that such inaccessible voids contain far greater volumes of conduit water than do diver-accessible voids. Thus, the microbial biomass and biogeochemical activity in inaccessible voids may be greater than in diver-accessible voids. Direct observation and sampling of diver-inaccessible voids will likely be limited to drilling and remotely controlled video and sampling devices for the foreseeable future.

Unusual bacteria and other organisms sampled from underwater caves have the potential to provide valuable genetic resources for basic research and biotechnology applications (Martin et al., 1994). Study of underwater cave microflora may contribute substantially to a better understanding of groundwater biogeochemistry, carbonate geochemistry, speleogenesis, subsurface microbial ecology, paleo-ecology, the ecology of cave macrofauna, and global nutrient cycling.

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SPELEOTHEMS OF AEROSOL ORIGIN

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Peculiarities of morphology, structure, and restricted occurrence of some types of gypsum speleothems (crystals, rims, hollow "stalagmites") have been studied from caves of the Western Ukraine, Kugitang Range (Turkmenistan), and Guadalupe Mountains (USA). All of these speleothems seem to be formed by precipitation from aerosols controlled by air flow patterns. Enhanced radioactivity of caves and high ionization of the cave air seem to be the major prerequisites for autochthonous cave aerosol formation. As a result of radioactive decay and the impact of alpha particles on condensation aerosols, aeroions of chemical compounds and solid aerosols are formed. Mechanisms of transport and precipitation of aerosol material to produce the above formations are suggested. We conclude that many subaerial speleothems are of aerosol genesis.

INTRODUCTION

Most mineral formations in caves (speleothems) are considered to originate from the precipitation of dissolved substances from water solutions under vadose (stream or film water, lakes, dripping water) and, less frequently, phreatic conditions. Precipitation occurs as a solution evaporates, or at other physico-chemical thresholds (for example, loss of carbon dioxide) that disturb the equilibrium state. A publication by Cser and Maucha (1968) presents limited data proposing an aerosol origin for just one type of speleothem: needlelike helictites (presumably aragonite). In view of the lack of measured data known about cave aerosols in relation to mineral formations, we are obliged to build a justification on theoretical considerations, and to derive it from a consideration of morphology, structure, and spatial localization of the mineral formations.

In this paper we attempt to substantiate an aerosol origin for several types of gypsum speleothems of various morphology and size occurring in caves of different types and in different regions. Advances made during the past decade concerning the physical properties of cave environments leads to a new model of formation of autochthonous aerosols in caves and mechanisms of speleothem growth involving aerosol effects.

GYPSUM SPELEOTHEMS IN THE GYPSUM CAVES OF THE WESTERN UKRAINE

Gypsum crystals of varying shapes and sizes are the most common type of speleothem in the large gypsum caves of the Western Ukraine. These large maze caves were formed in Miocene gypsum strata under confined conditions due to dispersed upward recharge from an underlying aquifer (Klimchouk, 1991). During the late Pleistocene and Holocene the caves were in a "relict" state under vadose conditions; in places the water table remains today in the lower part of the gypsum strata. The low permeability of a superincumbent clay stratum prevents downward percolation into the gypsum strata except at local areas of tectonic weakness or where the confining bed has been removed.

In the caves of the region, gypsum crystals of tabular, prismatic, and columnar habit are widespread, having typical sizes of 1-2 cm, although crystal individuals or aggregates up to 5-10 cm are not rare. Needlelike (acicular) crystals forming "hoarfrost" are also common and commonly cover crystals of a previous generation. Gypsum crystals are unevenly distributed throughout the caves, normally strictly localized on the lower or middle part of walls. It was previously believed (Dubljansky and Smol'nikov, 1969; Dubljansky and Lomaev, 1980) that the crystals formed under subaqueous conditions, in low-current lakes supersaturated with respect to calcium sulfate. Later authors suggested that the crystals formed subaerially due to growth through precipitation of gypsum from supersaturated water films slowly moving down the wall (Klimchouk and Rogozhnikov, 1982; Rogozhnikov, 1984; Klimchouk and others, 1990). The possibility of crystal formation from aerosols was also suggested in the last citation. The largest, most prominent crystals grow at the expense of gypsum precipitation from water drops that accumulate on the tips of individual crystals.

In most cases, crystal sites are strictly localized and cover an area of some dozens of cm^2 to m^2, the boundaries being more or less distinct. Crystals characteristically settle on corners formed by passage intersections (Figs. 1-4). As a rule, crystals may occur on one particular corner of an intersection. In many places crystals settle on a central boulder or ceiling pendant at an intersection (Figs. 5-7). Crystals are often restricted to certain levels, especially hoarfrost-like crystals (Figs. 8-9). The site boundaries are usually horizontal and linear, especially in the cases of the hoarfrost crystals. Another typical occurrence is around holes of lower-level passages entering larger passages of an upper level (Fig. 1f). Lower-level passages commonly contain water-table lakes in the lowermost part of the gypsum strata. Crystals nor-

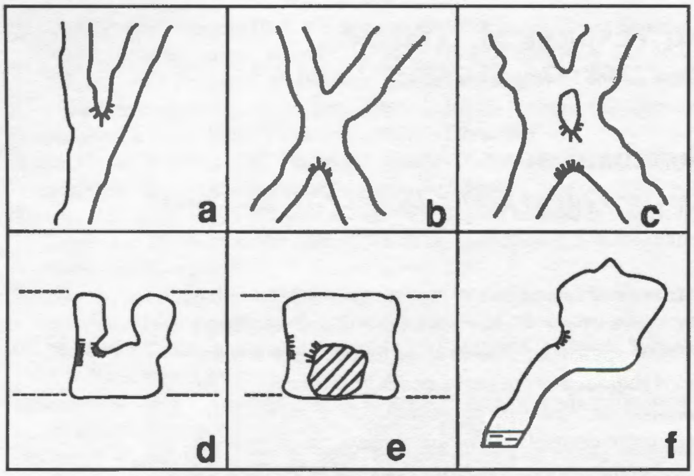

Figure 1 Maps showing typical crystal accumulation sites in gypsum caves of the Western Ukraine. A, B, and C are plan views. D, E, and F are cross sections.

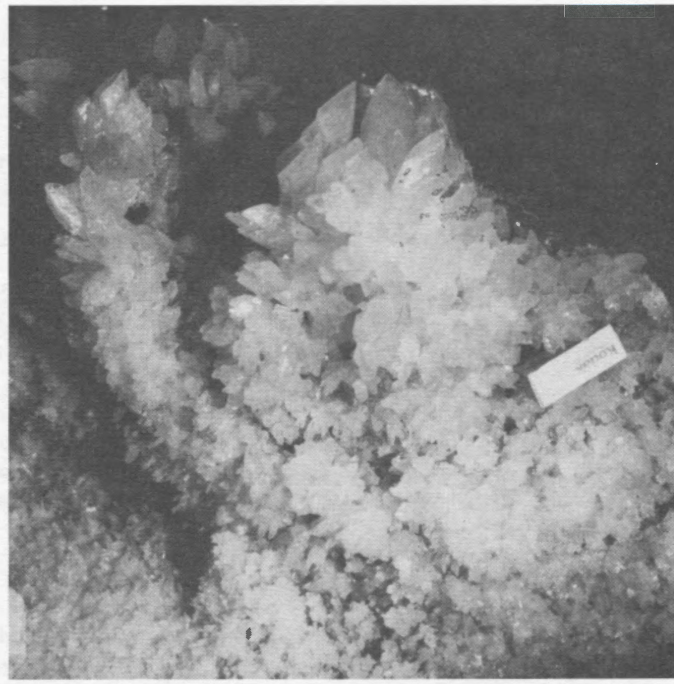

Figure 3 Typical site of gypsum crystals on corners of passage intersections, Dzhurinskaja Cave, Western Ukraine. Photo by A. Klimchouk.

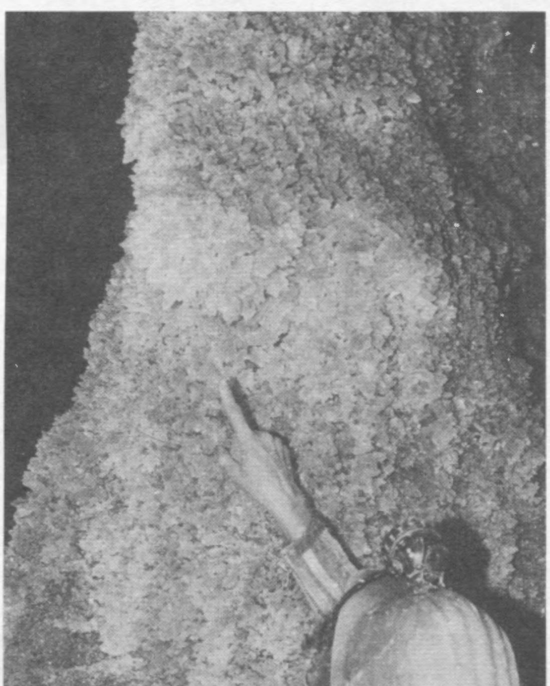

Figure 2 Typical site of gypsum crystals on corners of passage intersections, Slavka Cave, Western Ukraine. Photo by A. Klimchouk.

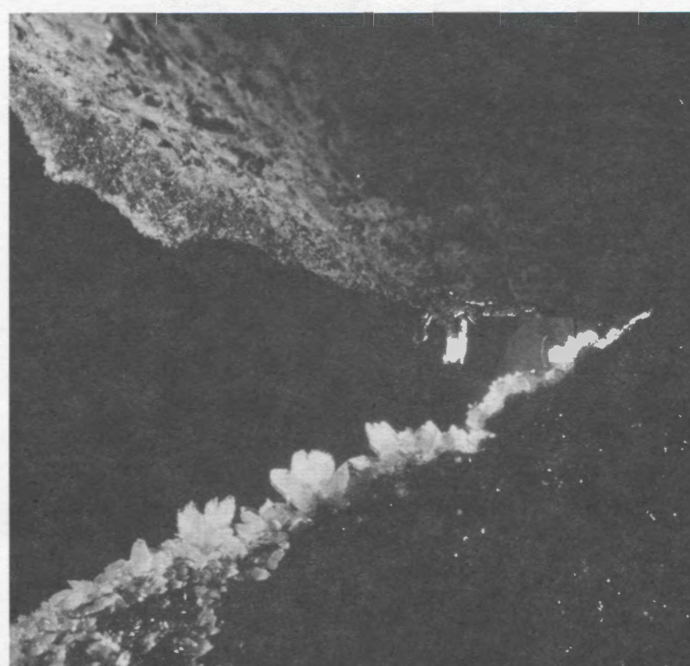

Figure 4 Typical site of gypsum crystals on corners of passage intersections, Optimisticheskaya Cave, Western Ukraine. Photo by A. Klimchouk.

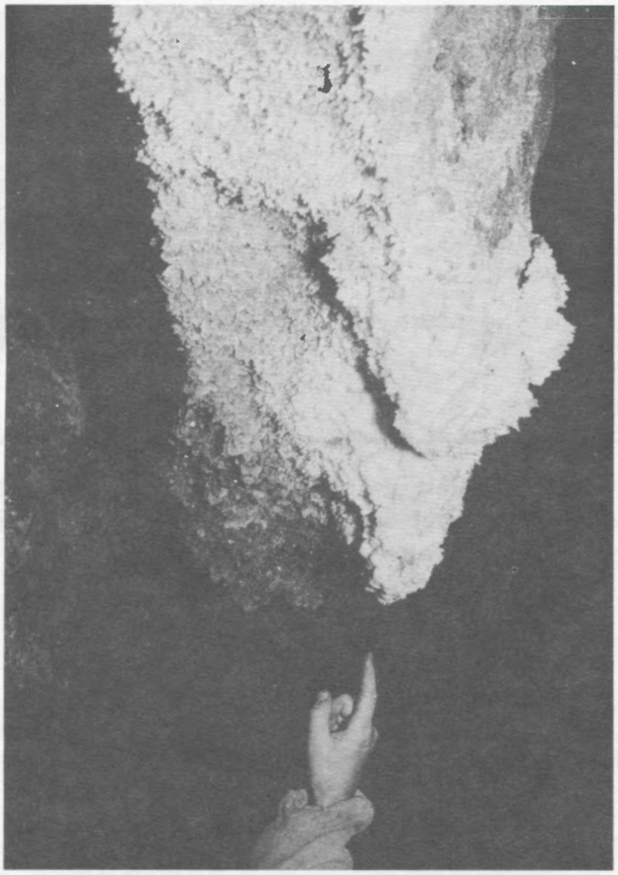

Figure 5 Typical site of gypsum crystals on pendants located at passage intersections, Slavka Cave, Western Ukraine. Photo by A. Klimchouk.

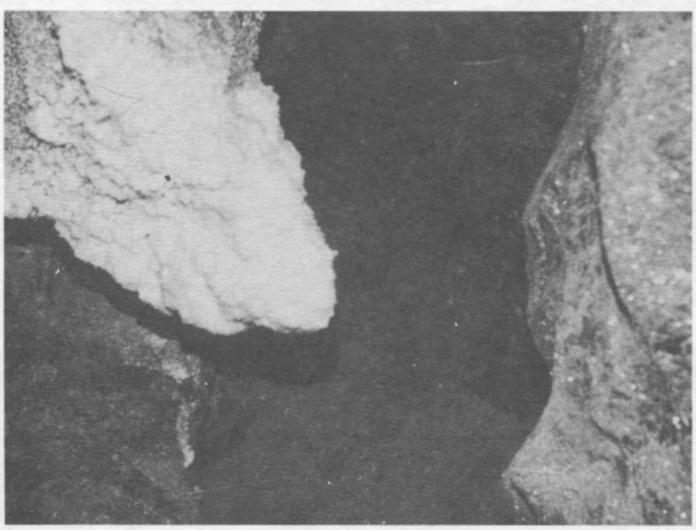

Figure 6 Typical site of gypsum crystals on pendants located at passage intersections, Slavka Cave, Western Ukraine. Photo by A. Klimchouk.

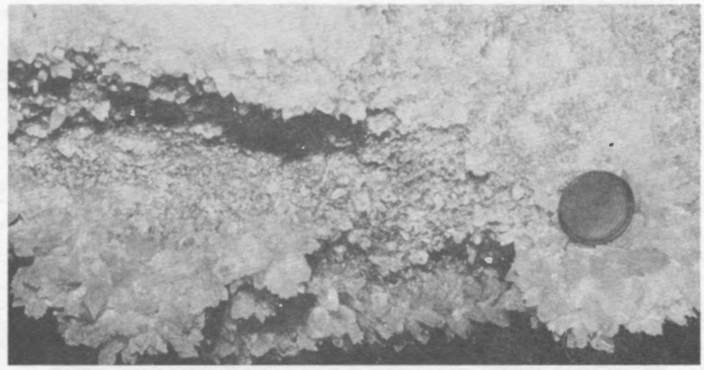

Figure 7 Typical site of gypsum crystals on pendants located at passage intersections, Slavka Cave, Western Ukraine. Photo by A. Klimchouk.

mally are localized along the upper edge of the hole, but in places they surround it. Other than large crystals, rims of white microcrystalline gypsum commonly surround such holes. The "Whale-Fin" formation in Atlantida Cave is an excellent example (Figs. 10 and 11).

The above relationships show that the localization of crystal formation is controlled by the movement and interaction of air currents. Where mixing of two air currents with dissimilar properties occurs, physicochemical thresholds may be perturbed and result in the formation of crystals. We suspect that cave air flow can transport gypsum in the form of aerosol particles, as well as Ca^{2+} and SO_4^{2-} ions in hydroaerosols. The mechanisms of origin of the particles are discussed below. At low air-exchange rates in the studied low energy caves (according to the classification of Heaton, 1986), stable air currents and air strata with dissimilar properties (temperature, humidity, aerosol content) can form, with distinct boundaries between them. Deposition of material from aerosols is controlled by various factors enumerated in the discussion.

GYPSUM "FROST" IN CAVES OF THE WESTERN UKRAINE

In the caves of the region, localized settlements of small separated gypsum crystals often occur, typically with needlelike shape, sometimes called "cave snow" or gypsum "snow" (Hill and Forti, 1986). The term "snow" may be more properly reserved for a true airfall deposit, so we suggest the term "frost" for such deposits that seem to form in place. The crystal size within these deposits ranges from fractions of millimeters to several millimeters. Petrographic study has shown that the smallest particles of frost consist of small-sized radial-fibrous aggregates of gypsum crystals (Turchinov, 1993). Larger crystals have a prismatic and tabular shape. The gypsum frost looks as if it had been poured up to several centimeters thick on the surface of the clay and boulders lying on the floor. The gypsum frost deposits usually have rather distinct boundaries and are located at passage intersections, at passage widenings, or in large passages and rooms having several adjoining smaller passages

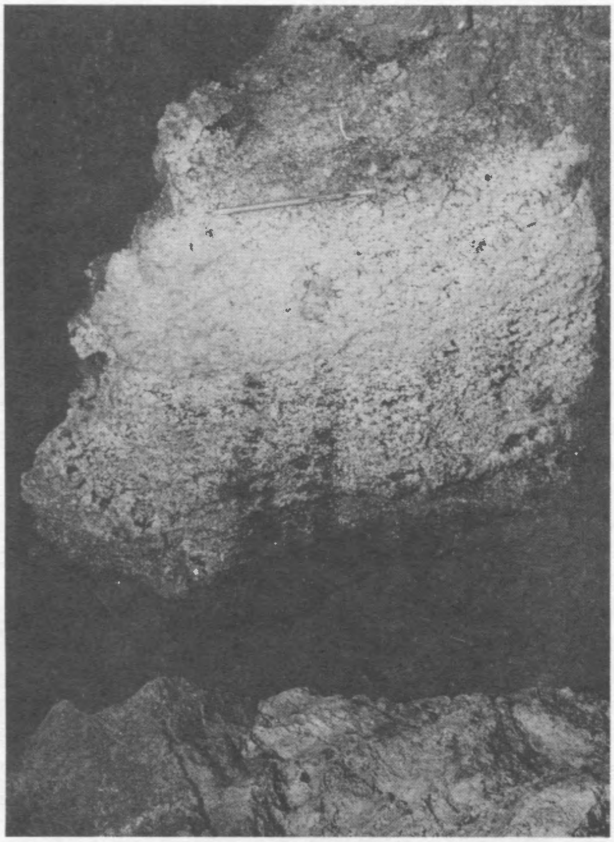

Figure 8 Hoarfrost-like crystals settled on the corner and restricted to a certain level, Slavka Cave, Western Ukraine. Photo by A. Klimchouk.

Figure 9 Hoarfrost-like crystals settled on the pendant and restricted to a certain level, Slavka Cave, Western Ukraine. Photo by A. Klimchouk.

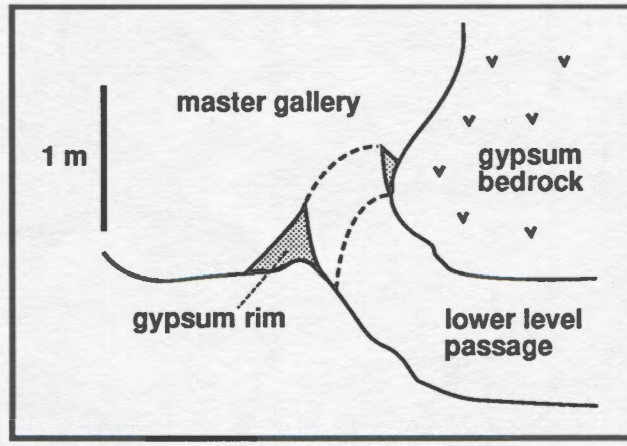

Figure 10 Schematic diagram showing typical cross section through the gypsum rim "The Whale-Fin" in Atlantida Cave, Western Ukraine (see Fig. 11).

Figure 11 The "Whale-Fin" gypsum rim in Atlantida Cave, Western Ukraine (see Fig. 10). Photo by V. Kuzovkov.

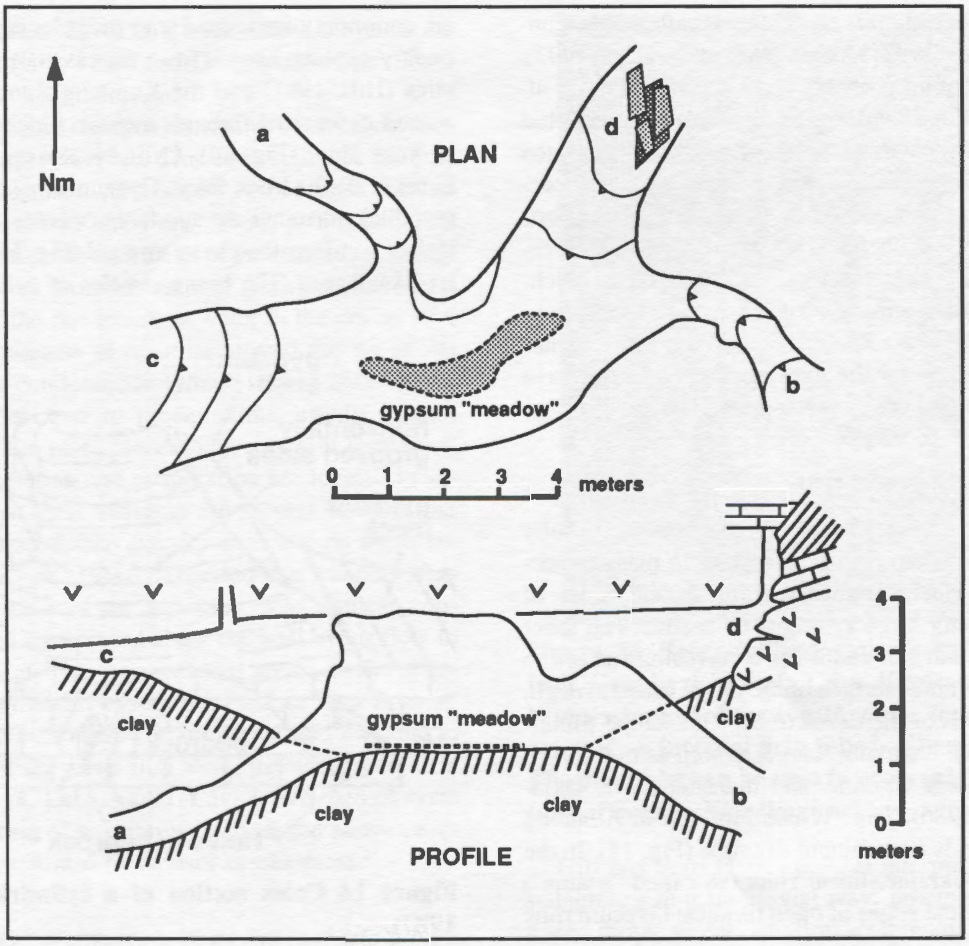

Figure 12 Location of gypsum frost in Dzhurinskaja Cave, Western Ukraine (see Fig. 13).

Figure 13 Photograph of gypsum frost sites in Dzhurinskaja Cave, Western Ukraine (see Fig. 12). Photo by A. Klimchouk.

(Fig. 12). Such accumulations are always elongated in plan view and form "trails" stretching for several meters along the passage axis or from one passage to another across the room (Fig. 13). The above observations suggest that the localization of gypsum frost is controlled primarily by air currents.

GYPSUM SPELEOTHEMS IN THE CAVES OF THE KUGITANG RANGE AND GUADALUPE MOUNTAINS

We suggest an aerosol origin for some unusual speleothems most clearly developed in caves of the Karljuk Group of the Kugitang Range, Turkmenistan, as well as in the caves of the Guadalupe Mountains, New Mexico. Gypsum rims and hollow gypsum "stalagmites" with internal drip tubes are among such formations.

Hill (1987) demonstrated that the large caves of the Guadalupe Mountains were formed chiefly by dissolution of limestone by sulfuric acid. The sulfuric acid formed in a zone where rising water bearing hydrogen sulfide gas mixed with oxygenated meteoric water and left diagnostic signatures of isotopically light elemental sulfur and secondary gypsum deposits (Spirakis and Cunningham, 1991; Cunningham and Takahashi, 1992; Cunningham and others, 1993). Caves of the Karljuk Group probably have a similar origin, although a rigorous geologic and karstologic substantiation has not yet been made. The caves of both regions share common mineralogic features; in particular they contain abundant secondary sulfate (gypsum) as massive blocks and crusts, and various individual sulfate speleothems. The recent discovery of canary-yellow, isotopically light elemental sulfur in Geophysicheskaya Cave in the Kugitang Range, Turkmenistan, further supports a hypogenic origin of the Karljuk Group caves. Brief characteristics are given below for the gypsum formations in these caves, for which an aerosol origin is suggested.

Gypsum rims

Shells or projections (up to 1 m) of cryptocrystalline usually white gypsum surround apertures in bedrock or in massive secondary material. The rims commonly form around holes of smaller cavities adjoining large passages or rooms. The inner surface of a rim is smooth and continues a corrosion surface to an adjoining cavity; the outer surface of the rim is usually rough. Gypsum rims are known in the caves of the Guadalupe Mountains (Hill, 1987) and the Kugitang Range, as well as in the gypsum caves of the Western Ukraine, and in Jester Cave, Oklahoma (Hill and Forti, 1986). The "Whale-Fin" rim in Atlantida Cave, Western Ukraine, is a prominent example (Fig. 11). In the caves of the Western Ukraine, linear rims (so-called "seams") are widespread and line the edges of open fissures. Gypsum rims are commonly associated with irregular cavities in blocks of secondary gypsum known from the caves of the Guadalupe Mountains (Hill, 1987) and the Kugitang Range. Such cavities may extend downward through gypsum blocks for 1.5-2.5 m to the bedrock floor (Fig. 14). Cylindrical rims are a continuation of holes in the bedrock floor. Gypsum rims up to several centimeters thick surround the apertures of holes in massive gypsum as if they continue the cavity upward (Fig. 15) and often form blister-like shapes. The best examples of cylindrical rims are from

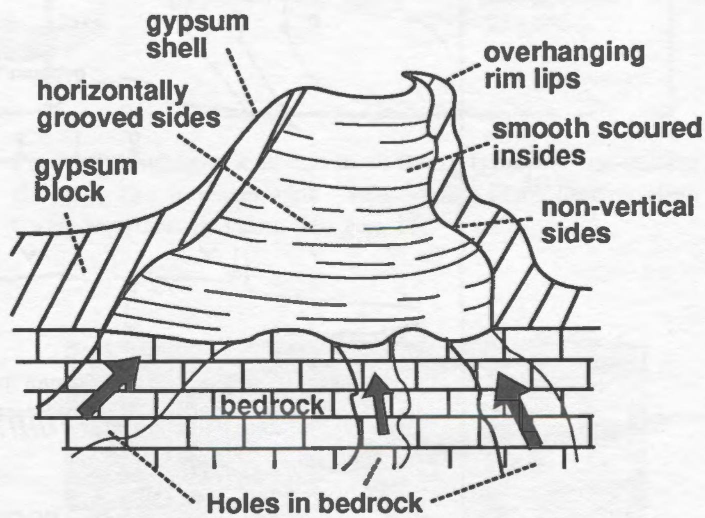

Figure 14 Cross section of a cylindrical rim (from Hill, 1987).

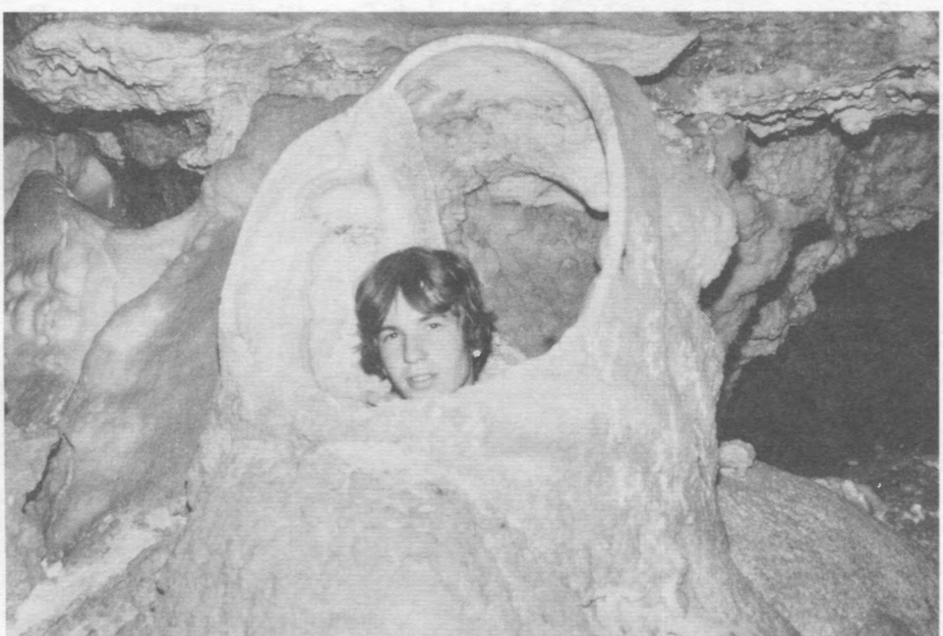

Figure 15 Cylindrical rim, Lower Maze, Endless Cave, Eddy Co., New Mexico. The 1.8 m-tall caver is standing in a 1.5 m deep hole in bedrock which is a continuation of the hole in massive gypsum. A rim of gypsum surrounds the caver's head. Photo by A. Hill (from Hill, 1987).

Carlsbad Cavern, Endless Cave, and Lechuguilla Cave in the Guadalupe Mountains (Hill, 1987) and Geophysicheskaya Cave in the Kugitang Range, Turkmenistan.

In all cases, gypsum rims surround apertures of small cavities (fissures) adjoining larger cavities. This indicates that the formation of these speleothems is controlled by air currents coming from adjoining cavities. Hill and Forti (1986, p. 54) and Hill (1987, p. 134) suggest that the formation of the rims is caused by condensation of moisture from air coming from the hole, with further evaporation of the condensation water in the dry air of a large room and precipitation of material around the lip of the hole. But processes of condensation (which lead to dissolution) and evaporation (which lead to precipitation) usually cannot occur concurrently at the same place. Such a system may work if the zones of condensation and evaporation are located in series, and conditions for mass transport are present between the zones. Local relief around rims usually does not fit these requirements. Hill and Forti (1986) suggested that condensation occurs on the inside walls of the adjoining hole, and the condensation water is then transported along the wall by air flow to the zone of precipitation. This interpretation seems doubtful because upward transport would be required, and air flow in small (usually marginal) cavities is slow and laminar and not able to drive the movement of the water film along the wall (such as in the deeper sections of Lechuguilla Cave). We demonstrate below that the formation of gypsum rims in all the above cases can be satisfactorily explained by aerosol mechanisms.

Hollow "stalagmites" of gypsum with an internal drip tube

These forms are represented most clearly throughout Lechuguilla Cave and in Geophysicheskaya Cave (Morosko Hall, Fig. 16). They also are known from some other suspected hypogenic caves that have massive gypsum blocks, and an unusual occurrence from a small epigenic cave in New Mexico (Torgac Cave, Carol Hill, personal communication). These hollow stalagmites are composed of white massive gypsum, located on blocks of secondary gypsum under drip points, and are up to 3 m tall and up to 0.5 m in diameter. Vertical drip tubes are usually 10-15 cm in diameter and continue deep into the gypsum block becoming wider toward the bottom. In places where dripping stopped long ago, old hollow stalagmites are commonly recrystallized and covered by gypsum overgrowth crystals on the outer side (Fig. 16); the tube may be completely overgrown in the process. In Lechuguilla Cave, a complete evolutionary sequence is displayed from whole gypsum blocks to relict hollow columns that have been completely overgrown with acicular aragonite. Recrystallized hollow stalagmites tend to have a radial structure. The hollow gypsum stalagmites in Torgac Cave are either rare remnants from more extensive secondary deposits, or are true stalagmitic features formed from vadose dripwater high in sulfate.

Figure 16 Recrystallized gypsum "stalagmites", Morosko Hall, Geophyzicheskaja Cave, Kugitang Range, Turkmenia. Water stopped dripping through these "stalagmites" long ago and an internal drip tube has been partially overgrown. The drip tube can be seen in cross sections of broken formations. *Photo A. Klimchouk.*

Hill and Forti (1986, p. 132) interpret the formation of such stalagmites in a traditional way: precipitation of material from water drops as the solution evaporates. The drip tube forms when the geochemical conditions change and the drops fall undersaturated and are able to dissolve some gypsum. No alternative hypothesis has been suggested in the literature at this time.

PHYSICAL PROPERTIES OF CAVE AIR

Before proceeding to a substantiation of the aerosol origin of the aforementioned gypsum formations, it is necessary to consider some physical properties of the cave air.

Temperature and humidity

Air temperature and humidity in caves depend on many factors, the most important of which are annual mean temperature of the outside atmosphere, cave pattern, extent and character of interaction between inside and outside atmospheres, presence and character of water flow, and so forth. The caves of the Western Ukraine have limited air exchange with the outside, occur in similar geologic settings, and have similar cave morphologic patterns. Different caves are characterized by mean temperatures ranging from 8.0-10.0°C between cave levels, and relative humidity varying from 98-100%. Temperature and humidity differences between levels of any single cave usually do not exceed 0.5-1.0°C and 1-2%. The caves of the Kugitang Range and

Guadalupe Mountains differ by pattern and character of air exchange and are marked by great variability of meteorological parameters. In Carlsbad Cavern, with its large air exchange, temperature varies between 12.1-20.0°C (average = 13.3°C), and relative humidity varies between 69-100% (Hill, 1987). In Lechuguilla Cave, where air exchange is restricted, temporal and spatial variation of temperature is much smaller: from 18.0-19.4°C. Internal temperature differences within this huge 3-dimensional cave system drive convective air circulation within the cave, but many zones are characterized by a stagnant regime (Cunningham and LaRock, 1991). Air temperature of different sections of the Kugitang caves ranges from 17°C (Geophysicheskaya Cave) to 22°C (Promezhutochnaya Cave). Internal temperature and humidity differences can be as great as 5-6°C and 30% RH in the well ventilated caves (Cup-Coutan Cave) but are much smaller in the caves with restricted air exchange.

Radioactivity

As bedrock (limestone, dolomite, gypsum) always contains some dispersed uranium and thorium, caves may be regarded as cavities primarily surrounded by radiation sources (Gadoros, 1986). One of the members of the uranium decay series, radon, is able to diffuse into a cavity at a considerable rate and maintain high concentrations compared to the external atmosphere. Elevated levels of radon and its daughter products are a fundamental characteristic of cave air. Concentrations of radon and its daughters are controlled by the rate of radon diffusion from the bedrock, as well as by the overall air exchange rate. Many measurements of beta and gamma activity in caves have demonstrated that in closely adjacent cave sections, or even at different corners of the same hall, the amount of activity can be very different (Gadoros, 1986). Corresponding differences can be expected in the radon emanation rate, but radon concentrations are highly dependent on air flow. Thus, local differences of radon concentration may be significant both in cave sections with slow air flow and in those with intense air exchange.

Radon is the alpha-active isotope and produces daughter products during further decay: isotopes of polonium, bismuth, and lead. Most of them, in turn, are alpha emitters. Alpha particles have an energy of 4-10 MeV (5.482 MeV for those produced by radon decay) and a penetration distance in air of 2.5-10.6 cm. Impact of alpha particles is the major reason for the elevated ionization of cave air.

Recent studies have shown that the caves of the Western Ukraine and Kugitang Range are characterized by a high content of radon in the air (Klimchouk and Nasedkin, 1992). Mean radon concentrations in Optimisticheskaya and Ozernaya Caves are, respectively, 20.9 and 8.06 kBq m^{-3}, with variations of 18.2-23.7 and 5.82-10.8 kBq m^{-3} respectively (winter period). In the Kugitang caves the measured radon values in the internal parts range from 13.01-68.11 kBq m^{-3} (spring period). In Carlsbad Cavern the radon contents are rather low and uniformly distributed due to active ventilation; the measured concentrations vary within 0.296-3.33 kBq m^{-3} (Ahlstrand,1980). In Lechuguilla Cave the measured concentrations range from 0.185-3.515 kBq m^{-3}, but the distribution is quite inhomogeneous and corresponds to microclimatic peculiarities of different zones (Cunningham and LaRock, 1991). The highest measured concentration in the caves of the Guadalupe Mountains is 3.7 kBq m^{-3} (Hill, 1987). In general, the radon levels in the caves of the Guadalupe Mountains are much lower then those in the caves of the Kugitang Range and Western Ukraine.

Ionization and electrical forces

Recent studies have shown that cave air is characterized by high ionization (if compared to the open air), that is caused by enhanced radioactivity. The air of an average city normally contains 70-80 positive and 800-900 negative ions cm^{-3}; in mountain regions these figures range between 1000-4000 ions cm^{-3} (Tardy and Hiros,1989, and references therein). In open air, and almost exclusively in the majority of the cases in city air, positive ions are in excess. The measurements conducted through many years in five Hungarian caves (448 measurements) have shown an average content of positive aeroions as high as 32671 cm^{-3} (maximum = 680000; minimum = 1150), and negative aeroions of 43480 cm^{-3} (maximum = 908000; minimum = 680) (Tardy and Hiros,1989). The unipolarity quotient ($Uq= n+/n-$) is, on average, around 0.84, so in cave air negative ions are in excess.

During radioactive decay and the attendant ionization of air, positive and negative ions form equally. An excess of negative ions in the caves is explained (Gadoros, 1989a; 1989b) by ion interaction with hydroaerosols, most of which are negatively charged when produced due to the Lenard (or waterfall) effect. Some of the positive ions interact with negative hydroaerosols and are therefore neutralized. As a result, excess negative ions remain, and a negative field charge is formed in the cave space. According to estimations by Gadoros (1989a) the field strength may be as high as 100 V m^{-1}.

In conclusion, from the above arguments, the behavior of small ions and charged aerosols is determined to a certain extent by forces of electric interaction. In particular, negative particles are attracted to positively charged walls by the electric field strength produced by the field charge.

Aerosols

Direct measurement of the quantity and composition of aerosols in caves is limited. The presence of particles of 10^{-3}-10^{-5} cm can be easily determined by means of the Tyndall effect—by lighting points in a light beam of a well-focused lamp (Fig. 17). Aerosols can consist of a dispersed phase of solid or liquid (hydroaerosols) particles. Because this article discusses processes occurring in deep internal parts of caves with slow air

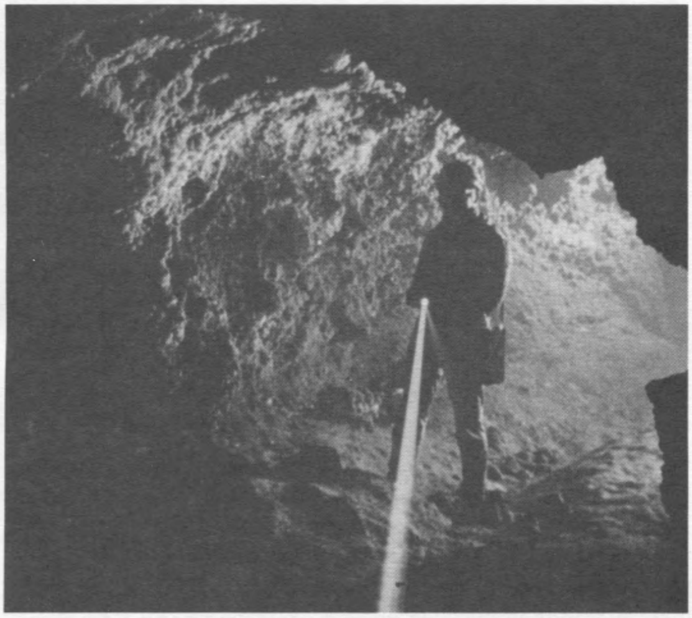

Figure 17 A laser light beam in Atlantida Cave, Western Ukraine, identifies the presence of aerosols (Tyndall effect).

exchange, we do not consider here allochthonous aerosols (those brought into a cave from the outside atmosphere).

Available measurements of solid aerosols show their presence in the internal parts of caves to be considerable (Table 1). Some publications mention aerosol composition: for limestone caves, ions of Ca^2+, Mg^2+, HCO_3-, and SO_4^{2-} are mentioned; for salt mines Na^+, Cl^-, K^2+, Br^{2-}, and Mg^{2+} are noted (Institute of Geological Sciences, 1986). Previous studies (Pashchenko and Sabelfeld, 1992; Pashchenko and others, in press) have suggested that the only mechanical processes to generate natural solid autochthonous aerosols are from (1) the fall of small particles from the ceiling, or (2) dispersion of material when falls of breakdown occur.

Table 1: Aerosol content of caves. "nd" no data

Cave	particles/m^3	mg/m^3	Character	Source
Kluterhohle, Germany	2500	nd	Ca^{2+}	Inst. Geol. and Geophys., 1986
Mierusym, Hungary	147	nd	calcium salts	"
Magura, Bulgaria	nd	0.002	nd	"
Tetri-Megvime, Georgia	nd	0.02-0.05 0.07-0.08 0.07-0.08	Ca^{2+} Mg^{2+} HCO_3^{2-}	"
Sataplia, Georgia	5200	0.14		Tintilozov, 1976
New-Athon Cave, Georgia	4200	0.17-0.28		"
Kungurskaya, Russia	1000-10000	nd	particles > 1 μm	Pashchenko and Sabelfeld, 1992

Hydroaerosols are a characteristic and important component of cave air. Special theoretical consideration was provided by Gadoros and Cser (1986), where dispersion of water drops falling from the ceiling is referred to as a source of hydroaerosols. The most important property of hydroaerosols formed in this way is the initial presence of dissolved material. Fine droplets become highly concentrated after their formation because of evaporation. Gadoros and Cser (1989) have shown that evaporation of droplets may occur even at a relative humidity of 100%. According to calculations at humidities greater than 98%, droplets smaller than 10 μm can be stabilized as droplets smaller than 5 μm with a Ca^{2+} concentration of 700 mg L^{-1} and forming hydroaerosols with approximately 1 mg m^{-3} of solid and an overall Ca^{2+} content of 1 mg m^{-3}. The size and the solute content of the aerosol droplets is very sensitive to the relative humidity.

Measurement of aerosol content is difficult. Available data are summarized in Table 1. Some data on hydroaerosol composition were obtained by the condensation method, and they can be regarded as minimum values due to dilution by condensing vapor while cooling. For Beke Cave, Hungary, data on Ca^{2+} content in hydroaerosols are: 0.1-0.5 mg m^{-3}, with an extreme value of 1.45 mg m^{-3} (Tacacs and others, 1984). Similar data are referred to for Tetri-Megvime Cave, Caucasus (Table 1). For Ohtynsky Cave, magnesium carbonate concentrations are reported between 7.17-7.21 mg L^{-1} in the condensed moisture (Homza and others, 1970).

DISCUSSION: THE AEROSOL ORIGIN OF SPELEOTHEMS

Aerosol effects are rarely considered as possible causes of speleothem formation. None of the fundamental monographs on physical speleology or cave deposits refer to aerosol effects. This can be explained by either the supremacy of aqueous-mechanism stereotypes or by limited data on cave aerosols and their properties. Moreover, some important physical properties of cave air were studied only during the past decade; many of them remain poorly understood.

Taking into consideration the properties of the hydroaerosols originating from dispersion of falling drops, Cser and Maucha (1968) suggested an aerosol origin for needlelike helictites. These are single crystals or polycrystals grown together, with pointed ends and no internal capillary canal. Due to the electrostatic effect, supersaturated and charged hydroaerosol droplets are deposited at the tips of helictites, which possess the highest potential gradient. Such an explanation seems convincing and was supported by the experiments, but it cannot be applied to dry caves (in particular, to the caves of the Western Ukraine and Kugitang Range, where few or no drips are the presumed source of the hydroaerosol-carrying solute).

We believe that natural radioactivity and alpha-decay of radon and its daughters play a significant role in the formation of autochthonous cave aerosols, both solid and liquid. Charged alpha particles create a series of ions that may serve as condensation nuclei, forming liquid droplets. The ability of ions to act as condensation nuclei is clearly demonstrated in a Wilson (cloud) chamber. This is likely to be the major mechanism in the formation of cave aerosols, but droplets originating by this mechanism do not initially contain a solute.

High-energy alpha particles (5.482 Mev) are able to dislodge ions out of a mineral crystal lattice. Moreover, as the microrelief on the mineral surface develops, the alpha particles may knock out fragments, generating small-sized solid aerosol particles. That alpha-decay can cause detachment of small particles (containing approx. 10^1-10^3 atoms) from a solid matrix has been shown by Baranovsky and others (1981); such particles may then participate in a process of coagulation and growth of the particles. Dubashinsky and others (1988) has estimated that for particles $\leq$0.1 µm, the adhesion energy of any bond is as high as several 0.1 Mev. The same order of adhesion energy is required to physically dislodge particles from massive rock, according to the above work. The energy derived from alpha-decay is obviously much higher, and must contribute significantly to the generation of aerosols.

Dubashinsky and others (1988) have carried out a series of experiments which demonstrated that above a radioactive soil surface the concentration of large aerosol particles (<1.1 µm) is 2.5-10 times greater than observed in a control (nonradioactive) situation. The difference in concentration increases considerably with time.

Ions and large-sized particles combine with the condensation aerosols in the air, or become condensation nuclei themselves. Study of aerosols in Kungurskaya Cave, Ural, has revealed that most of the solid insoluble aerosol particles of allochthonous origin immediately absorb water and are coated by water when they enter into the cave (Pashchenko and Sabelfeld, 1992). Ions and gypsum particles dissolve in water, and the hydroaerosols receive the calcium sulfate solute as a result. Further capture of gypsum particles and evaporation of the hydroaerosols droplets may lead, if the conditions (relative humidity or temperature) change, to solution supersaturation. If such a droplet touches a rock surface, the mineral phase will immediately precipitate. A microcrystal may also form in the aerosol droplet, if it joins other particles that can play the role of crystalline nuclei. Eventually, the hydroaerosol may turn into a solid aerosol in this way.

Because of an inhomogeneous distribution of both climate-independent radioactivity and airborne radon concentration, the rate of aerosol generation during radioactive decay may vary considerably in the cave space. Normally the highest aerosol productivity can be expected in fissures and small marginal passages. Precipitation of a solute from a hydroaerosol depends on many conditions. As noted above (for details see Gadoros and Cser, 1989) evaporation from the droplet's surface and the solute concentration are very sensitive to the relative humidity. This can explain the prevailing localization of aerosol formation in the zones of interaction of different air currents, where temperature and humidity gradients exist. The most probable cause of material precipitation is evaporation of the hydroaerosol droplets when an air current enters a cavity with lower relative humidity, generating microcrystals of gypsum which may then fall out where air current velocity decreases. It is likely that electrostatic effects play a certain role in particle deposition.

All of the caves from which the above examples are taken are primarily of hypogenic origin and were not related to the surface during their formation. After an initial phreatic stage, the caves were in the subaerial zone but not open to the surface for a long period of time. This state is characterized by limited air exchange and very slow and laminar air currents within the system. Even at the modern opened entrances, the conditions of low air exchange still prevail in most of the internal parts of the cave systems. Local differences of laminar air-flow properties may be quite considerable under these conditions, determining the complicated structure of the air-exchange pattern. Laminar air flows, currents, and zones of interaction may hold their stability in space over long periods of time. As for aerosols and "ionic gas", their migration in the cave space is controlled by air-flow movements. This explains the presence of sharp boundaries around the aerosol crystal accumulations. The study in Kungurskaya Cave has demonstrated distinct air stratification and steep gradients of aerosol concentration in the cave, in accordance with temperature differences (Pashchenko and Sabelfeld, 1992; Pashchenko and others, in press).

In this article, the effects of aerosols are considered with special reference to gypsum formations. But many calcite and aragonite speleothems may also have an aerosol origin, especially hoarfrost-like crystals (specifically, wind-controlled aragonite displays such as the "directional" aragonite in the Far East section of Lechuguilla Cave). The apparent prevalence of gypsum among the aerosol formations may be explained by the lower energy of its crystal lattice compared to calcite: the approximate value of E_{cryst} for gypsum is 650 kcal mol^{-1} while E_{cryst} for calcite is 700 kcal mol^{-1} (Sokolov, 1962). Gypsum produces free ions and aerosol particles more easily than calcite. While the mean energy differences seem small, integration of the mass and charge affects over time are probably significant.

Returning back to the speleothems described above, let us consider the application of the suggested mechanisms to their origin.

Gypsum crystals

Peculiarities of localization of crystal sites support an aerosol origin. Precipitation of material occurs in the zones of interaction of different air currents at passage intersections, or at sites where small passages join a large passage. The nature of the physicochemical threshold causing gypsum precipitation needs further clarification. Mixture of a moist air current with drier air (a difference of 1-2% relative humidity is high enough) causes evaporation of the aerosol droplets and precipitation of the solute upon contact with a suitable substrate. In zones where condensation occurs on the upper part of the wall and a water film flows downwall, water approaches saturation with respect to gypsum and forms drops at the tips of those crystals which are properly positioned. Such downwardly oriented crystals continue their active growth approaching a considerable length (up to several dozen centimeters), but this is yet another mechanism of crystal growth.

Gypsum frost

Microcrystals of gypsum probably precipitate in aerosol droplets. Radial-fibrous aggregates of crystals form which, as they grow further, precipitate and deposit the forms of gypsum cave frost. Further growth and recrystallization of the gypsum aggregates then occurs on the floor (Turchinov, 1993).

Gypsum rims

All rims seem to form in the same situation: they surround apertures by which small cavities (or fissures) adjoin with a larger room. Rims can form around a hole in the bedrock if it is gypsum (Western Ukraine; Jester Cave, Oklahoma), or in blocks of secondary gypsum laying on the floor of limestone caves of the Guadalupe Mountains and Kugitang. In the latter case, tubes in gypsum blocks correspond to cavities into the bedrock floor and are formed as their continuation by corrosive action of the outcoming moist air containing aggressive hydroaerosols. As the air current blows through the gypsum, the hydroaerosols become saturated with gypsum as a result of the above processes. Entering a large room that contains air of lower relative humidity, the hydroaerosol droplets evaporate and form microcrystals of gypsum that precipitate around the hole. When prolonged precipitation occurs, the rim forms a projected shell of blister-like shape above the hole.

Hollow "stalagmites" of gypsum with internal drip tubes

These always form on or near gypsum blocks. Vertical canals in the gypsum blocks are dissolution tubes that form beneath drip points. Upward growth of the hollow stalagmite walls begins when an upwardly-moving air current is established through the tube. The conditions and mechanisms of the stalagmite growth are the same as for rims; such a stalagmite is essentially a hyperelongated rim, growing upward around the drip axis at the expense of the surrounding gypsum mass. The differences are that the initial aperture has a distinct rounded shape which configures the outflowing air current, and that hydroaerosols, formed as a result of drop dispersion, take part in the process along with the condensation hydroaerosols. A similar origin for the cylindrical gypsum rims surrounding holes and hollow stalagmites is supported by situations where they lie next to each other and share a single cavity in the gypsum block (Fig. 18). That these sites continue to be active sites of aerosol deposition after chemical changes in the water is demonstrated by the eventual replacement of all sulfate by calcite and aragonite.

CONCLUSIONS

Elevated radioactivity is a fundamental characteristic of the air in caves. Radioactive decay is accompanied by ionization of the air and formation of condensation hydroaerosols, "ionic gas" containing the ions of the surrounding rock, and autochthonous solid aerosol—small-sized particles of the surrounding rock. In such a way a mineral substance is dissolved and a solid phase is introduced into the cave air. This substance can be transported by airflow and precipitated when physicochemical thresholds of various types are encountered.

Precipitation of material from aerosols plays an important role, underestimated until the present time, in the formation of many types of speleothems. Peculiarities of morphology, structure, and location of the gypsum formations support their aerosol origin. Although the suggested mechanism of speleothem formation from aerosols is still speculative, it is in good agreement with the above model of autochthonous aerosol generation and readily explains the peculiarities of the speleothems. Further experimental studies using recently developed instrumentation

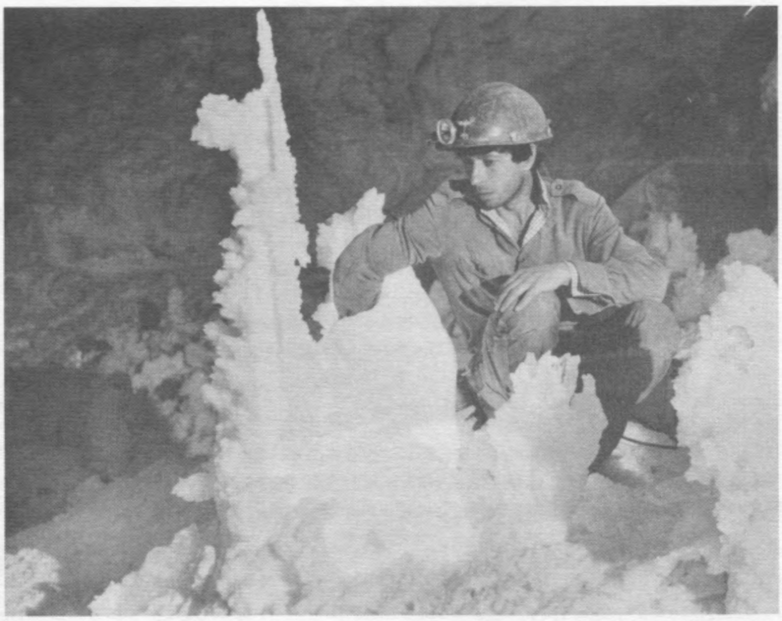

Figure 18 Cylindrical rim and "stalagmite" with drip tube in Geophyzicheskaja Cave, Kugitang Range. The caver is lowering a flash lamp into a cylindrical rim. A hollow "stalagmite" with a drip tube is located on the left. The cylindrical rim and hollow "stalagmite" have a common hole in the gypsum basement. Photo by A. Klimchouk.

need to be performed on the physical properties of the cave environment, in particular, on aerosol properties and behavior.

The cave formations considered here are of different types, morphology, and sizes, and occur in caves of different types and regions. This demonstrates a universal character and widespread application of aerosol mineral-forming processes. The examples given for gypsum formation do not exhaust the possible list of aerosol speleothems. Many types of subaerial cave formations can be included in such a list, including those composed of calcite, which have been traditionally interpreted as growing by capillary mechanisms from thin films of condensation water on rock surfaces. For some types of such formations, satisfactory explanation exists other than aerosol processes. The aerosol origin is especially suitable for numerous needlelike and hoarfrost-like forms, and possibly for common forms such as cave popcorn.

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HELICTITE BUSH FORMATION AND AQUIFER COOLING IN WIND CAVE, WIND CAVE NATIONAL PARK, SOUTH DAKOTA

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Limited petrographic, mineralogic, and isotopic data obtained from helictite bush and boxwork speleothems in Wind Cave, Wind Cave National Park, South Dakota, suggest a bacterial role in the subaqueous precipitation of helictite bushes, help to constrain the chemical conditions under which the bushes precipitated, and provide an independent calibration of paleotemperatures for the Wind Cave aquifer. The helictite bushes display three types of growth fabrics: canal-wall crystals resembling soda-straw speleothems, fine-grained to micritic transition-zone crystals, and coarsening-outward palisade crystals. Radial sections of canal-wall crystals contain broken rings of suspected bacterial filaments occasionally displayed as moldic porosity; bundles and clumps of filaments and iron-bearing opaque bodies are prevalent in the transition-zone crystal layers. The bushes are predominantly low-magnesium calcite containing minor amounts of dolomite, reflecting the bicarbonate-buffered chemistry of the slowly draining Wind Cave aquifer. Fluid-inclusion paleotemperatures from boxwork calcite spar provide an independent calibration of the calcite-water paleothermometer for Wind Cave speleothems by not having to assume the $\delta^{18}O_w$ *of the paleowaters. The Wind Cave aquifer has cooled 28°C in the last 200,000 years according to oxygen isotopic data from the bushes.*

INTRODUCTION

The helictite bush speleothems in Wind Cave, Wind Cave National Park, South Dakota grow upwards from the floor or ledges, although some (for example, the Emperor Maximus helictite bush) grow back down toward the floor from an upward extending trunk. The helictite bushes have been termed "a twig-like variety" of helictite speleothems (Hill and Forti, 1986) and "heligmite bushes" (Ford, 1989). We continue the cavers usage of the name helictite bush in this paper. Two hypotheses have been offered to explain the origin of the helictite bushes: normal subaerial calcite precipitation by capillary seepage (Palmer, 1981; 1988) and subaqueous calcite precipitation (Davis, 1989; 1991; Palmer and Palmer, 1989). Subaerial precipitation by capillary seepage involves hydrostatic pressure and is a well-documented mechanism responsible for most helictite speleothems (Hill and Forti, 1986). Subaqueous precipitation hypotheses include formation via thermal and chemical mixing of "localized plumes of thermal water...related to features like submarine smoker chimneys" and involving the "common-ion effect" (Davis, 1989), or by a mechanism similar to the formation of algal tufa towers at springs around the edges of Mono Lake, California (Davis, 1991). In order to better understand the origin of these unique speleothems and their relation to the Wind Cave aquifer, we present petrographic, mineralogic, and isotopic data from samples of helictite bush and boxwork speleothems collected in Wind Cave along the route from the Boxwork Chimney to Calcite Lake (Fig. 1). Calcite lies at the lowest elevation on the route and represents the current water-table of the Wind Cave aquifer.

PREVIOUS WORK

Palmer (1981, 1988) described the helictite bushes as bushy growths of calcium carbonate formed subaerially via capillary seepage of fluids enriched by weathered limestone powder. However, Palmer (1988) noted it was possible for the bushes to grow subaqueously under "unusual chemical conditions" suggested by D. Davis in a talk presented at the 1988 NSS convention (Davis and LaRock, 1988). Davis (1989) provided descriptions of the bushes and hypothesized that the bushes developed subaqueously where ascending plumes of calcium carbonate-saturated thermal water mixed with localized zones of ground water saturated with calcium sulfate derived from gypsum remnants in the Early Mississippian-age Pahasapa Limestone bedrock that contains the cave — clearly "unusual chemical conditions." On the basis of petrographic observations, Palmer and Palmer (1989) concluded that the bushes may have formed in pools and that the central canal is secondary and lined with or-

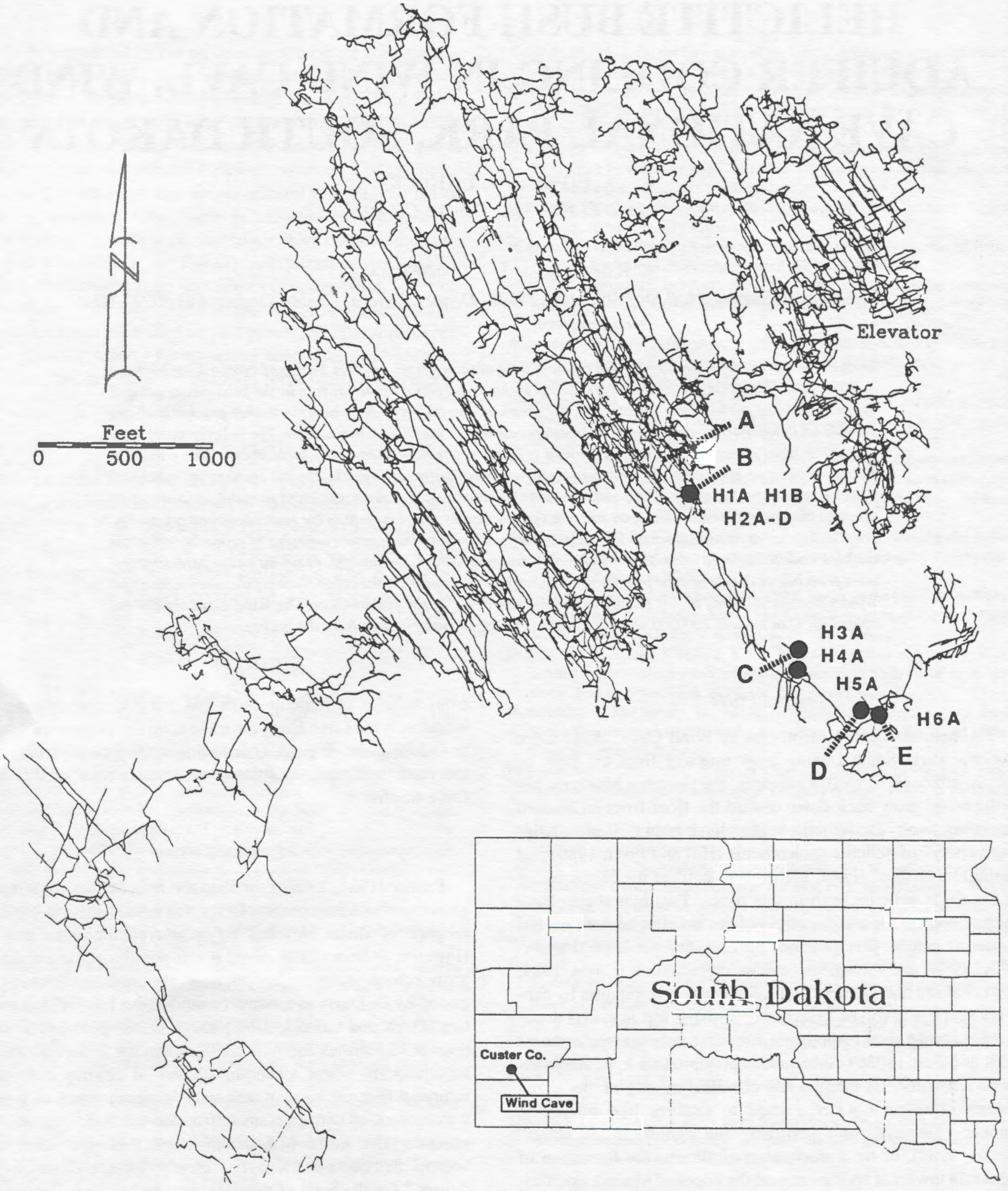

Figure 1. Plan view line-plot of Wind Cave, South Dakota with location of helictite bush/boxwork speleothem sample sites H1A through H6A. The cave-route from the Elevator entrance descends the Boxwork Chimney (A), passes through the Garden Gate (B), includes the Emperor Maximus (C) and the Black Forest (D) helictite bush areas, and reaches the lowest elevation at Calcite Lake (E), which represents the present surface of the Wind Cave aquifer.

ganic filaments. Additional discussion of subaqueous origin includes the analogy to Mono Lake (Davis, 1991).

Citing undocumented carbon and oxygen isotopic data from helictite bushes in Wind Cave, Ford (1989) suggested a subaqueous origin since the bush isotopic values are in the same range as those of subaqueous calcite crust speleothems (Ford and Bakalowicz, 1983; Bakalowicz and others, 1987) lining the lower 93 m of Wind Cave passages (particularly below the Boxwork Chimney). The primary episode of crust deposition occurred between 350 and 200 ka (Ford and others, 1993). The crusts provide a record of aquifer drainage after Wind Cave became hydrologically detached from the active, thermal springs that formed the cave. These springs have retreated about 15 kilometers south to present-day Fall River springs in the town of Hot Springs. The crusts mark a major change in aquifer chemistry (Palmer and Palmer, 1989; Ford, 1989; Ford and others, 1993) from thermal spring waters to cooling backwaters. In these backwaters, calcite crusts were deposited by CO_2 degassing (not the common-ion effect), which was controlled by hydrostatic pressure in a well-mixed zone between 0 and 70 m below the paleowater table. Concentrations were close to equilibrium with respect to calcite. This bicarbonate-dominated aquifer has persisted in Wind Cave for the last 350,000 years on the basis of uranium-series dates of calcite crusts near Calcite Lake (Ford and others, 1993) and chemical analyses of the modern Wind Cave lake water (Millen and Dickey, 1987; Miller, 1989).

METHODS

Nine previously broken helictite bush speleothem fragments and one boxwork speleothem fragment (LaRock and Cunningham, 1989) were collected on December 3, 1988, near Wind Cave survey stations along the route from the Boxwork Chimney to Calcite Lake (Table 1). Sample splits were obtained from each specimen for petrographic examination, for determination of whole-rock mineralogy by X-ray powder diffraction (XRD), and for obtaining whole-rock stable carbon and oxygen isotopic data. Eight radial petrographic thin sections and one longitudinal petrographic thin section of the bush specimens were prepared and examined with transmitted light under various magnifications as great as 500X. Sample H4A was analyzed for fluid inclusions. Semi-quantitative oxide weight compositions in a few specimens were obtained from a limited number of random energy dispersive X-ray (EDX) spot analyses using a scanning electron microscope (SEM).

RESULTS

Helictite bush petrography

All of the Wind Cave helictites possess one or more hollow, irregularly shaped, planar to ovoid central canals that have widely varying dimensions (0.5-10 mm). Most canals are open with smooth walls, but a few specimens showed partial, localized blockage by bridging calcite crystals and/or opaque material. Each bush specimen possesses a basic micro-stratigraphic sequence consisting of three types of crystal growth fabrics (Fig. 2) that are developed radially outward from the central canal and listed below.

Fabric 1: A 0.1-1.5 mm-thick canal wall is composed of euhedral to subhedral calcite crystals that have the crystallographic *c* axis oriented parallel to the long axis of the canal, similar to soda-straw speleothems. Recrystallization of the canal-wall calcite exists in some specimens (Fig. 3). Common opaque to translucent filaments, suspected to be of organic origin (Palmer and Palmer, 1989), form discontinuous rings within the canal-wall crystals and are occasionally expressed as moldic porosity.

Fabric 2: A transition zone 0.01-0.1 mm-wide is composed of sub-isopachous, whitish to opaque, very fine to micritic calcite, interlaminated with opaque to translucent material. Some of this material exists as dendritic or similar groupings of fossil organic(?) tubular filaments encompassing opaque bodies. The filaments are particularly pronounced in longitudinal section existing as bundles along and across crystal boundaries (Fig. 4).

Fabric 3: A 0.1-0.75 mm-wide palisade layer contains a sequence of uninterrupted calcite crystal growth phases progressing from small (<0.1 mm), equant crystals that have random orientations to large (>0.5

Table 1 . Sample descriptions

Sample No.	Survey Station	Locality	Speleothem description
H1A, H1B	JF47-48	Garden Gate	Stub-shaped helictite bushes.
H2A, H2B H2C, H2D	JF48-49	Garden Gate	Small-diameter, twisted helictite bushes approximately 15 m southeast of H1A and H1B.
H3A	LB7	Emperor Maximus	Small helictite bush on shelf directly across from main helictite bush.
H5A	OL8	Black Forest	Branching, black helictite bush.
H6A	JF110	Calcite Lake	Nonbranching, thin helictite growing down from a ledge about 25 cm above the lake.

mm), bladed, palisade crystals that have the *c* axes oriented perpendicular to the long axis of the canal. The palisade crystals exhibit radial optical extinction. Tubular translucent filaments occasionally radiate outward through the palisade crystals and appear to originate from the transition-zone growth surfaces.

A visual count yielded over 20 alternating layers of fabrics 2 and 3 encrusting the basic microstratigraphic sequence of the bushes from the Garden Gate area (the greatest elevation above Calcite Lake of all sample localities). The bush from the Emperor Maximus area and the helictite from Calcite Lake area display only the basic sequence of canal-wall, transition-zone, and palisade growth fabrics. The bush from the Black Forest area has many irregular, overlapping central canals. Bushes in the Black Forest are almost buried by translucent calcite raft speleothems.

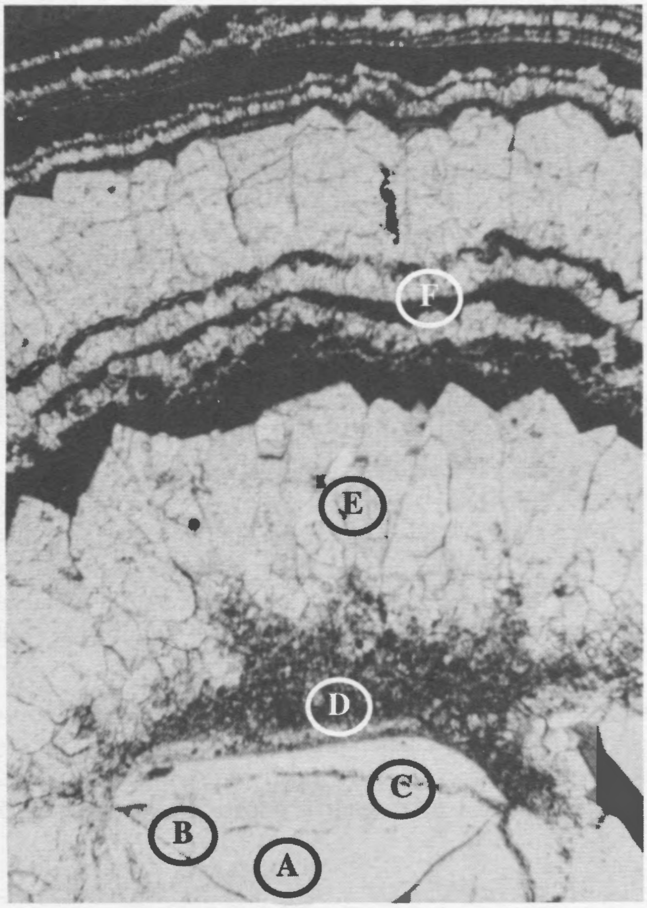

Figure 2. Photomicrograph of a radial section from Garden Gate helictite bush sample H2A. This example most clearly presents the three types of growth fabrics surrounding the central canal (A-off bottom of photo): canal-wall crystals (B) that contain discontinuous rings of suspected bacterial filaments (C), micritic transition zone that contains abundant bacterial(?) filaments (D), and palisade crystals (E). The outer microstratigraphy displays repetitive transition-zone and palisade fabrics (F). Scale across scene is 1.056 mm.

Mineralogical and isotopic analyses

X-ray powder diffraction (XRD) profiles show the whole rock bush samples are mostly calcite with minor dolomite and quartz. The calcite contains 3 mol percent magnesium (Mg) which represents low-Mg calcite (Goldsmith and others, 1961). Dolomite and quartz appear to increase toward Calcite Lake based on comparing the relative sizes of the mineral peaks on the XRD profiles. None of the samples contain aragonite or gypsum, although some contain trace amounts of illite. The H4A boxwork whole-rock sample is 92 percent calcite with minor dolomite and 8% (by weight) acid-insoluble residues, which are composed primarily of quartz, kaolinite, trace amounts of il-

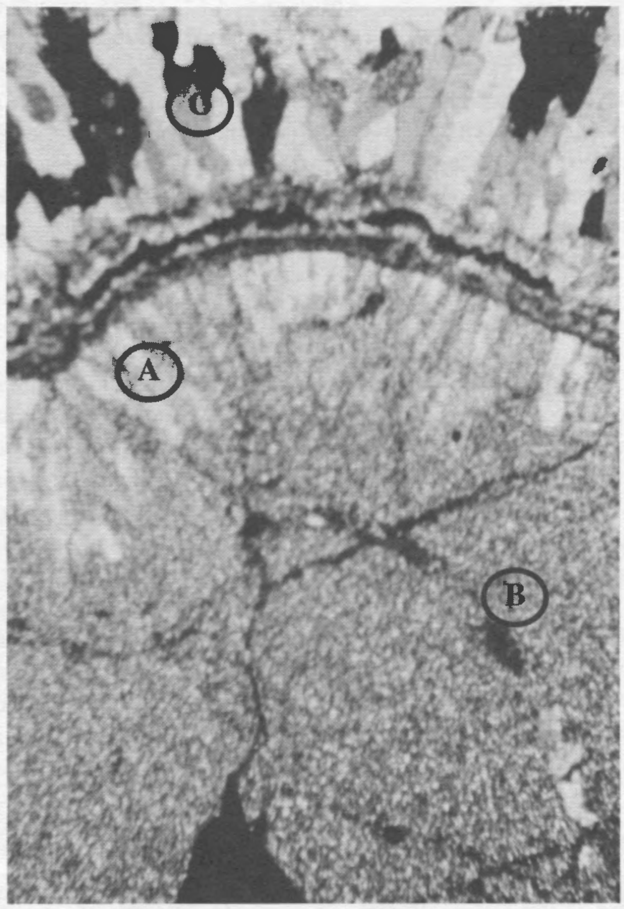

Figure 3. Photomicrograph of a radial section from Garden Gate helictite bush sample H1B. The view uses polarized light and displays recrystallization of the canal-wall calcite crystals (A). Discontinuous rings of suspected bacterial filaments can be seen in the canal-wall crystals (B). Radial extinction is displayed by the bladed calcite crystals in the outer palisade layer (C). Scale across scene is 1.056 mm.

lite/smectite, and potassium feldspar (R. Pollastro, U.S. Geological Survey - USGS, written comm., 1993).

Stable carbon and oxygen isotopic values (Table 2) obtained from whole bush specimens range from -5.6‰ to -6.56‰ (PeeDee Belemnite, PDB) for carbon ($\delta^{13}C$) and -14.86‰ to -16.51‰ (PDB) for oxygen ($\delta^{18}O$). $\delta^{18}O$ values were corrected from the Standard Mean Ocean Water (SMOW) standard to PDB using the method of Craig (1961). Discrete isotopic values obtained from microsampling of canal wall and palisade layers in sample H1B were similar to the above values. The bush localities display a general trend toward Calcite Lake of heavier isotopic compositions in the whole-rock analyses; the outer palisade layers are isotopically heavier than the canal wall within the H1B sample. All helictite bush $\delta^{18}O$ and $\delta^{13}C$ values (Fig. 5) plot within the "hydrothermal calcite box" as defined in Ford and Bakalowicz (1983) and Ford (1989) and are between the isotopic values for Wind Cave calcite crust speleothems and calcite raft speleothems at Calcite Lake in Wind Cave (Bakalowicz and others, 1987; Millen and Dickey, 1987).

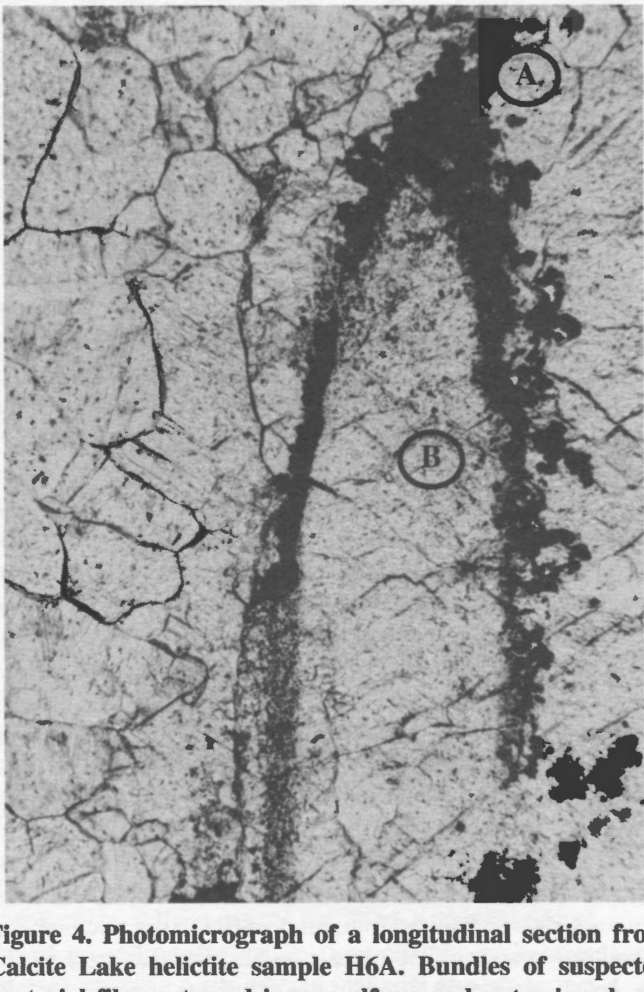

Figure 4. Photomicrograph of a longitudinal section from Calcite Lake helictite sample H6A. Bundles of suspected bacterial filaments and iron-, sulfur-, and potassium-bearing opaque bodies (A) extend along and across calcite crystal boundaries (B). Scale across scene is 0.43 mm.

Table 2. Stable carbon and oxygen isotopic values and calculated calcite precipitation paleotemperatures from helictite bush and boxwork speleothems, Wind Cave, South Dakota. Carbon isotopes were measured relative to the PeeDee Belemnite (PDB) standard. Oxygen isotopes were measured relative to the Standard Mean Ocean Water (SMOW) standard and were calculated to PDB according to Craig (1961). All temperatures calculated after Craig (1965) using the oxygen isotope value for water ($\delta^{18}O_w$ = -11.37‰ PDB) obtained from measured fluid inclusion temperature of homogenization of 54.8°C from sample H4A boxwork spar. CWX = canal-wall crystals, PX = palisade crystal layers.

Sample	$\delta^{13}C$ (‰PDB)	$\delta^{18}O$ (‰SMOW)	$\delta^{18}O$ (‰PDB)	Temperature (°C)
H1A	-5.94	- 15.56	- 15.78	37.9
H1B	-5.90	-15.71	-15.93	38.7
H2A	-5.78	-15.90	-16.12	39.7
H2B	-5.92	-16.29	-16.51	41.9
H2C	-5.70	-15.68	-15.90	38.5
H2D	-5.87	- 16.06	- 16.28	40.6
H3A	-6.56	- 14.64	- 14.86	33.1
H4A	-5.21	-15.92	-16.14	39.9
H5A	-5.61	-15.52	-15.74	37.7
H6A	-5.69	-15.10	-15.32	35.6
H1B CWX	-6.40	-16.00	-16.22	40.3
H1B PX	-5.70	-15.20	-15.42	36.0
H1B PX	-5.70	-14.80	-15.02	33.9

The calcite-water paleothermometer (modified by Craig, 1965) provides an equation to calculate the paleo-temperature of calcite precipitation using the oxygen isotopic value from calcite ($\delta^{18}O_c$) and the oxygen isotopic value from the water ($\delta^{18}O_w$) that precipitated the calcite (both relative to the PDB standard):

$$(1)\ T(°C) = 16.9 - 4.2\,(\delta^{18}O_c - \delta^{18}O_w) + 0.13\,(\delta^{18}O_c - \delta^{18}O_w)^2$$

Paleotemperature calculations for Wind Cave speleothems have previously been determined by assuming the $\delta^{18}O_w$ (PDB) value of the water. Using a $\delta^{18}O_w$ value of -12.4‰ (PDB) from modern waters in the Calcite Lake area, Millen and Dickey (1987) determined an average formation temperature of approximately 30°C for most Wind Cave speleothems and a maximum value of 61°C from a sample of boxwork. Our helictite bush $\delta^{18}O_c$ values yield whole-rock temperatures of 28-36°C. Using a $\delta^{18}O_w$ value of -16.0‰ (PDB) from Pleistocene meteoric water (Millen and Dickey, 1987) would yield whole-rock temperatures of 12-19°C for our helictite samples.

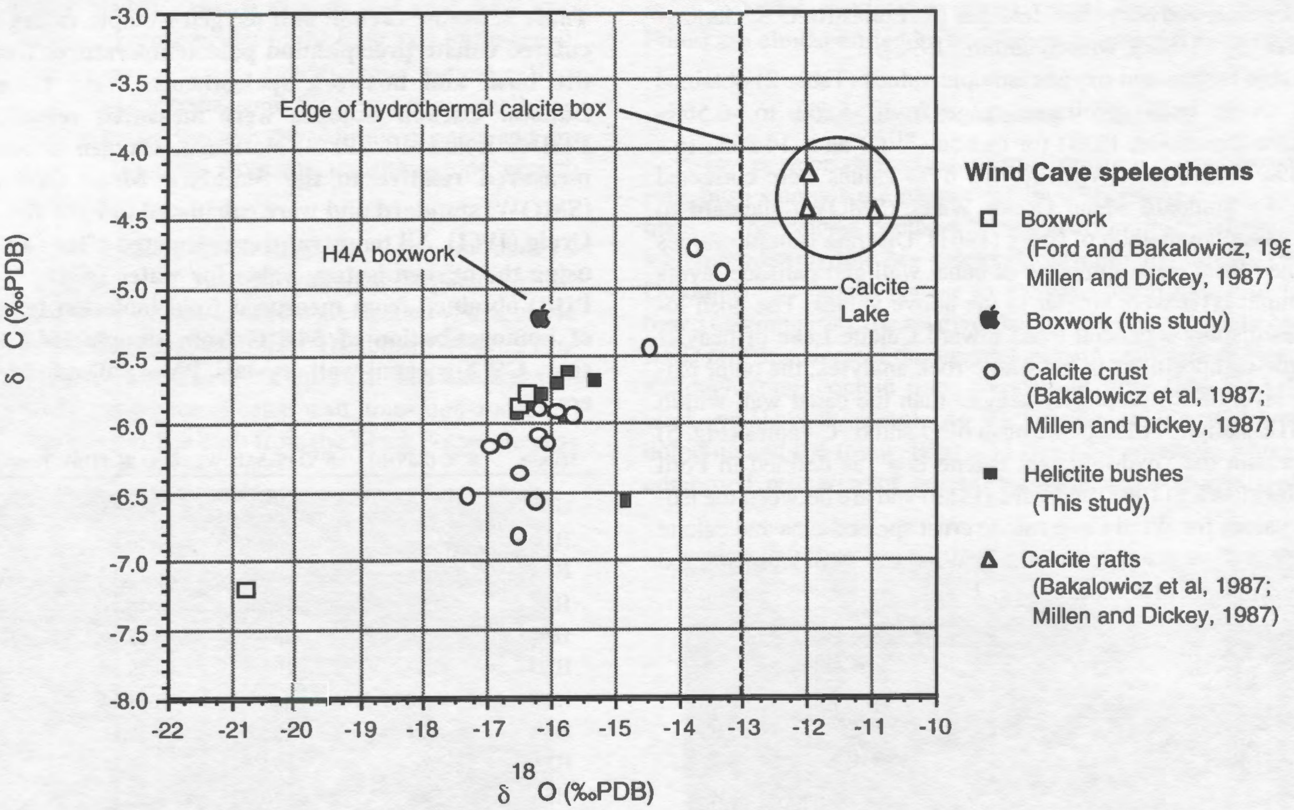

Figure 5. Plot of $\delta^{13}C$ (‰PDB) vs. $\delta^{18}O$ (‰PDB) for Wind Cave speleothems. The edge of the "hydrothermal calcite box" is denoted by the dashed -13‰ $\delta^{18}O$ line.

Boxwork fluid-inclusion temperatures and isotopic calibration of paleowater

Fluid inclusions from the calcite spar part of a boxwork speleothem (sample H4A) yield a mean homogenization temperature (T_h) of 54.8°C (B. Crysdale, written comm., 1991). Solving equation (1) for $\delta^{18}O_w$ by using the whole-rock $\delta^{18}O_c$ value from sample H4A and T_h (°C) from the fluid inclusion analysis yields a $\delta^{18}O_w$ value of -11.37‰ (PDB), which is slightly isotopically heavier than modern Wind Cave lake waters. This is used as the heaviest $\delta^{18}O_w$ value to calculate maximum paleotemperatures (°C) for the bushes (Table 2) as well as recalculating paleotemperatures for other reported Wind Cave speleothem $\delta^{18}O_c$ values. Whole-rock bush temperatures range from a maximum of 41.9°C from a specimen at the Garden Gate area to a minimum value of 33.1°C from sample H3A near the Emperor Maximus helictite bush (Fig. 1). The helictites at Calcite Lake (H6A) formed at 35.6°C. The discrete temperatures in Garden Gate sample H1B cool from 40.3°C in the canal wall to 33.9°C in the outer palisade crystals. These temperatures of deposition are within the hydrothermal calcite box, but follow the cooling history of the Wind Cave aquifer (Ford, 1989; Ford and others, 1993).

DISCUSSION

Implications for helictite bush growth

Petrographic examination of nine specimens revealed abundant translucent to opaque filaments in the canal-wall, transition-zone, and palisade crystal layers that are probably bacterial in origin and that appear similar to filaments of suspected *Leptothrix* fossil-bacteria in Mississippian-age orange calcite in Black Hills, South Dakota caves (Palmer and Palmer, 1989). The filaments are present in all phases of helictite bush growth, but notably within the canal-wall crystals as possible nucleation sites. The filaments may have provided a framework for the earliest phases of canal-wall growth, comparable to the algal tufa tower analogy of Davis (1991). Subsequent transition-zone crystal growth occurs as filament-rich micritic crystals, giving way to a radial palisade layer that has significantly fewer filaments. Opaque bodies associated with the helictite bush filaments probably contain trace amounts of iron-, sulfur-, and potassium-bearing compounds as inferred from random EDX spot analyses; the general appearance of the opaque bodies indicates trace pyrite may be disseminated through the transition-zone layers (P. Hansley, USGS, personal comm., 1994). The presence of these compounds may be associated with bacterial metabolism. Additionally, carbon-isotope values from the bushes are lighter than those of inorganically fractionated carbon, but not light enough for organically-fractionated carbon, suggesting that bacterial processes may have played a minor role in the carbon fractionation. The closest speleothem analogy may be the "pool fingers" described by Davis and others (1990) in Lechuguilla Cave, New Mexico, a possible biothem (Cunningham and others, 1995).

It does not appear that the bushes formed by mixing of calcium sulfate-saturated groundwater and calcium carbonate-saturated groundwater, a process known as the common-ion effect. Davis (1989) suggested bush deposition by the common-ion effect where thermal springs of calcium carbonate-saturated groundwater mixed with localized zones of calcium sulfate dissolved from remnants of evaporites in the Pahasapa Limestone. It is unlikely that localized zones of calcium sulfate saturation would remain within the dominant bicarbonate aquifer associated with calcite crust subaqueous deposition (Ford and others, 1993). The calcite pseudomorphs after gypsum that are near the contact between bedrock and calcite crusts and lack of observed gypsum remnants (Palmer and Palmer, 1989) also indicate that gypsum was replaced or removed before outer calcite crust and bush growth commenced. The outer palisade crystals from a subaqueous helictite which formed by the common-ion effect in Lechuguilla Cave, New Mexico, have sweeping, undulatory extinction (Davis and others, 1990). The palisade crystals in Wind Cave helictites do not display this type of extinction, but they display radial extinction prevalent in other calcite speleothems including stalactites.

Most helictite speleothems in other caves contain small-diameter (<1 mm) central canals through which solutions move by seeping capillary water under hydrostatic pressure, and the helictites thicken by means of intercrystalline seepage through the canal wall to radially growing outer crystals (Hill and Forti, 1986). The large-diameter central canals of the Wind Cave helictite bushes argue against subaerial calcite precipitation under hydrostatic pressure (Davis, 1989; Palmer and Palmer, 1989); the bushes thicken by cyclical encrustation of transition-zone and palisade layers (not from intercrystalline seepage). The lighter isotopic value and warmer temperature of the canal wall compared to the palisade layers in helictite bush sample H1B indicates the canal wall grew early in the cooling history of the aquifer. On the basis of similarity between carbon and oxygen isotope values from the bushes and the calcite crusts, it appears that the early canal-wall crystals of the bushes grew in shallow pools under subaqueous conditions. Bacterial processes and CO_2 degassing at the pool surface, not the common-ion effect, caused calcite precipitation. Short-term rises in the water table during the overall draining of the aquifer (Ford and others, 1993) provided slight differences in the local hydrologic head which forced water from the calcite floor crust-bedrock boundary to seepage points in pools where canal-wall crystals formed.

This calcite floor crust "plumbing system" has a lower hydraulic conductivity than the cave passage due to the presence of smaller, less-connected voids and red sediment-fill, particularly well-exposed past the Garden Gate area. This plumbing system is best developed in the lower-cave level along the route to Calcite Lake where most, but not all, helictite bushes occur. It is reasonable to assume that a slight lag-time existed between water table rises in the cave passages and the crust-bedrock boundary. This allowed water, possibly enriched with bacteria and/or nutrients (such as iron-compounds) from the sediments, to emerge from seepage points into pools and form the canal wall. The similarity of the mineral composition of the bushes to other Wind Cave speleothems and lack of any unusual minerals from the XRD analyses indicate a local aquifer source for the water. Micritic transition-zone crystals covered the outer surface of the canal wall during periods of subaerial exposure, which later were encrusted by palisade crystals (representing another slight water-table rise and subaqueous conditions). Oscillating water table levels during the lowering of the Wind Cave aquifer for the past 200,000 years (Ford and others, 1993) are also responsible for the encrusting microstratigraphy, occasional blockage of the central canal by calcite, illite and/or organic (?) matter, recrystallization of the calcite, and recent deposition of calcite rafts on the bushes.

Implications for the paleohydrology of Wind Cave

Fluid inclusions from boxwork calcite spar calibrated the calcite-water paleothermometer without the need to assume a paleowater $\delta^{18}O_w$ value. The calibrated paleothermometer yields near-maximum paleotemperature values for the Wind Cave aquifer and associated speleothems because boxwork calcite spar formed during the earlier, thermal spring dissolution of Wind Cave (Ford, 1989). Calcite crusts cover most boxwork and postdate its development (Palmer and Palmer, 1989). Because the bushes below the Boxwork Chimney grow upward through calcite floor crusts at fractures or along crust contacts with fallen breakdown blocks of bedrock (Davis, 1989) and the external layer of the crust consists of palisade calcite crystals that also coat the helictites (Palmer and Palmer, 1989), an approximate minimum date of 200,000 years (Ford and others, 1993) can be inferred for initiation of bush growth, particularly at the Garden Gate area. The Wind Cave aquifer has cooled by 28°C in the past 200,000 years using the maximum temperature from the Garden Gate bushes (41.9°C) and the average modern lake temperature of 13.9°C.

A trend toward cooler speleothem precipitation temperatures and heavier isotopic compositions from calcite crusts to modern calcite rafts (Fig. 6) is coincident with cooling after detachment from the thermal spring system and with draining of the Wind Cave aquifer as documented by Bakalowicz and others (1987), Ford (1989), and Ford and others (1993). The isotopic composition and temperature ranges of the helictite bushes indicate deposition during an aquifer level between the levels for precipitation of most calcite crusts in lower Wind Cave and for precipi-

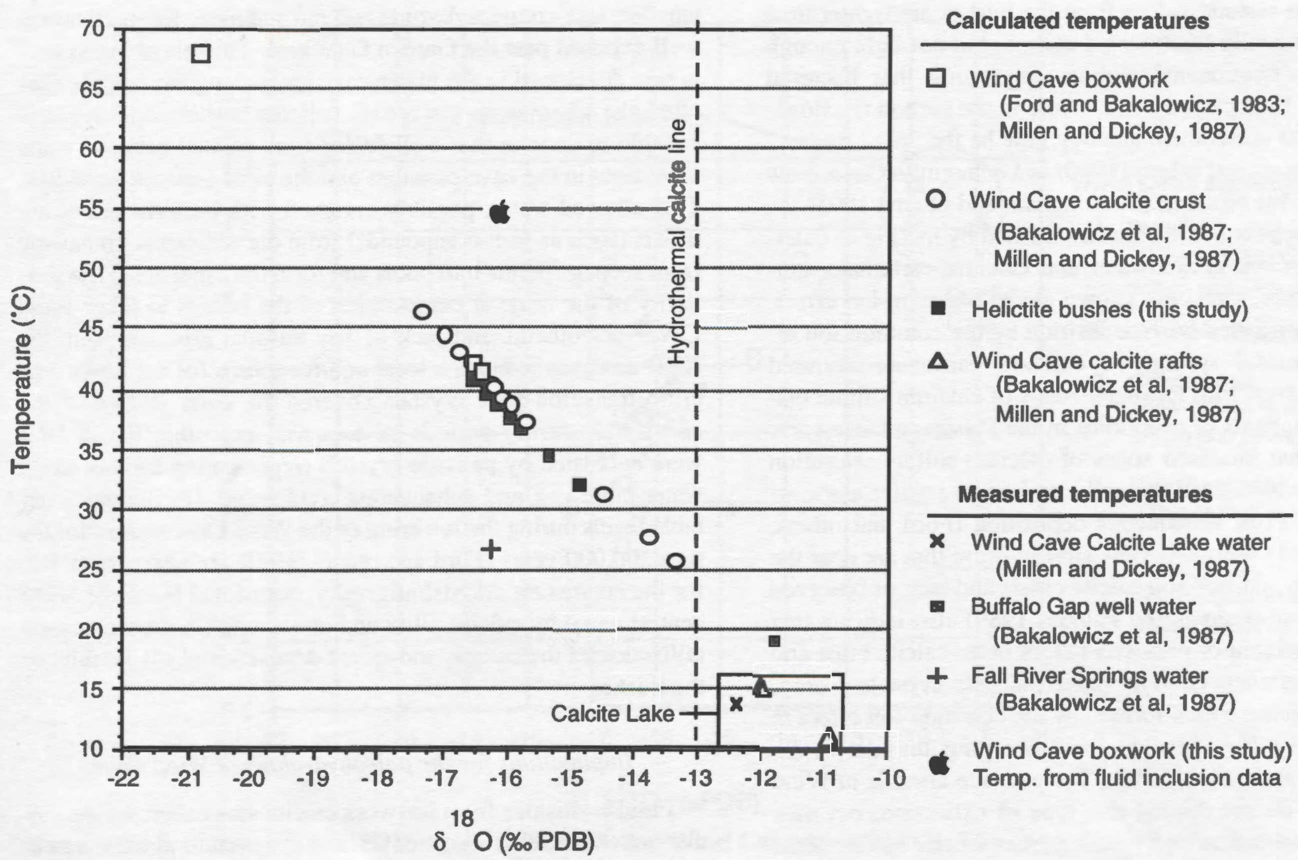

Figure 6. Plot of temperature (°C) vs. $\delta^{18}O$ (‰PDB) for Wind Cave speleothems and regional waters showing a trend toward heavier isotopic compositions and cooler calcite-water temperatures coincident with the draining of the Wind Cave aquifer. Temperatures are either speleothem paleotemperatures or modern water temperatures measured in Wind Cave and nearby springs/wells. Speleothem paleotemperatures are either calculated after Craig (1965) from speleothem isotopic composition or measured from fluid inclusions in boxwork spar sample H4A.

tation of calcite raft speleothems at Calcite Lake. The isotopic signatures of the bushes are not related to isolated hot spring vents or "smoker chimneys." Heavier isotopic values of the bushes towards Calcite Lake indicate the bushes are younger in that direction.

The $\delta^{18}O_w$ (-11.37‰ PDB) for the H4A boxwork calcite spar is between $\delta^{18}O_w$ values (Millen and Dickey, 1987) for mid-Tertiary meteoric water (-5‰) and Pleistocene meteoric water (-16.0‰). Modern Wind Cave lake water is fractionated towards a slightly lighter $\delta^{18}O_w$ (- 12.4‰ PDB) than occurred during the time of earlier boxwork calcite spar deposition. The $\delta^{18}O_w$ value from the boxwork is closer to that of the artesian well water (-11.8‰ PDB) from the Pahasapa Limestone below Buffalo Gap approximately 12 kilometers east of Wind Cave, while the Fall River thermal springs are depleted to -16.22‰ PDB (Bakalowicz and others, 1987).

CONCLUSIONS

a) The Wind Cave helictite bushes are possibly biothems -- speleothems with a bacterial (biological) role in their development.
b) The bushes are mostly calcite and probably formed subaqueously in shallow pools near the surface of a bicarbonate aquifer by bacterial processes and CO_2 degassing; not as a result of mixing of calcium carbonate-saturated groundwater with calcium sulfate-saturated groundwater (the common-ion effect).
c) The Wind Cave aquifer cooled by at least 28°C since the bushes began to grow approximately 200,000 years ago.

FUTURE RESEARCH

The difference observed in sample H4A between the isotopically calculated temperature (39.9°C, Table 2) and the fluid inclusion homogenization temperature (54.8°C) may be the result of using a whole-rock isotopic value. The fluid inclusion calibration of the calcite-water paleothermometer would be considerably improved by isotopic analyses of discrete calcite crystals (containing fluid inclusions) from boxwork, bushes, crusts, or other calcite speleothems. Fluid-inclusion data can also be applied to other isotopic studies for calibration of paleotemperatures. Radiometric age determinations and isotopic analyses of discrete helictite bush growth layers would provide a more-detailed record of paleotemperature fluctuations during the draining of the Wind Cave aquifer. The suspected organic origin of the filaments in the bushes could be tested by fluorescence microscopy and staining techniques, but this is a questionable approach because the filaments are probably fossil forms. Detailed microstratigraphy of helictite bush growth layers and coincident calcite wall crusts would benefit from cathodoluminescent microscopy. Microstratigraphic SEM-EDX analytical mapping of the crusts and bushes would provide elemental compositions to enhance understanding of the paleochemistry of the aquifer.

Acknowledgements

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DISCUSSION: WHAT ARE "ANTHODITES"?

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The following comments have been evoked by Dr. William B. White's (1994) paper "The anthodites from Skyline Caverns, Virginia: the type locality." They are intended not as criticism of Dr. White's analysis of the composition of the speleothems (which is a valuable contribution), but to raise the question whether the term "anthodite" is being consistently and appropriately applied in this paper, and in recent usage in general.

White's introductory paragraph cites Hill and Forti (1986) as authority that anthodites "have been described in many caves" and follows them in saying that "anthodites range in size from tufts of crystals a few centimeters across to aragonite 'trees' that can approach a meter in height." However, neither of these statements is justified by the original definition of anthodites from the Skyline Caverns type locality. I maintain that Hill and Forti's usage is taxonomically corrupt.

The term "anthodite" is of comparatively recent origin, having been first published by Henderson (1949). He describes them as follows:

> ...clusters of slender branching tubular formations. None were seen that were longer than about 18 inches and most of them averaged about 6 inches.
>
> The [Skyline] cavern officials have given these complexly branching tubular formations a new name, "anthodites" from the Greek word "anthos" meaning flowers....It appears that cavern guides are always alert to their duty of stimulating the imaginations of their visitors.
>
> Thus they make a distinction between anthodites and helectites [sic]. They limit helectites [sic] to the distorted twig like lateral projections of calcium carbonate which are found on a stalactite and anthodites to the small cluster of complexly branching tubular stalactites [sic] of about equal length....the majority of them seem to be clusters of small tubes originating near a common point, radiating outward and downward.

The above differentiation between helictites and anthodites is obscure, but both Henderson's and White's anthodite illustrations from Skyline Caverns indicate quill-like speleothems, with limited subparallel branching, radiating from a central mass.

Hill and Forti, however, arbitrarily "placed anthodites in a surface-flow-origin category, as opposed to helictites which grow by means of a central capillary canal." This is in clear contradiction of the original definition, which specifies that anthodites are tubular. They retrospectively trace references to anthodites to sources as early as 1671, without pointing out that these sources must have used other terminology prior to 1949. Their discussion indicates that they are in fact referring to acicular aragonite or quill-like calcite speleothems lacking central canals.

The most common feature which Hill and Forti call "anthodites" is aragonite in needle-like, often dendritically branching form, a speleothem quite distinct from anthodites as originally defined. White's allusion to meter-high aragonite trees could only be in reference to this feature. The name "frostwork" for this type of cave aragonite was coined by the guides in Wind Cave, South Dakota, in the 1890s (E. L. McDonald, quoted in Owen, 1898, p. 130). McDonald and Owen render the term as two words, "frost work"; Tullis and Gries (1938) make it a single word, which is the norm today. In any case, this nomenclature has clear priority over "anthodites" for this form.

The type anthodites from Skyline Caverns provide no basis for Hill's statement (1976, in the original *Cave Minerals*) that "'frostwork' is a type of aragonite anthodite." Nor is this usage justified descriptively, since acicular aragonite is more like frost than flowers. Its resemblance to frost was noted at least as early as the description of Wind Cave by Todd (1894). (Though cited by Hill and Forti as commenting on "anthodite needles," Todd of course did not use that term, and was not discussing speleothems like those of Skyline Caverns.) If we wish to maintain clarity and consistency in terminology, non-tubular, acicular aragonite should be called frostwork, not anthodites.

It is, in my opinion, unfortunate that the term "anthodite" was ever published in the first place. Henderson's account makes it obvious that the word was invented by laymen not well versed in cave mineralogy, and he himself says that "this newly coined name may or may not have been needed." Neither a fundamental distinction between anthodites and helictites, nor a connection between anthodites and frostwork, can be made on the basis of information from the type locality. The original anthodites might better have been considered simply a quill-like subclass of helictites.

To be consistent with Henderson's original definition, if the word "anthodite" must be used at all, it should be applied only to quill-like helictitic speleothems having central canals. Examples closely resembling the Skyline Caverns type seem not to have been described from many other caves, though they are well developed in LaSunder Cave, Colorado. Speleothems of similar morphology, but made up of strings of conical aragonite "beads"—found in Cave of the Winds, Colorado; Carlsbad Cavern, New Mexico; and several other western U.S. Caves—appear to be related.

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WHAT ARE "ANTHODITES"?: REPLY

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Donald Davis's comment on my paper concerning the anthodites of Skyline Caverns (White, 1994) is mostly concerned with nomenclature rather than the technical content of the paper. However, he does touch on a very important and largely uninvestigated problem in cave mineralogy, so perhaps a few counter-comments are in order.

The term "anthodite" was indeed invented by the management of Skyline Caverns so they would have a name for what seemed to them to be unique features of their show cave. The same could be said for most other speleothem names. "Popcorn," "cave grape," "gypsum flower," "cave pearl," and even "flowstone" are descriptive terms devised by cavers and show cave owners and applied to objects seen in caves. Almost never have speleothem terms (with the exception of the word "speleothem" itself [Moore, 1952]) been introduced in a formal, scientific way with characterizing features carefully spelled out. Further, the names are usually invented based on superficial inspection of external morphology rather than a detailed investigation of internal mineralogy and microstructure. The result is a bewildering collection of names which are only slowly taking on precise definitions, sometimes only by modifying the original usage of the name.

The plethora of names combined with the absence of real mineralogical and petrological data have made a scientifically accurate classification of speleothems impossible. There have been many attempts such as the rather elaborate classification devised by Halliday (1962). I tried to construct a two-level classification by distinguishing between "form" and "style" of speleothems (White, 1976). "Form" referred to the basic depositional mechanism and "style" referred to variations on the basic mechanism. No one seems to have been very interested. Hill and Forti (1986) wisely organize their speleothem descriptions as an alphabetical list with little emphasis on classification.

Mr. Davis suggests that anthodites are a style of helictite. I disagree. The distinction has to do with mineralogy and with crystal growth habit.

Helictites in their basic form are composed of calcite, grow by the addition of material at the end of a central canal, and exhibit their characteristic twisted tubular shapes because of a rather delicate balance between the rate of fluid flow through the canal and the rate and habit of crystal growth at the tip. Some details of helictite growth are known through Moore's (1954) microscopic study of a single specimen and Andrieux's (1965) rather more detailed investigation of crystal orientation and growth mechanism. There are many styles of helictite and further study of crystal growth patterns by examining thin sections in a polarizing light microscope or luminescence microscope would be very instructive.

Unlike calcite which tends to form equant crystals, aragonite tends to grow much faster along one axis, yielding acicular or fibrous crystals. Aragonite also has a tendency to form dendrites, crystals which show a branching habit. The anthodite, as the term is now used, refers to branching clusters of aragonite crystals. These speleothems vary considerably in size. They have no central canals. Their mode of growth is unknown as is their internal structure and the crystallographic relationships between the core crystals and the branches.

If the speleothems consist of only a single mineral, the distinction between the helictite and the anthodite is quite clear and unambiguous. A large collection of photographs of both forms from the Moulis Cave in France was published by Gèze (1958). Difficulties arise when both calcite and aragonite are present in the same speleothem. Aragonite is thermodynamically metastable in the cave environment and appears there only when trace impurities in the water inhibit the nucleation and growth of calcite, thus permitting the necessary supersaturation for aragonite deposition to build up. Because of the sensitive dependence of mineral deposition on details of the water chemistry, a speleothem sometimes begins its history as calcite and later switches to aragonite. Or the speleothem can begin as aragonite and later switch to calcite. The result is an ambiguous morphology with characteristics of both helictites and anthodites of which the helictite-like structures described from Timpanogos Cave, Utah (White and Van Gundy, 1974) are examples. The quill anthodites and the beaded helictites described by Hill and Forti (1986) are further examples.

Because aragonite is metastable, it will eventually invert to calcite, leaving behind a speleothem with the external and internal structure of aragonite but with the mineralogy of calcite. Such is the case with some of the Skyline Caverns anthodites described in the paper under discussion. To further confuse an already confusing situation, there are straw stalactites and masses of stalactitic calcite that apparently formed as a primary deposit mixed with the anthodites as seen in Figure 1C. The speleothems shown in Figure 1A (printed upside down in the NSS Bulletin) are more representative examples of anthodites as the term is now used. Thus the anthodites in the type locality are not the best possible examples of the speleothem, a situation not uncommon in the earth sciences.

In conclusion, I would argue that there are two distinct speleothems that might be called the helictite and the anthodite. But there also exist intermediate forms of mixed mineralogy whose relationships to the monomineralic forms can only be resolved by detailed examination of the internal microstructure.

As to Mr. Davis's other suggestion, that the term "frostwork" has precedence over "anthodite," there is no formal mechanism to resolve the issue other than usage in the scientific literature. The Wind Cave frostwork is more fibrous than most of the anthodites described elsewhere. My own inclination would be to regard frostwork as an anthodite style in comparison to perhaps three or four other styles. Again, we must await a detailed microscopic examination of a selection of the speleothems.

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BOOK REVIEWS

BAT BOMB by Jack Couffer, The University of Texas Press. Austin, Texas. 1992, 252 pp. $24.95

Most readers of popular caving books are, at least, vaguely familiar with the story about research on the use of bats as an offensive weapon during World War II. Now speleohistory buffs can have the complete story.

Jack Couffer, then a very young member of the research team, has put together an extremely readable text chronicling the sometimes bizzare activities of the 'special weapons group' assigned to the project. The group is made up of as odd a collection of characters one might imagine including a Bengal tiger cub. In the team are a movie star, several somewhat eccentric scientists, a barn-storming pilot, a possible gangster, and several teenagers taken right from high school. The two most notable of this last category are the author and future famous bat researcher Denny Constantine (NSS 518). The most compelling character from this cast, the individual who brought them together, is Dr. Lyle Adams (NSS 973), dental surgeon by trade and an imaginative and productive inventor by avocation. His plan was, of course, to use bats as a transporting mechanism to deliver incendiary devices into the eaves of the Japanese Empire and thus burn it into submission while minimizing the risk to the bomber crews. The idea seemed plausible to some in the Pentagon. Apparently after some intercession from the White House, approval was given to Adams to put together a research team to test the validity of the concept.

The scheme, known as Project X-Ray, was unusual from the start. Most of the group had little or no military training and had little use for it. They found ways to get the individuals or equipment they needed from outside of normal military channels. The book is full of remembrances and adventures that would do the crew of M*A*S*H proud.

The Mexican free-tailed bat was selected as the species to deliver the detonation device. This species was strong enough to carry the explosive and there seemed to be an inexhaustible supply of them from caves in Texas and New Mexico.

Cavers will recognize the locations of the project's collecting sites. Devil's Sinkhole, Carlsbad Caverns, and Ney, Frio, and Bracken Caves were selected to provide bats for the project. The last three caves, all located in Texas, were the focus for the collection of most of the bats. Particularly interesting are vivid descriptions, largely gleaned from Constantine's work, of the insect-laden environment of the bat caves. These caves are definitely not the place for the weak of heart or stomach.

Much was learned about bat metabolism, physiology, and the ecology of bat caves during the research for this morbid project. Most likely the scheme would have been a success had it been attempted in combat conditions. This was proven to some extent when some errant bats set fire to parts of the military airfield at Carlsbad. However, it appears that interservice rivalry, petty jealousy, and certainly the parallel development of the atomic bomb led to the termination of the project after two years of effort.

The entire story has been put together in an extremely readable and credible form by the author. The work appears to be well researched as shown by the references used and the effort expended by the author to locate surviving members of the team in order to corroborate the details of the story. Thirty-one photographs help supplement the story, however there is a bit of redundancy in their selection. A map or two showing the collecting and testing localities would have been helpful to readers unfamiliar with the region. These small problems do not detract from the story.

I recommend *Bat Bomb* as a highly entertaining and educational diversion into an unusual chapter of American speleohistory. I expect to see a movie version of the story soon. Hopefully, the plot and characters will not be much changed from the book.

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The Wilderness Underground, Caves of the Ozark Plateau. 1992. Text by H. Dwight Weaver, Photo Editors James N. Huckins and Rickard L. Walk. Columbia and London: University of Missouri Press, 113 p.

Available from: University of Missouri Press, Columbia, Missouri 65201.

The Wilderness Underground might be classed as a "coffee table book" with all of its very attractive photographs of caves and cave features of the Missouri, Arkansas, Oklahoma, and Kansas Ozarks. However, it goes far beyond the classical "coffee table book" with its explanative text. The excellent photographs by numerous Ozark cave photographers have been well chosen by the photo editors, James N. Huckins and Rickard L. Walk to illustrate the informative text by H. Dwight Weaver.

The text provides a basic introduction to the study of the cave environment and its geologic and geomorphic setting. Early in the text, Weaver talks about protection of this unusual and unique wilderness area. The cave protection laws passed in Missouri and Arkansas are mentioned and their implications for protecting the cave resources are illustrated.

The geographic, geologic and geomorphic setting of the "cavernous Ozark region" is presented, illustrating the diverse scenic features that can be found in this beautiful section of America. This area with its karst topography and features contains numerous caves which have been developed commercially or are available to the public because they are on public access lands. The Missouri Department of Natural Resources manages many areas with karst features as well as several nice caves. Many other caves are also present on private lands which require permission to visit.

In a section called the "Underground Mystique," Weaver discusses the history of cave exploration in the region from Indian exploration as early as 10,000 B.C. through the early settlers of the Ozark hill country in the 1800's to the Nineteenth and Twentieth Century Speleologists, including such notables as Luella Agnes Owen, a geologist from St. Joseph, Missouri, Ruth Hoppin, a biologist from the Smithsonian, Willard Farrar, a geologist for what is today called the Division of Geology and Land Survey within the Missouri Department of Natural Resources and finally J Harlen Bretz, a geologist from the University of Chicago who worked on caves in Missouri. The Missouri Speleological Survey, Inc., a nonprofit organization of volunteer and professional groups is one of the more recent parts of the history.

A discussion of the "Ozark Bedrock" provides the detailed geological setting for the book. A description of the rock units in the Ozarks is summarized for additional background.

Without the groundwater, the caves would not be present and so a brief discussion of groundwater and its ability to flow through the rocks provides further background to the origin and occurrence of the Ozark caves. This discussion of origin is further explored in a section called "Cave Origins." Here the scenario that forms the caves and provides their beauties is laid out in a very understandable manner. This is illustrated by several features in the Ozarks such as Big Spring and Grand Gulf.

The "Treasured Underground Beauty" is the title of a chapter illustrating the most beautiful aspect of Ozark caves, the uniqueness of passage and room sculpture and the beauties of the speleothems that have formed within those passages and rooms. This discussion of cave features and their origins is accompanied by excellent photographs of cave entrances, rooms, passages and numerous varieties of speleothems. This is the largest and best illustrated chapter in the book.

A section on "Ozark Cave Life" illustrated with photographs of endangered species as well as those that are more abundant, discusses the life forms found within the caves in the Ozarks. Even relics of those forms that are now extinct have been found in Ozark caves.

The final chapter of the book "Sunless Sanctuaries" illustrate the delicate nature of the caves of the Ozarks. A statement of the wise use and preservation of caves as an underground wilderness rounds out the final chapter.

Included in the final section of the book is a Glossary which gives definitions of cave and karst terms, a Bibliography, and a list of The Photographers whose photographs illustrate the sections of the book.

Besides being a very attractive "coffee table book," this informative book is an excellent beginning discussion of caves and their characteristics.

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ABSTRACTS OF THE NATIONAL SPELEOLOGICAL SOCIETY

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Norma Dee Peacock, Editor

ARCHEOLOGY

AN ANCIENT ROCKY MOUNTAIN CAVER

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Approximately 8000 years ago, a man in his early 40s entered a small cave at an altitude above 3000 meters in the Southern Rocky Mountains. He died there of a cause or causes unknown. His physical remains were found in 1988 by three NSS cavers, who contacted appropriate federal authorities, Native American representatives, and academic and privately-based researchers. In this paper we describe and discuss preliminary results of the Hourglass Cave Study.

THE CAVE OF LAS RUINAS (CERRO RABON, OAXACA, MEXICO): A MAZATECAN POSTCLASSIC FUNERARY AND RITUAL SITE

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In 1971 the discovery of a cave beneath the Sun Pyramid at Teotihuacán threw new light on the role of the subterranean in Mesoamerican civilizations. Subsequent discoveries in previously Mayan areas have confirmed the role of caves as sacred sites, with an increasing number being found beneath later major temple structures such as the group found in the Petexbatun region of eastern Guatemala.

A survey has been carried out in a karstic region of the state of Oaxaca, Mexico, situated far from all major ancient ceremonial and economic centers. We hoped to investigate the importance of the subterranean in Mesoamerican culture, and especially that of the Mazatecs. Recent discoveries made by this and other studies in the Cerro Rabón plateau (Sierra Mazateca) have revealed evidence for previously unknown prominent underground ritual and funerary activities.

Some 52 different caves and rock shelters were surveyed. A brief discussion of the morphological variation encountered and methods of underground archaeological survey will be presented. The cave of Las Ruinas has been chosen for a more detailed examination in this paper. The example of Las Ruinas best illustrates

—a typology for the considerable number and variety of funerary and other structures documented in the cave.

—different aspects of the relationship between human society and the subterranean environment.

The pottery found in the archaeological survey has allowed a relative chronological dating of all 52 studied sites. All belong to the Postclassical Period. The pottery also facilitated an evaluation of external contacts and influences on this region.

THE CHRONOLOGY OF PREHISTORIC EXPLORATION IN SALTS AND MAMMOTH CAVE, KENTUCKY: AN EVALUATION OF THE ^{14}C DETERMINATIONS

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Over the last 30 years a total of 54 radiocarbon determinations have been obtained from Salts and Mammoth Caves in Mammoth Cave National Park, Kentucky. These range from 4120±70 B.P. to 1920±160 B.P. and fall within the Late Archaic and Woodland periods of North American prehistory. I evaluate these 54 determinations, which include 13 new dates on paleofeces obtained in 1993, as they relate to the overall pattern of cave exploration in the two sites. I employ a statistical technique to test whether the dates themselves are stratified in a significant way.

PETROGLYPH CAVE, BELIZE: AN ANCIENT RITUAL SITE

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(paper not presented)

To the ancient Maya, caves were the embodiment of the realm of sleep, dreams, trances and the afterlife. The more impressive cave systems which were still penetrable by the Classic Maya often show evidence of a ceremonial complex involving human sacrifice, the placing of caches, the ritual destruction of objects, preparation of food offerings, and entry into visionary states.

An extensive investigation, still unpublished, was carried out by the authors in Petroglyph Cave, Belize, in

1978; the project team camped on the floor of the three-hundred-foot entrance sinkhole for five months.

This paper will summarize the findings of an unusual project in a truly remarkable setting. It will be argued that the petroglyphs for which the cave is named are expressions of entoptic art resulting from trance induction.

THE CUEVA CHEVE TABLETS

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The Cueva Cheve Tablets were removed from the archaeological site in Chamber 1 of the cave, Cueva Cheve, in the Cuicatec region of Oaxaca, Mexico, in March 1991. The two tablets are boards of the same size (18" length by 7" width by 1/2" thickness) and have a design made of turquoise and jade mosaic inlay. The design relates a battle. Each tablet is broken in two pieces. The tablets likely date from the Cuicatec Late Postclassic. A description of these tablets and the circumstances of their recovery will be reported in this paper.

REGIONAL VARIATION IN MAYA CAVE ART

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The Maya area is well endowed with cave art, one of the rarest art forms known in the world. Over 25 caves with paintings and handprints have been documented in a recent survey by the author, and an undetermined additional number contain carvings. This paper outlines regional differences in the corpus. For example, cave painting in the Puuc area of western Yucatan has a relatively coherent style and subject matter, distinct from contemporaneous cave painting in the southern lowlands. Cave painting in southern Belize is stylistically heterogeneous. The paper considers the issue of stylistic variation in Maya cave art from a functional, chronological and sociological perspective.

EXCAVATIONS IN BURIED CAVE DEPOSITS: IMPLICATIONS FOR INERPRETATION

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As conduits for transporting water, Maya caves are frequently wet and may be seasonally flooded so they often contain cultural deposits buried under layers of mud which tend to be so plastic that they are difficult to excavate and impossible to screen. In the past, such areas have tended not to be investigated. Ethnohistorical sources suggest that wet or watery places were sought for the performance of rituals. It is important to assess the extent to which archaeology's inability to explore such areas has biased data and interpretations.

The Petexbatun Regional Cave Survey [PRCS] is the largest and most intensive Maya cave investigation ever undertaken. Over the last four years the PRCS has attempted to develop new field techniques for cave archaeology, including several techniques for the exploration of water-logged environments. Over the last two years a method, using chemical deflocculants, has been developed for dissolving cave mud. Field testing of the method in 1993 in areas where the project had conducted complete surface collection recovered large numbers of sherds indicating that sherd density was several orders of magnitude greater than previously reported. In addition, the percentage of Preclassic sherds in the test unit indicate a far more intensive early utilization than suspected. More importantly there is little overlap between the artifact assemblages recovered by the use of deflocculants with that recovered from surface collection which has important ramifications for the reconstruction of cave ritual. In general, this new technique has revealed a greater intensity of utilization in buried areas and has produced an array of small artifacts that reflect a broader range of activities than suggested by surface survey alone.

BIOLOGY

BIODIVERSITY AND CONSERVATION OF NORTH AMERICAN CAVE FAUNAS: AN OVERVIEW

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The species diversity of cave faunas varies geographically, environmentally and phylogenetically. Biodiversity generally decreases from the tropics to the boreal regions, but cave faunas do not necessarily follow this pattern. For example, cave bat diversity is highest in the tropics, but groundwater biodiversity is highest in large karst aquifers, like the Edwards Aquifer of Texas. Terrestrial cave invertebrate diversity probably depends more on geologic-physiographic complexity and the age of a karst area than on climate. High species diversity, however, is rarely found in desert or boreal areas. Specific examples from Belize, Mexico, the United States, and Canada are given.

Being rare is not the same as being endangered and being common is not the same as being abundant. In Texas, examples abound of rare cave species that probably are not endangered yet, whereas some fairly common species in urbanizing areas are endangered. It can be argued that some species that are "abundant," such as the Mexican Free-tailed bat, are threatened or endangered because of their specific ecological requirements and their dependence for birthing on a relatively few, large but vulnerable, caverns. Other bats, such as *Myotis velifer incautus*, have been driven out of many caves in Texas but seem to be more ecologically "flexible" than freetails.

The conservation of cave and karst faunas may be most critical to human welfare in the tropics, where certain bats are critical to forest ecology, and in major karst areas, where maintenance of water quality and abundance coincides with good karst management. Recent work in Alaska has demonstrated the connection between karst conservation and good forest management. Most cave species are of no immediate economic importance to humans, but neither are most large, attractive species that are more popular. Conservation at the species level is useful for several reasons to be discussed.

CAVES AND BATS

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Bats, aided by their ability to navigate and orient in the dark using echolocation, are the only vertebrates that have successfully exploited caves (and increasingly, abandoned mines) for permanent shelter. From tree line to tree line, these structures supply bats in most major ecosystems with relatively permanent and climatically-controlled summer and winter homes, maternity and bachelor roosts, or predator-free environments in which to mate, feed or rest during long migrations.

The distribution of cave-dwelling bats varies predictably with the geographic distribution of caves. On a smaller scale, cave-specific attributes (physical dimensions, topography and microclimate) determine the presence or absence of bats as well as faunal composition and characteristics.

In North America (excluding Mexico) more than half of 43 bat species use caves during some part of the year. However, only about 5 percent of the 40,000 caves in the U.S. provide suitable roosting conditions for these animals. Consequently, caves can be a crucial resource for the survival of some species. For example, fewer than 10 caves house 95 percent of hibernating Gray Bats, an endangered species. Fewer than 25 caves in the southwestern states are home to most of the millions of Mexican Free-tailed Bats that migrate to the U.S. from Mexico every spring to give birth.

Bats reach their greatest number and diversity in the tropics. In Central America and South America, where bats are the dominant land mammals, more than 100 species can occur together in an area. Caves in these areas can provide homes for a large number of species, including many that pollinate and disperse dominant rainforest and desert plants.

Guano produced by cave-roosting bats is a major energy source for unique, and highly adapted, cave communities around the world. Guano accumulations from large bat colonies, particularly in tropical and subtropical climates, provide a source of income for local inhabitants.

Worldwide, cave-dwelling bats face increasing threats to their survival. To blame are: habitat destruction, vandalism and disturbance, pesticides and inadequate wildlife protection laws. Tropical species face additional threats from poachers and misguided vampire bat eradication programs.

CENTERS OF BIODIVERSITY IN CAVES

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While there are likely tens of thousands of cave-limited species world-wide, most caves contain only a handful of species. In most areas, even high diversity caves contain only 10 to 20 species at most. The exceptions, such as Mammoth Cave in Kentucky, have usually been explained on the basis of particular historical events (e.g. glacial maxima) occurring in unique geographical positions (e.g. distance from glacial boundaries). However, some exceptionally high-diversity cave and karst areas, most notably Movila Cave in Romania, Bayliss and other "bad air" caves in Australia, the Edwards Aquifer in Texas, and Lucayan Caverns in the Bahamas, share an important feature—"redox" environments and, most likely, sharp redox boundaries. Redox environments are areas of high productivity, often the result of chemoautrophic bacteria. This relatively high productivity may allow the development of a diverse cave-limited fauna, given appropriate geographical and historical conditions.

BIODIVERSITY OF SUBTERRANEAN AMPHIPOD CRUSTACEANS: GLOBAL PERSPECTIVE AND STRATEGIES FOR PROTECTION

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Amphipod crustaceans are among the most abundant, widespread and taxonomically diverse invertebrate groups found in subterranean groundwater communities. The vast majority are stygobionts, which by definition are species generally restricted to subterranean waters and showing some degree of troglomorphy (e.g., loss of eyes and pigment). The world's subterranean amphipod fauna is composed of approximately 750 species, which are distributed among 36 families and 138 genera. However, 12 families contain about 94 percent of all stygobiont amphipods, and the families Niphargidae, Crangonyctidae, Hadziidae (complex) and Bogidiellidae are the most important with respect to the numbers of stygobiont species they contain. The two largest genera—*Niphargus* (predominately European) and *Stygobromus* (predominately North American)—are composed exclusively of stygobionts and each has over 100 described species.

Although many regions of the world have significant diversities of stygobiont amphipods, the most remarkable species richness has been documented to date in the central and southern European-Mediterranean and eastern and southern North American–West Indian regions. Both of these regions have extensive karst terrains that remained unglaciated during the Pleistocene and were exposed to marine transgressions in the south during the Cretaceous and/or Tertiary. An essential first step in conservation and protection of stygobiont amphipods, and for other groups as well, is to document the biodiversity of these organisms, both regionally and globally. Data on taxonomic diversity and phylogenetic relationships are critical to the development of protection strategies for rare, threatened or endangered subterranean faunas and their habitats.

EFFECTS OF SEPTIC SYSTEM OUTFALL ON MACROINVERTEBRATE POPULATIONS AND THEIR FOOD RESOURCES

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The aquatic community in Banners Corner Cave, Russell Co., Virginia is affected by overlying septic systems. Impacted sites had low dissolved oxygen concentrations and high conductivity, Cl^-, NO_3^-, and fecal coliform levels. High densities of *Caecidotea recurvata*, a troglobitic isopod, in Banners Corner Cave were suspected to be a result of organic enrichment by septic outfall. Isopod density, sediment organic matter, bacterial biomass, and fungal biomass were measured in reference and impacted sites. Isopod densities range from 3.0–74.6/m^2 with highest densities in moderately impacted and unimpacted sites. Heavily impacted sites had no isopods. Sediment organic matter ranged from 0.02–0.09 gC/g sediment, and bacterial biomass ranged from 0.07–1.60 mgC/g. Sediment organic matter and bacterial biomass were significantly greater (one-way ANOVA, a=0.05) in all impacted sites as compared to reference sites. Fungal biomass was negligible in sediments in all sites. Septic outfall generally reduced isopod densities, presumably by direct toxicity and reduction of dissolved oxygen. At moderate levels, septic outfall may increase food availability without toxic effects, but this did not occur often in Banners Corner Cave. High isopod densities appear to be due to the presence of CPOM rather than organic enrichment by septic outfall.

EVOLUTION AND DISPERSAL IN TEXAS SALAMANDERS OF THE GENUS *EURYCEA*

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Recent cave discoveries and laboratory studies of Texas cave salamanders have further advanced our knowledge about this interesting group. Several new species have been found in recently discovered caves north of Austin and the hydrologic systems they inhabit are being studied. Other discoveries from caves in Glenrose and Edwards limestone shed light on the dispersal potential of salamanders through conduits and across groundwater divides. DNA studies showing the degree of relatedness of different populations reveal two major groupings aligned with geographic distribution.

BIODIVERSITY IN CAVES: IMPERILED OR NOT?

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In recent decades it has become apparent that anthropogenic perturbations are not restricted only to surface ecosystems. Rather, evidence continues to mount globally that various caves, springs, cenotes, blueholes and anchialine and various crevicular habitats, as well as regional groundwater have become altered by surface activities of humans. Although the Federal Endangered Species Act has resulted in numerous cave-adapted species being listed and "protected," examples of extirpated populations, such as the blind shrimp *Palaemonias alabamae* Smalley and the Gray Bat, *Myotis grisescens* (Howell) in Shelta Cave, Madison County, Alabama, demonstrate that simply being listed may not afford adequate protection. On a grander scale, numerous North and Central American karst systems as well as those in many locations in the western Atlantic (e.g., Bermuda, Bahamas) have been severely disturbed. Horrendous management problems exist at all levels and often mismanagement is realized long after damage has occurred. An additional problem is that very little is known about so few cave species; those animals recognized represent only a fraction of projected totals for extant or even extinct forms.

In addition to halting surface perturbations in karst areas, efforts should be made to encourage detailed taxonomic, life history, and ecological studies of karst (surface and subsurface) ecosystems. Additional cave biologists are needed in order to ensure the study and documentation of spelean diversity. Without adequate information concerning physicochemical and biological parameters, decisions for appropriate short and long term protection and management of karst ecosystems will be ineffective.

A NEW SPECIES OF THE SUBTERRANEAN AMPHIPOD GENUS *PARAMEXIWECKELIA* (Hadziidae) FROM VAL VERDE COUNTY, TEXAS, WITH COMMENTS ON ITS BIOGEOGRAPHIC AND PHYLOGENETIC RELATIONSHIPS

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During fieldwork in the 1980s, Dr. Robert Hershler collected stygobiont amphipods from unnamed springs on the east side of Devils River about 32 km north of Del Rio in Val Verde, Co., TX. The samples contained numerous specimens of an undescribed species of *Paramexiweckelia,* and fewer specimens of *Seborgia hershleri* and *Stygobromus* sp. (*flagellatus* group). Prior to the present study, *Paramexiweckelia* was known only from a single species described from a resurgence in the Bolsón de Cuatro Ciénegas, Coahuila, in northern Mexico. The new species from Val Verde County brings the total number of species of freshwater stygobiont amphipods in the family Hadziidae from continental North American, north of Yucatan Peninsula, to 10. *Paramexiweckelia* is the most primitive of the six regionally endemic hadziid genera of northern Mexico and Texas. It forms an "outgroup" to the other genera as indicated by a number of important plesiomorphic characters.

Morphologically, the two species of *Paramexiweckelia* are closely similar, but they are separated geographically by approximately 350 km and the Sierra Madre Oriental. The distribution track of this genus parallels in part the distribution tracks of another hadziid amphipod, *Mexiweckelia,* and two stygobiont isopods—the cirolanid *Speocirolana* and stenasellid *Mexistenasellus*. These three genera also occur in both central Coahuila and south-central Texas. The discovery of yet another species of stygobiont amphipod in south-central Texas, associated with the Edwards underground aquifer, is further indication of the remarkable biodiversity of the marine-relict crustacean fauna that inhabits this extensive karst system

THE IMPACT OF UBANIZATION ON ENDEMIC CAVE FAUNA IN TRAVIS AND WILLIAMSON COUNTIES, TEXAS

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An estimated 38 species of terrestrial troglobite are endemic to Travis and Williamson Counties (and immediate adjacent limestone outcrops in Burnet and Hays Counties). These include seven species on the U.S. Fish and Wildlife Service List of Endangered Species: the Tooth Cave spider *Neoleptoneta myopica* (Gertsch), the Tooth Cave pseudoscorpion *Tartarocreagris texana* (Muchmore), the Bee Creek Cave harvestman *Texella reddelli* Goodnight and Goodnight, the Bone Cave harvestman *Texella reyesi* Ubick and Briggs, the Tooth Cave ground beetle *Rhadine persephone* Barr, the Kretschmarr Cave mold beetle *Texamaurops reddelli* Barr and Steeves, and the Coffin Cave mold beetle *Batrisodes* (*Excavodes*) *texana* Chandler. The geologic factors responsible for the endemicity of this fauna include faulting and canyon incision. Maps and demographic data will be used to demonstrate the impact of the rapid growth of Austin and adjacent cities on the endemic cave fauna. A brief overview of attempts to conserve the cave fauna will be given.

COMMUNITY ECOLOGY OF THREE CENTRAL TEXAS CAVES

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In 1991, I began baseline ecological monitoring of LakeLine Cave, Thor Cave, and Testudo Tube, in Williamson County, Texas, under contract to the Simon Development Co., Inc. The studies were required by a permit issued by the U.S. Fish and Wildlife Service to mitigate the development of a shopping mall on an endangered species karst area near Austin. LakeLine Cave was set aside in a small preserve for the benefit of *Texella reyesi,* the Bone Cave harvestman, and *Rhadine persephone,* the Tooth Cave ground beetle. The company also acquired two other karst preserves and supported my studies.

The three caves have different communities and physical dynamics. The caves were wired with temperature-humidity sensors linked to digital data loggers and were visited monthly for over a year. During the visits, species were inventoried in marked zones and temperature and humidity readings were taken with a high-precision digital thermometer. I found that the two endangered species have precise microhabitat requirements. Cave cricket emergences were studied for one year, including monthly four-hour counts and quarterly overnight vigils. I tracked the seasonal abundance of two to three species of crickets, daddy longlegs, fire ants and other species to determine the minimal ecological requirements for a sustainable endangered species cave preserve. I found that raccoons and crickets contribute large amounts of nutrients to some caves and that *Peromyscus* mice consume large numbers of crickets. Fire ants are making inroads on Central Texas cave ecosystems. Data were accumulated showing some competitive exclusion between *Rhadine subterranea* and *Rhadine persephone*. Studies are continuing.

A PRELIMINARY STUDY OF THE INVERTBRATE CAVE FAUNA OF CHINA

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During the XI International Congress of Speleology in 1993 we collected biological samples from five caves in two regions of China. Despite drastic alteration of four of these caves for tourism, limited collecting resulted in significant discoveries of invertebrate animals, including several undescribed taxa and new cave records for known species. A non-tourist cave near Guilin in south China and four tourist caves on the Liaoning Peninsula in northeastern China were investigated. The cave near Guilin yielded aquatic snails, ostracods, atyid shrimps, trichoniscid isopods, polydesmid millipedes and dytiscid beetles. The shrimps, isopods and beetles represent new genera; most or all of the species collected from this cave appear to be troglobitic. Collections from Liaoning caves included cyclopoid copepods, ostracods, amphipods, onychiurid collembolans and campodeid diplurans. Some of these represent new species, others represent new cave records. The record for the stygobiont amphipod crustacean *Pseudocrangonyx asiaticus* is the first for the species from a Chinese cave (a previous collection was from a spring), whereas the record for *Grammarus nekkensis*, a non-stygobiont amphipod, is the first from a cave and also a significant range extension for this species.

The invertebrate cave fauna of China is very poorly known, but our preliminary sampling suggests a potentially significant biodiversity. Unfortunately, habitats in many large caves have been drastically altered or destroyed during development for tourism. We suggest that biological inventories be made in as many unaltered caves as possible and that government officials be urged to protect the most biologically diverse caves in their natural state.

LONG-TERM ECOLOGICAL MONITORING OF KARST RESOURCES AT MAMMOTH CAVE NATIONAL PARK, KENTUCKY

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As part of a National Park Service initiative to expand resources management programs, Mammoth Cave National Park has been selected to develop strategies for long-term ecological monitoring of cave and karst resources. Key elements of the proposed watershed approach include synoptic and flood pulse water quality sampling, correlative biomonitoring of these same waters, and acquisition of land use and demographic data for each drainage basin. Ecotones at selected natural, modified natural and artificial entrances will be equipped for continuous atmospheric monitoring, and periodic census data on both vertebrate and invertebrate populations will be collected. In the constant temperature zone, impacts from inadvertent abrasion, substrate compaction, vandalism, lint deposition, latrines and food service will be monitored. Methods will include permanent photopoints, gravimetric measurements of lint accumulation, continuous atmospheric measurements, and periodic census of the terrestrial cave community.

EVOLUTION OF THE AMPHIPOD *GAMMARUS minus* IN CAVES: AN ANALYSIS OF TIME

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The amphipod *Gammarus minus* is estimated to have invaded underground basins multiple times, from as early as 2 million years ago to about 100,000 years ago. There is evidence for directional selection in the evolution of troglomorphy in cave populations. These time estimates, however, indicate that observed rates of morphological change in *G. minus* are less than expected from neutral models. Eye size has evolved faster than antenna size, and may reflect that while the evolution of antenna size is due to selection, the evolution of eye size is due to additive effects of neutral mutation and selection. Genetic evidence also indicates that karst window populations of *G. minus* are derived from cave populations, and suggests rapid loss and re-acquisition of eye components. An hypothesis that eye reduction in cave populations may originally result from selection for mutations at the regulatory loci is proposed.

CONSERVATION AND MANAGEMENT

RESTORATION

Jerry Trout and Jim Werker

It is timely to produce a handbook for cave restoration. Our goal is to initiate a forum for gathering techniques and procedures that have been proven in cave environments. We will present information and lead discussion that we hope will become the basis and catalyst for a collection of cave restoration data. Topics will include types of speleothems that can be *repaired*, types of materials that can be *removed*, areas and types of speleothems that can be *cleaned*, and environmentally safe materials and equipment to use. Other issues for discussion include volunteers, documents, safety, logistics, Material Safety Data Sheets, agency agreements and time involved.

INTERIM RESULTS OF THE CONTEMPORARY CAVE USE STUDY

John Wilson

This report presents some preliminary information on the habits of cavers today. Gender differences, aging of the caving population, and changing cave equipment are all topics to be covered. The significance of these trends for cave managers will be considered.

LINT IN CAVES

Bill Yett and Pat Jablonsky

This presentation will cover the research and investigations explored during the past two years regarding lint and its effects on a cave environment.

Implications and control of lint deposits in show caves has received scant systematic study. The potentially detrimental effects of uncontrolled lint accumulations in caves include degradation of the appearance of the cave, provision of a food source for opportunistic organisms, and even a medium for dissolving cave surfaces. A number of show caves regularly clean tour trails and cave surfaces with water, and a few use some other methods of cleaning for the abatement of lint. Plausible and useful techniques to control lint are being examined by the authors who are also studying the composition of lint by laboratory methods and the dynamics of lint movement in caves. Conclusions indicate that the most promising strategies to control lint deposits in caves involve careful attention to trail designas well as custodial and maintenance procedures. The application of some "clean room" technology may also be useful.

LITERURE REVIEW: POULTRY-WASTE POLLUTION A NEW THREAT IN KARST TERRANES? (WHAT LITERATURE?)

William S. Berryhill, Jr.

Several investigators, residents of karst areas, and others have become concerned over the last 3 or 4 years about the potential for water quality problems caused by chicken and turkey farms and by poultry processing facilities. Although a few reports have been published that address general agricultural land-use influences on karst water quality, there are none in the open literature (to my knowledge at present) that deal specifically with the problem of poultry-waste pollution in karst. Yet the threat is very real. I base this opinion on the following facts. The poultry industry is growing. Farms and processors are expanding into areas like the Valley and Ridge counties on both sides of the Virginia–West Virginia border. In some karst areas regulatory control and enforcement are virtually non-existent. Growers like karst because water soaks right into the soil without leaving puddles. Chickens and turkeys are shitting machines, producing significantly more manure on a weight basis than mammalian livestock. They also die, causing a putrefaction problem. A large poultry farm produces *tons* of manure and dead birds, rich in nitrogen, pathogens, and BOD, *per day*. Sediment loading can also cause trouble. Each of the conventional waste management practices (composting, export, burning, feeding, burial, sinkhole dumping and land application) has drawbacks.

This paper will present a review of the literature on water quality impacts on poultry growing, processing, and waste management. It is necessarily not specific to karst terranes. The literature on agricultural impacts in karst will also be reviewed. And if I can find anything on poultry-waste in karst, it will of course get top billing.

PHOTOMONITORING

Val Hildreth and Jim Werker

During the past year, we have developed a faster, easier photomonitoring system that offers more accuracy and repeatability, streamlines labor and tedium, and reduces cave impact. We will present this efficient, unobtrusive system and compare this new permanent technique to the traditional methods. Topics will include speleothems and areas that should be photographically monitored, recommended supplies/equipment for repeatability and philosophy/procedures for minimizing cave impact.

EQUIPMENT AND TECHNIQUES

COUPLING MINERALOGICAL DATABASE INFORMATION WITH ADVANCED THREE-DIMENSIONAL CAVE SURVEYING

John Rowlan
Room C-245 Building 203, 9700 S. Cass Ave., Argonne, Illinois 60439 (paper not presented)

CSS_Surveyor is an interactive, three-dimensional modeling tool for displaying mineralogical and arbitrary user-defined database information onto cave survey plots. The program is also a new-generation cave survey program, providing advanced graphics and an easy-to-use user interface. Through Open-GL, the program will run on almost any workstation, as well as the Power PC line of processors.

CSS_Surveyor is unique in that it provides an easy to use interactive method for graphically illustrating the relative locations within the cave survey plot of mineral and speleothem data. For cave exploration, the program can display various user-defined attributes such as leads, water, rope drops, etc.

In addition to providing the ability to select and zoom into any region of the cave and provide the usual suite of cave surveying functions, the program also provides the user with 3-D trackball interaction within a user-selected region of the cave. Slowly rotating selected passageways in 3-D can often provide more insight than that from an arbitrary plan or profile view. Of course, the program also allows any plan or profile view to be specified.

CSS_Surveyor is built upon an easy-to-use graphical user interface which makes full use of menus, buttons, and graphical displays, which provide accurate and easy interaction with the cave model and attribute databases. CSS_Surveyor currently accepts data in KARST, COMPASS, and our CSS (for Cave Survey Standard) formats, allowing data portability from other tools currently in use.

A 3-D SYMBOL SET FOR STAGE-4 CAVE MAPS

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A computer program called Interactive Cave Map (ICM) is being used by the author to explore the application of interactive computer graphics to the generation and display of Stage-4 cave maps, i.e., cave maps designed to be viewed on the computer graphics screen. ICM displays four basic types of information: Traverse Lines Information (TLI), Passage Walls Information (PWI), SYmbols Information (SYI), and AuXillary Information (AXI). This paper concentrates on SYI.

The symbol set, implemented using parameterized icons, allows the depiction in 3-D of objects appropriately addressed by the "Basic Cave Map Symbols" of the 1976 NSS Standard, including: Passage Features, Speleothems, Floor Materials, and Miscellaneous. It should be noted that not all "symbols" in the 1976 NSS Standard address objects found in caves. Some are attempts to convey other types of information, e.g., cross sections and ceiling heights attempt to convey PWI, survey stations to convey TLI, and north arrows and scales to convey AXI. The icon parameters include three offsets from a survey station (for placing the symbol), three factors (for scaling the symbol), and three angles (for orienting the symbol).

Hardcopies of the maps of Corkscrew Cave (an artificial cave used for testing the computer program) and of Cueva Catanamatias (a real cave in the Dominican Republic) are used to illustrate the symbol set.

THE OTR COMPASS COURSE

George Dasher
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In 1988, I took over the responsibilities of running the compass course at OTR. This course is an eight-station, seven-shot course, where contestants compete to see who can close a loop with the smallest error. Each year the layout of the course is changed, and there are often severe vertical shots incorporated into the design of the individual courses.

The end result of these five years is that I have managed to collect a good deal of data on the instruments most cavers use to survey in caves. Predominant among these instruments are Suuntos; Sistecos are a poor second and Bruntons a poorer third. I have tossed out all the "bad" data sets, averaged the azimuths and inclinations for each individual shot, compared the individual azimuths and inclinations to these averages, calculated a difference for each shot, and then averaged these differences. The end results are that I have found Suuntos to be the most accurate of the three instruments and that the clinometers are more accurate than the compasses.

And how much do most cave surveying instruments deviate from these averaged norths and horizontals? The compasses were typically 1 degree off the averaged north, and the clinometers 0.4 degrees off the averaged horizontal. The need for compass courses is obvious once a graph of all the data is viewed.

A LIGHTER, SAFER MITCHELL SYSTEM

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Backpacking to remote vertical mountain caves requires an ascender system that is light, compact, yet relatively safe. The Mitchell System shown in the NSS publication *On Rope* is too heavy and large for this application. Mountain cavers have eliminated the use of sewn webbing for foot loops, exchanged tubular webbing for static line, added safety tethers, and constructed ultra-light seat harnesses for a smaller, lighter, yet "safe" system. Each modification to the Mitchell System can be made independent of all other modifications. The talk will consist of: (1) A discussion of each of the modifications. (2) A demonstration on building an ultra-light, yet safe seat harness. (3) Demonstration of how a safety tether can guard against the more common Mitchell System failures, and add to the comfort of the system.

CAVE RESCUE ORGANIZATIONS, ACCIDENTS AND INCIDENTS IN CUBAN CAVES

M. Roberto Gutiérrez Domech
Speleological Society of Cuba (paper not presented)

Larger caves in Cuba are horizontal, and even though most have several levels, connection between them is possible without many difficult climbing operations. Mostly our bigger systems are of fluvial genesis, and many of them are at some time of the year completely or partly occupied by underground lakes or running streams. For this reason, for years accidents and incidents were mainly related to water. With a seven-month rainy season in which frequent tropical storms develop, the Speleological Society of Cuba (SEC) had less than 30 rescue calls before the 80s.

With the arrival of new techniques such as single rope, cave diving, and others, a group of previously inaccessible caves were attacked, and the character of accidents changed. Now the SEC has the unpleasant experience of recovering dead bodies of members.

Even though most of the groups with problems try to rescue themselves, exploration of vertical caves and problems with bad quality of equipment made necessary a rescue program. The Speleological Society of Cuba has a National Rescue Commission, with a Central Medical Group. Each one of the 14 Cuban provinces and the Special Municipality of the Isle of Youth (Isle of Pines) has a rescue team. There is a program of instruction with an annual first-level course, and a second-level course has been organized for 1994.

The absence of statistical records and the different groups of people participating in rescue operations in caves, mountains, canyons, and other wild places in Cuba make it difficult to have a complete record of these kinds of problems. This is a first step.

LOCATING THE CAVE ENTRANCE

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Recently, I have completed a publication on the caves of a drainage area in Greenbrier County, West Virginia. It has become painfully obvious that most cavers—including many experienced cavers—have no idea what to describe while locating caves in a given area or above the mega-monster-cave.

The proper method—which should prevent multiple trips to the cave to redescribe the entrance—should include not only marking the cave location precisely on a topographic map, accurately determining the coordinates, but also providing a good, written description of where the cave is located and of the appearance of the cave entrance. There is no such thing as too much of a written description.

The written description of the cave location should include items such as: Is the entrance north or south of a fence?, What trees or obvious rock outcrops are nearby?, and, How far and what direction is the entrance from the nearest road, valley bottom, or stream? Give azimuths to obvious locators—e.g., houses, barns, junkpiles, etc., and include a sketch of where the cave is located.

The written description of the appearance of the cave entrance should include: the depth, diameter and shape of the sinkhole, the diameter and shape of the cave entrance, Is the cave entrance in bedrock or soil?, Are there any streams which flow into or out of the cave entrance?, What is immediately above or below the cave entrance?, and—if necessary—Are there any interesting features in the cave entrance? This may include a picture of the cave entrance.

To summarize, it is very important to keep lavish written records of where each cave is located and of the appearance of the cave entrance. The bottom line is overkill, overkill and overkill. The other option is 501 trips to the same cave entrance to re- and redescribe its location and appearance.

EXPLORATION - INTERNATIONAL

THE EXPLORATION OF KALMANSHELLIR, ICELAND, 1993

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During July 1993, a joint Icelandic-American expedition explored and surveyed the Kalmanshellir lava tube system of west-central Iceland. Although segmented at nearly forty ceiling collapses and several lava plugs, the length of the cave exceeds four km, making it the longest known cave system in Iceland. The expedition was a joint project of Hellarannsóknafélag Íslands (the Icelandic Speleological Society), the National Speleological Society, the York Grotto, and Speleo-Research Associates.

The Kalmanshellir cave system is formed in a single lava flow unit near the origin of the Hallmundarhraun lava flow. This lava flow also contains the Surtshellir-Stefánshellir lava tube system (previously the longest cave in Iceland). Víðgelmir (the most voluminous cave in Iceland), and nine other smaller caves. The depth of Kalmanshellir is only about 50 m and the end-to-end distance is nearly two km. A portion of the cave was previously explored by local farmers and Icelandic cavers. Several cave segments contained long lava soda straw stalactites (some exceeding a meter in length) and tall lava stalagmites.

Primary obstacles to exploration of Kalmanshellir included the remote location and the subarctic environment. These obstacles were overcome by a well-organized team using 4-wheel drive, 6-wheel drive vehicles and with equipment usually employed by high-altitude mountaineering teams. Cave survey accuracy was hindered by the strong magnetic effects of iron in the lava cave walls, but was overcome by foresight-backsight averaging underground coupled with surface theodolite surveys to accurately locate each surface collapse.

In addition to the exploration and survey of Kalmanshellir, some expedition participants also surveyed Leioarendi (600 m), visited the caves of Surtshellir, Stefánshellir, Víðgelmir, and Hallmundarhellir, and became the first international team to descend the 120 m deep Þríhnúkagígur Pit.

THE CAVE OF THE RIO SAN RAMON, HUEHUETENANGO, GUATEMALA, MARCH-APRIL, 1992

Steve Knutson
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(paper not presented)

In the Spring of 1992, an NSS Expedition visited the "Puente de Tierra" north of Barillas in the Department of Huehuetenango in Guatemala. The Puente is formed with the submergence of the Rio San Ramon for a distance of some 0.7 km. A through-trip of the cave was accomplished with some difficulty, requiring some 1200 meters of rope for a cave of about the same length. The dry season river flow was estimated at some 400–500 cfs.

RECONNAISSANCE EXPLORATION IN THE SIERRA MIXTECA ALTA, OAXACA, MEXICO

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The Sierra Mixteca Alta, a high mountain range within the Sierra Madre del Sur in central Oaxaca, México, has extensive limestone outcrops but little is known and nothing is documented about its karst development and cave potential. A small expedition of cavers from Colorado and Oaxaca explored the region last winter and found the area worth further investigations. The remote *municipio* of Itundujia had been visited four previous times by small teams of U.S. cavers but each group had found the local people extremely uncooperative and access to the caves denied. This most recent team, including two official representatives of the state of Oaxaca, was also denied access to the area caves but they were able to determine the nature of the hostilities among the local people.

In the *municipio* of San Miguel el Grande, the team explored five new caves. Exploration was stopped in each cave by recent sediment fills that have resulted from severe soil erosion in the Sierra Mixteca Alta.

Further north, the team learned of several caves in the *municipio* of Nunuma but they were not explored due to limited time and delicate political relations. Nearby, in the *municipio* of Yosonicaje, the local people and officials were warm, interested, and supportive of our interest and shared several caves with us. This town was determined to be the best objective for further efforts and the Oaxaca and Colorado cavers hope to continue an alliance in exploring them.

THE GRANITE KARST OF ATHERTON TABLELANDS, QUEENSLAND, AUSTRALIA

Larry Flemming*, Carl Snyder and Emily Davis Mobley
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Granite Gorge Park in Queensland Australia exhibits many features typical of soluble rock including a short cave with active stream, and surface features which are similar in appearance to slickrock. While the system is far less complex than some previously reported granitic karst systems in the eastern U.S., the solution like features are more obvious.

HOKEB HA, BELIZE: EXPLORATION AND RESEARCH WITH THE JASON FOUNDATION EXPEDITION V

T.E. Miller
Big Cyprus National Preserve and Department of Geology, Florida International University

Blue Creek's impressive exit in southern Belize was used by the Maya of the Classic Period. Modern mapping and exploration began in 1979 by McMaster University (Canada) cavers led by Tom Miller and John Wyeth. In the 1980s Miller and Wyeth, aided by Logan McNatt, explored the river completely to the upstream entrance. In 1993–94, the *Jason Foundation for Education* supported surveys by Miller, Wyeth, and Carol Vesely that increased the known length to more than seven kilometers.
In March, 1994, 60 hours of live TV were broadcast during the Jason Expedition V from the cave, tropical rainforest, and nearby reef, via satellite to educational downlinks in North America and England.

Contemporaneous with the broadcast, flow (24°C) from the cave was gauged (350–1500 L/s), and stream, pool, and stalactite waters were analyzed with a Hach spectrophotometer and titrator. The waters were generally bicarbonate, calcite-saturated with pHs of 7.5–8.2, and dissolved solids of 300–500 mg/L. Some pools contained phosphate and nitrate levels exceeding 1–5 mg/L (attributed to bat colonies), but nutrient levels were generally low. Traces of dissolved sulfate, iron and copper were found.

Blue Creek Cave developed as the White River abandoned an impressive limestone gorge. At least 4 progressively-abandoned levels developed in the brecciated limestone, most of which are still swept periodically by floods exceeding 30 meters in depth. Large "bellholes" and bell basins are common features of the cave; most breakdown is eroded and reworked speleothem.

THE PURIFICACÍON KARST IN 1994

Peter Sprouse
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Purificación is a large karst area located in the state of Tamaulipas in northeastern Mexico. Cavers began investigating the area in 1971, and since 1977 intensive exploration has taken place under the banner of the Proyecto Espeleológico Purificación. In 1993 and 1994, six expeditions resulted in extensions to the two longest caves in the area. In Sistema Purificación, Mexico's longest cave, a March 1994 underground camp resulted in 2500 meters of new passage surveyed. A dive in the bottom sump in May 1993 resulted in a 50 meter increase in the depth to 955 meters. To the southeast, 32-kilometer-long Cueva del Tecolote was the site of a 10-day underground camp in March 1993, during which 4000 meters were mapped. Across the varied terrain of the Purificación Karst, the PEP cavers have been conducting reconnaissance of both cave entrances and interesting karst features.

THE SEMUC CHAMPEY, ALTA VERAPAZ, GUATEMALA - A RIVER CAVE PARADISE

Steve Knutson
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(paper not presented)

Tzemooc Cham-pe is K'ek chi for, roughly, "place of incredible arousal" and indeed it is: travertine deposition has bridged the Rio Cahabon for 300 meters and formed beautiful pools amidst the tropical forest. An NSS Expedition attempted a through-trip of the river cave beneath the travertine in April 1993, but found that despite the dry-season low flow of some 400–500 cfs, the cave is sumped for about 40 meters. The sump was reached from both ends.

CUEVA DEL MANO, EXPLORATION OFTHE RESURGENCE OF CUEVA CHEVE, OAXACA, MEXICO

Carol Vesely
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Cueva del Mano is located on the Rio Santo Domingo in the Sierra Juarez and is the resurgence for Cueva Cheve, the deepest cave in Mexico. Prior exploration had resulted in over six kilometers of mazy, well-decorated passages leading a kilometer south into the mountain towards Cueva Cheve. In April 1994, eighteen cavers spent a total of 12 days camped in the Rio Santo Domingo canyon continuing the exploration of Cueva del Mano and locating and exploring several other caves on both sides of the canyon. Over three kilometers of additional passage was surveyed in Cueva del Mano and the cave was extended farther south by over a hundred meters. Underwater passages in Mano were also pushed with over 870 meters of beautiful, clean borehole and mazy side passages surveyed. Large formations were discovered submerged twelve feet below river level. Many leads remain both above and below water.

MIXTLANCINGO, THE PLACE OF CLOUDS

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In the high mountains of the state of Guerrero the Mixtlancingo River, born in the valley of Coaxtlahuacan, traverses a series of dolomite ranges through a series of spectacular caves. Most of the surface course of the river is in the bottom of a narrow gorge with many cascades. From the nearby ridges, the surface course can always be located by a faint mist caused by these cascades.

This area was first visited in December 1992, when the entrances to Primer Resumidero, Segundo Resumidero and Resumidero Chico were located. Since then, several trips have followed, in which we have managed to explore a significant part of the system. Primer Resumidero, 700 m long, was first traversed in January 1993, through a spectacular underground canyon, and involved the rigging of 8 cascades and several traverses, to resurface at the bottom of the narrow gorge that leads to Segundo Resumidero. Since then, Segundo Resumidero has been mapped, through 10 difficult cascades, for 1.5 km of spectacular underground canyon, and exploration has stopped at the top of another series of cascades. Resumidero Chico, which drains a small stream, was explored in December 1993, for 500 m to a sump.

THE CAVE OF THE RIO CANLISH ,VERAPAZ, GUATEMALA, APRIL 1994

Steve Knutson
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(paper not presented)

It was thought that the Semuc Champey, as a river cave formed when a spring deposited travertine that bridged the river for some 300 meters, was a unique feature for this part of and perhaps the whole world. Scouting in April 1993, however, turned up another, only 20 km from the first. This is the submergence of the Rio Canlish for about 1 km, straight line. The resulting cave was the objective of an NSS Expedition in April of 1994. The river is some 20–30 cfs dry season flow.

CAVING IN GUISHOU PROVINCE, PEOPLE'S REPUBLIC OF CHINA

Mike Newsome
China/USA Caves Project; Rt. 2 Box 554, Newport, Virginia 24128

Southwest China contains one of the largest unexplored karst areas in the world. Since 1991, the China/USA Caves project has been organizing cooperative expeditions with Chinese cavers from the Guizhou Normal University, Guiyang, Guizhou, PRC. Most recently a small expedition took place in March 1994. During this expedition, a connection was made between two of the caves whose survey was begun on the earlier expeditions. The problems of organizing caving in China (permission, transportation, accommodation), and plans for continuing this project in the future will be presented.

YERBA BUENA, CHIAPAS, MEXICO

Don Coons
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Ruben Comstock
Yerba Buena, Chiapas, Mexico

The Yerba Buena Cave Project completed its fifth season as a resounding success. In total, project members have discovered and surveyed over 25 kilometers of cave, with a combined vertical extent of more than a mile. The largest discovery of the season was Aire Fresco, a 5+ kilometer system forming the main drain of the mountainside. Much more remains to be done.

EXPLORATION - UNITED STATES

EXPLORATION AND MAPPING OF CAVES IN AILAAU LAVA FLOWS, PUNA DISTRICT, HAWAII COUNTY, HI

William R. Halliday and Kevin Allred

Recent exploration and mapping of lava tube caves in the Ailaau lava flows of the Puna District Hawaii County have led to a number of new concepts and records. Discovery of additional caves up-slope and down-slope from the historic sections of Kazumura Cave led to connection of that cave and other caves, resulting in a current length of 19.6 miles for Kazumura Cave without segmentation. This is the greatest length of any lava tube cave in the world. In addition, intrusive plugs of recent black lava separate it from 5+ mile Sexton's Cave, and Sexton's Cave from 5+ mile Olaa Cave. At least one of these may be penetrable. Th upper end of the recently expanded Doc Bellou-Fern's Cave System is about 75 feet from Kazumura Cave, and it appears to be a distributary branch of the Kazumura System. The John Martin's-Pukalani Systemmay also be a distributary branch, and 5+ mile Keala Cave may be a cut-a-round. Scattered segments of other systems or subsystems are also coming to light. The relationship of the Pahoa Caves to the others is not clear at this time.

KAMANAWANALEIA TRIP TO HAWAII: CAVES IN THE KONA AND NORTH MAUNA LOA AREAS

Dave Bunnell and Doug Medville

The 1994 Kamanawanaleia trip to the island of Hawaii took place on Jan. 14-30. Participants were: Dave Bunnell, Don Coons, Doug and Hazel Medville, Dale Pate, Bill and Laura Storage, Carol Vesely and Cyndie Walck. In the first eight days of this trip, 5.4 miles of passage were surveyed in 27 lava tubes along the Kona coast and on the north side of Mauna Loa. Tube elevations and temperatures ranged from near-sea level and a sweaty 78 degrees along the Kona coast to 11,000 feet and a chilling 37 degrees on Mauna Loa. While many tubes were completely surveyed, several were not finished and remain for future trips.

Two of the tubes surveyed in the Kona area approach each other at their ends. Both end in breakdown crawls and, if connected, would result in a 2 mile long tube—possibly the longest on that side of the island. Almost a mile was surveyed in another Kona tube, its upflow end left unsurveyed owing to foul conditions (remains of a recently dead goat).

On Mauna Loa, the 1855 lava flow produced nearly two miles of passage in several tube complexes, now connected via surface surveys. One of these tubes had 230 feet of vertical relief and several leads remain. Several other paleo- and historic flows containing tube complexes where examined and 2,000 to 4,000 feet were surveyed in each flow. Some of these tubes were complex, with a 7-way junction noted in one! A variety of interesting features were observed, including extensive crystal and mineral deposits, two inch thick lavacicles up to two feet long, and extensive floors of red and orange pahoehoe.

The Mauna Loa flows, while extensive both laterally and vertically, are not particularly thick and, as a result, the tubes tend to be broken up by entrance collapses and trenches. As a result, the probability of finding very deep or extensive caves in this area is low, despite the long lines of entrances visible on aerial photos.

UPDATE ON EXPLORATION/SURVEY IN LECHEGUILLA CAVE

Dale Pate
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Exploration and survey work in Lechuguilla Cave has been focused on pushing the northern boundaries of the system. To that end, concerted efforts have been made to push the North Rift, the northern boundaries of the Far East Maze and the north-trending passages in the Western Borehole.

In addition to pushing north, exploration/survey continues in other areas of the cave as well. The Dead Seas/Red Seas area in the Western Borehole has yielded a number of nice rooms and passages. And in April of this year a significant breakthrough was made in two areas near Hard Daze Night Hall, also in the Western Borehole.

RECENT EXPLORATIONS IN HIDDEN RIVER CAVE, KENTUCKY

Chris Groves and James Wells
Central Kentucky Karst Coalition, Bowling Green, Kentucky (paper not presented)

Hidden River Cave, in Hart County, Kentucky, has been known for several centuries. The cave's impressive entrance, refreshing natural breeze and underground river made it a popular spot among local residents and visitors in the 1800s and early 1900s. Sketchy accounts of exploration during the 1930s suggested that about three miles of passages had been seen by that time. Commercial tours of the cave were offered from 1900 until 1942, when pollution of the underground river made tours of the cave impossible.

Dramatic amelioration of the cave's water quality problems led exploration to continue in 1991, as a cooperative project of the American Cave Conservation Association, the Central Kentucky Karst Coalition and local NSS grottos. Mapping in the large, easily accessible passages in late 1991 soon racked up one and a half miles. Exploration slowed, however for much of 1992 and 1993 due to high water levels, to which the cave is very sensitivebecause of its location on the sinkhole plain. Very low water levels in the summer and fall of 1993 led to a surge in trips and several major breakthroughs during that time have pushed the known length of the cave to over five miles. A large, fine river trunk called Fractal River has over seventy going leads, including the main passage itself. This may well turn out to be a major cave for the Central Kentucky Karst.

RECENT EXPLORATION IN CARLSBAD CAVERNS: THE CHOCOLATE HIGH DISCOVERY

Steve Reames

Cavers have been exploring and surveying in Carlsbad Cavern, New Mexico, for over twenty years. In 1990 a group of climbers from Colorado started a promising climb in the New Mexico Room. In several trips, spread over two years, they gained over 400 vertical feet and placed a sequence of six fixed ropes. After exploring several small side passages along the way, they finally broke into a new area of the cave which they named Chocolate High. The Chocolate High area, one of the most remote regions of Carlsbad Cavern, has revealed over two miles of new passage. The area is well decorated and geologically interesting. Most of the new passage is in the Yates Formation, above the Massive Capitan which forms most of Carlsbad. This opens the door for future discoveries and the possibility of connecting to nearby Spider Cave.

THE EXPLORATION OF PIT 6083, HUALALAI VOLCANO, HAWAII

Kevin Allred, David Bunnell, Don Coons, David Doyle, William R. Halliday, and Carol Vesely

An unnamed pit on Hualalai Volcano, Hawaii County, Hawaii was found to be the deepest pit in the United States in January 1994. To avoid sharp volcanic rocks and loose rubble, descent was from a static line across the 500-foot mouth of the first element of the pit. Depth of the pit below this static line is 810 feet. Details of the pit and of the descent will be recounted. The pit is in a hostile environment, on private land, and an expeditionary approach acceptable to the land managers will be necessary for return descents.

RECENT DISCOVERIES IN FISHER RIDGE CAVE SYSTEM

Peter Quick

The Fisher Ridge Cave System, in Hart County, Kentucky was discovered in 1981. The first few years of exploration unfolded miles and miles of new cave. In the late 1980s major breakthroughs became fewer and fewer and mapping slowed down. By 1990, 50 miles of passage had been mapped.

In the fall of 1992 passages in the northwestern end of the system were discovered that ultimately led to a breakthrough into a nearby ridge, Northtown Ridge. A very complex and interconnected passage system was discovered. Since the breakthrough in 1992, 18 miles of passage has been mapped in the Northtown Ridge section of the cave. In this new area over 160 leads remain to be pushed, many with good prospects for major discoveries. It is thought likely that Northtown Ridge contains enough passage to increase the length of the Fisher Ridge Cave system to 100 miles within the next 10 years. Arduous exploration continues.

THE POWELL'S CAVE SYSTEM: TEXAS' SECOND LONGEST CAVE

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Jim Bowie died at the battle of the Alamo in 1836 and with him died the secret of a supposed fortune in silver buried near present-day Menard, Texas. Treasure hunters pock-marked the area digging for the precious metal. Near the turn of the 20th century one excavation opened what is now the main entrance into the Powell's Cave System, a group of 3 to 4 caves of which the longest is the Powell's segment. The artificial entrance leads into an extensive dry upper level maze, which leads to a lower level stream. Downstream leads to Neel's Cave and upstream to Silver Mine Cave, where a sinkhole and artificial shaft entrance were also dug open in search of Bowie's booty. Farther upstream the passage is suspected to reach a now-filled cave known as the Meteor Hole, a sinkhole whose sudden collapse caused locals to believe it is an impact crater. The Powell's Cave segment was initially surveyed to a length of 22.9 km between the 1960s and early 1980s. The Neel's Cave survey began in 1976 and culminated in 1982 when it was connected to Powell's by using scuba to dive upstream through seven intervening sumps. Silver Mine was surveyed between 1980–83, but repeated attempts have not yet established a route through the breakdown that separates it from Powell's. Significant errors in the 1960s survey prompted a resurvey of the Powell's section in 1989. The resurvey project is one of the more popular in Texas with an average of 47 cavers per trip during its 5-year history. New passages are still discovered, and the resurvey is expected to surpass the cave system's old length within a year.

GEOLOGY AND HYDROLOGY

STUDY OF IRON AND MANGANESE OXIDE DEPOSITS FROM JEWEL AND JASPER CAVES, SOUTH DAKOTA, CAVE OF THE WINDS, OCHER CAVE, FAIRY CAVE, PREMONITION CAVE AND PORCUPINE CAVE, COLORADO, AND TWO CAVES IN ARIZONA

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Samples of Fe- and Mn-oxides from nine Western caves were collected and analyzed by means of XRF, XRD and SEM. The samples, which typically are cyrtocrystalline, earthy and mostly consist of the minerals hematite, goethite, hollandite and romanechite, are commonly associated with dogtooth spar. The Fe-oxides typically display evidence indicative of bacterial precipitation by *Gallionella, Leptothrix* and *Siderocapsa.* Samples rich in Fe-oxides contain abnormally high concentrations of arsenic (300 to 15,000 ppm) and lead (200 to 8000 ppm). In contrast, some of the Mn-oxide rich samples contain abnormally high concentrations of thallium (500 to 3600 ppm).

Studies at both the Cave of the Winds and the springs of Manitou indicate that dissolutional formation of cave passages and the deposition of Fe- and Mn-oxides and calcite are related to the mixing of CO_2-rich mineral water and meteoric water. The similarity of the Fe- and Mn-oxides and associated deposits from all nine caves in this study suggests a similar origin.

REDOX EQUILIBRIA IN THE SYSTEM S-O-H AND ITS RELATION TO THE DEPOSITION OF ELEMENTAL SULFUR IN CAVES

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Redox equilibria for various reactions in the sulfur-oyxgen-hydrogen system were recalculated from the most recent thermodynamic data. These calculations were compiled into a redox potential (pe) – pH diagram. The results include a slightly revised boundary curve between reduced sulfur (H_2S and HS^-) and oxidized sulfur (SO_4^{-2}), the total sulfur activity at which solid sulfur first appears, and expansion of the sulfur field with increasing sulfur activity, and the pe, pH, and sulfur activity under which solid sulfur coexists with crystalline gypsum.

PRELIMINARY FINDINGS FROM EXPERIMENTS ON REGENERATION OF SOIL NITRATES IN MAMMOTH CAVE, KENTUCKY

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Historical references to the regeneration of nitrate minerals in cave soils are plentiful and have persisted for centuries. In contemporary literature on the subject, regeneration is largely accepted as a reality. Whereas some supporting analytical data have been presented, a controlled set of experiments have not been carried out, and that is the purpose of this investigation. Soil from three sites in Mammoth Cave has been leached of nitrates, split into 25 gram aliquots, packaged in permeable polyester cloth, and repositioned for regeneration under four different sets of conditions. At six month intervals, a soil sample representing each site and treatment has been retrieved and analyzed for nitrate. The greatest degree of regeneration has occurred in the group placed in contact with bedrock, and this explains why niter miners reportedly shoveled leached soil onto ledges for regeneration.

HIGH-RELIEF KARST IN THE LARAMIDE-AGE FOLD-AND-THRUST BELT OF THE SIERRA MADRE ORIENTAL, MEXICO

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All of the 1000+m caves in Mexico are developed within the Laramide-age fold-and-thrust belt of the Sierra Madre Oriental. Hydrologic drainage follows axial plane fractures, synclinal troughs, primary and auxiliary fault planes and the intersections of bedding planes and diastrophic joints. Natural stoping of pervasively fractured limestone that collapses into vadose passages and is removed by dissolution facilitates cavern development.

EXPLORATION AND GEOLOGY OF LAVA TUBES OF THE SUCHIOOC VOLCANO

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Beginning in 1992, a complex set of lava tubes has been discovered, explored and mapped in the lava flows of the Suchiooc, one of many volcanoes in the Chichinautzin monogenetic volcanic field. These explorations have included the longest and the deepest lava tubes mapped in Mexico, together with the discovery of an important archaeological site deep into one of the caves. In total over 10 km of passages have already been mapped.

In recent years several papers have appeared with detailed descriptions of lava tubes in Hawaii (Wood, 1981) and in California (Waters et al., 1990). It is generally accepted that lava tubes form either by the crusting of open lava channels or by the chilling of a shell around flow units (pahoehoe toes), and their later coalescence through remelting by continued flow of lava through some of them. This latter evolution has never been explained in detail, but has been inferred from the known process of emplacement of multiple lava flows and the relationships found between lava tubes and adjoining rock.

The longest and most complex lava tubes in Suchiooc occur in a branch flow from the main lava flow. A gradation is noticeable between the upper caves, where a master tube has developed, and the lower, less evolved tubes, where the system shows a tridimensional distributary and anastomosing pattern. The presence also of a large feeder tube cave, with no branches, higher up, helps us theorize about the evolution of lava tubes in a general way.

The most commonly cited form of lava tube formation, crusting of open lava channels, probably only happens near the vent, as in most of the flow the emplacement will be through pahoehoe toes. These will essentially function as capillaries in an artery system, and will present a very complex, tridimensional distributary pattern. As lava continues to flow through these micro-tubes, they will enlarge through remelting of their walls and start to coalesce. Those micro-tubes located in the hydraulically most efficient position will eventually pirate the flowing lava from the other tubes. Through continued flow along this tube, the walls and especially the floor will be eroded by remelting, creating a canyon shaped passage, while the upper tubes, now mostly inactive, might remain drained, but are most commonly refilled and plugged during the same eruption by surges in lava extrusion. This way a master or feeder tube, essentially unbranched, is developed. It is possible that the master tube has more than one superimposed or stacked levels. These have usually been explained as later flows developing a tube above a preexisting, previously drained lava tube. It is found here that, as the lava inside the master tube erodes its canyon, its surface will start crusting, developing levees, benches or even complete crusts that then separate the tube into upper and lower levels.

This same pattern of a deep, canyon or stacked shaped feeder tube cut deeply into the lava flow, and near surface, complexly anastomosing smaller tubes, can be recognized in almost all published descriptions of lava tubes. It is perhaps made clearer in Suchiooc, located at the top of a very steep and long escarpment, so the general gradient is much larger (up to 20 percent slope) than in shield volcanos, where lava tube studies have concentrated. In spite of these differences, it is felt that these conclusions are applicable to almost all lava tubes.

IS THIS CAVE GEOLOGICALLY SIGNIFICANT?

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The term "geologically significant" has different connotations depending on one's perspective. Geologists, cavers, resource managers for federal agencies and cave geologists unanimously agree that some caves are geologically significant, but they may not agree on others. The Virginia Cave Board evaluates the Commonwealth's caves in eleven categories for archaeological, biological, depth, economic, esthetic, geological, historical, hydrological, paleontological, length and recreational significance and selects the top ten percent of the caves for its Significant Cave List. It has been argued that virtually all caves are geologically significant by virtue of their existence. By this argument, all caves containing troglophiles or troglobites would be considered biologically significant. A more meaningful set of criteria to distinguish significance is useful. Significance is exhibited by outstanding or classic features characterizing speleogenesis, geomorphology, stratigraphy, structure or mineralogy, such as fracture controlled maze pattern, vadose or phreatic solutional features, dome pits, sections of stratigraphic formations or sediments, faults and fault related features, rare or unusual minerals or speleothems or speleogens. Caves that have been mined for minerals or mineral resources such as onyx, saltpetre, etc. should qualify as geologically significant. A goal of this talk is to encourage discussion among geologists of what constitutes geological significance with respect to cave resources.

APPLICATION OF THE STANDARD TABLET METHOD TO A STUDY OF DENUDATION IN GYPSUM KARST, CHOSA DRAW, SOUTHEASTERN NEW MEXICO

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Most studies of karst terrain development have been conducted in limestone karst. Studies of gypsum karst development and denudation are sparse. Very little research of this type has been conducted in the United States. The standard tablet method is one technique which has been used in the study of limestone denudation rates. A modification of this method is used in this study to analyze denudation rates in gypsum karst in southeastern New Mexico.

Exposed bedrock surfaces in the gypsum karst appear to undergo the most rapid denudation. Exposure to denuding processes such as precipitation and abrasion appear to increase denudation rates. Denudation of buried bedrock surfaces is slower than that of exposed surfaces. The standard tablet method can be a valuable tool when studying the mechanisms of gypsum cave formation. While this technique does not provide rates which are absolute, it does provide information concerning relative denudation rates, which can lead to a better understanding of the mechanisms of gypsum cave formation.

GEOLOGIC CONDITIONS OF THE DIFFERENTIATED DEVELOPMENT OF KARSTIFICATION IN THE CORDILLERA DE GUANIGUANICO, WESTERN CUBA

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(paper not presented)

The Cordillera de Guaniguanico is located in the province of Pinar del Río in western Cuba. This mountain chain is composed of the Alturas del Norte y del Sur, the Sierra de los Organos and the Sierra del Rosario. These mountains are characterized by their complex geologic structure typical of alpine mountains, deformed by neotectonic events. The rocks that make up these mountains are made up of siliciclastic, carbonate and siliciclastic-carbonate sequences from the Jurassic to the early Eocene. The central region, where limestones predominate, is considered to be the traditional capital of the cone and tower karst of Cuba.

The drainage network mainly originates in the Alturas de Pizarras and drains to the area where the carbonate rocks predominate. This drainage combined with the autochthonous waters have developed numerous karstic forms. The largest cave systems of the country are among these landforms. The cave systems of Santo Tomás, Majaguas-Canteras, Fuentes, and Palmarito are located in the Sierra de los Organos. Each of these systems of more than 20 kilometers in length, along with the smaller ones, are composed of several tiered interconnected cave passages.

The surface karst is related to the morphology of the existent karren, mogotes, poljes, etc. All this karstic apparatus is originated in the massive or irregularly stratified limestone rocks. These rocks have a low porosity, but are highly fractured. The development of the karst is directly related to the location of the lines of fracture and the bedding planes, as well as to the neotectonic movements and eustatic sea level changes.

The cave systems of Los Perdidos, Cañón del Santa Cruz, and Rangel, among others, are located in the Sierra del Rosario. Each of these systems is at least 10 kilometers long, and also shows tiered cave passages, although not as well defined as in the Sierra de los Organos.

The relief in Sierra del Rosario is different from Los Organos because of the more massive character of the higher groups and the predominance of great fluviokarstic valleys. This karst is originated in well stratified limestones that are highly fractured and sometimes interbedded with impermeable rocks. The karst is principally developed along bedding planes and fracture planes, in combination with neotectonic movements and eustatic sea level changes. [Translated from Spanish by Myrna Martinez.]

A NEW LOOK AT CONDUIT AND DIFFUSE FLOW SEPARATION IN KARST AQUIFERS

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The concept of conduit and diffuse flow in karst aquifers is intuitively apparent to anyone who has stood in a swiftly-flowing cave stream and watched water slowly drip from the ceiling. In recent years, the effectiveness of techniques used to separate conduit from diffuse flow in cave stream or karst spring hydrographs has been questioned; some known conduit systems produce low-variation hydrographs expected of diffuse flow aquifers. However, I've discovered that karst springs predominantly discharge diffuse flow when the hydrograph recession coefficient (a) is less than 0.01, fissure flow when $0.01 < a < 0.1$, and conduit flow when $0.1 < a$. These values were determined by dividing hydrographs into segments of equal slope, calculating a for each slope, and plotting them against the segments' mean discharge. Breaks in the resulting curves occur at each of the above values, which, with supporting geochemical data, demonstrate the validity of their relationships. Thus springs with low-variation hydrographs may discharge from conduits, because their groundwater is predominantly released from diffuse storage. The above relationship proves that karst aquifers are comprised of conduit, fissure and diffuse flow components, and that while a continuum of conditions exist, hydrologic behavior is governed according to which component dominates the conditions observed. These values now allow for a theoretical basis in hydrograph separation and interpretation, and provide standards for more meaningful comparison of different spring flows.

GENERAL CHARACTERIZATION OF THE KARSTIC LANDSCAPE OF CUBA

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Ana Nidia Abraham Alonso
Sociedad Espeleológica de Cuba and Instituto de Geografía (paper not presented)

The objective of this study is to spread the existing knowledge about karst development in Cuba. In addition the relation with the assimilation, transformation and nature conservation processes, as well as the spatial differentiation of the morphological and genetic types of the caves are presented.

The Cuban archipelago, with an area of 110,992 km^2, is composed of the great island of Cuba, the Isla de Pinos (today "Isla de la Juventud"), and another 4,195 islands and cays. This group of islands has had a complex paleogeographic evolution that is characterized by its origin during the formation of the American mediterranean.

The setting of this evolution was in the zone of interaction of the Caribbean plate and the North American plate, which produced a mosaic of igneous, metamorphic and pyroclastic rocks. These rocks have been deeply folded, faulted and dislocated by horizontal movement of the plates mentioned above, typical of the evolution of a continental margin with island arcs. Over this complicated folded basement there are strong carbonate sequences that were deposited primarily during and after the Miocene, also on top of the basement there are some outcrops of almost pure calcite that are sometimes metamorphosed.

One of the conditions that promoted the ample spreading and differentiation of the karst landscapes in the Cuban archipelago is the eustatic sea level change that resulted from glaciation during Neogene and Quaternary times. Another of the factors that promoted this spreading was the development of neotectonic movement.

The analysis of all the factors that developed the karstic landscapes serves as a starting point to understand the speleogenic and speleomorphologic characteristics of the country. This analysis is also important in the understanding of the influence of these characteristics in the assimilation processes of nature and their role in the differentiation of the humanized space, arising from an uneven distribution of natural resources.

These characteristics have conditioned the development of several kinds and degrees of modification of the karst landscape, posing the need to consider special conservation and protection measures, based on particular legislation. [Translated from Spanish by Myrna Martinez.]

CHARACTERIZATION AND QUANTIFICATION OF NONPOINT-SOURCE POLLUTANT LOADS IN A CONDUIT-FLOW-DOMINATED KARST AQUIFER UNDERLYING AN INTENSIVE-USE AGRICULTURAL REGION, KENTUCKY

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The Pleasant Grove Spring Basin, in southern Logan County, Kentucky, was selected for study because it is largely free of non-agricultural pollution sources. The drainage basin boundary was mapped and the basin area is approximately 10,082 acres. Reconnaissance water samples were collected at six locations over a 14 month period. Several sites were evaluated for continuous monitoring instrumentation. Pleasant Grove Spring, the principal resurgence for the basin, was instrumented to continuously monitor five water quality parameters, stage, discharge velocity and automatically collect event samples.

Results indicate that although nitrate is the most widespread, and persistent contaminant in the basin, concentrations do not exceed MCLs. Atrazine has been consistently detected in low concentrations and other pesticides occasionally occur. Triazines (including atrazine) have exceeded drinking water MCLs during spring-time flood events. Bacteria counts typically exceed drinking water limits and indicate a health hazard.

FLOODING OF SINKING CREEK, GARRETS SPRING KARST DRAINAGE BASIN, JESSAMINE AND WOODFORD COUNTIES, KENTUCKY

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In February 1989 a major storm crossed much of the eastern interior United States, causing widespread flooding. Sinking Creek, a large karst valley in northern Jessamine County, Kentucky, flooded, damaging several homes and closing a county road for over 2 weeks. The Kentucky Geological Survey began a study of the flood response of the Sinking Creek drainage basin in the fall of 1989. The objectives of the research are to determine the limitations on intake capacity of the Sinking Creek swallets, and estimate the impact of land-use changes in the basin.

Sinking Creek is the larger southeastern branch of the Garretts Spring karst basin. The smaller northwestern branch drains part of east-central Woodford County. Chenault Karst Window lies in the northwestern sub-basin, and Owens Karst Window lies in the southeastern branch between Sinking Creek and Garretts Spring. The total drainage area of the basin is 4,766 acres (19.3 hectares). The confluence of the sub-basins is underground and within 1,500 feet (457 m) of the resurgence at Garretts Spring.

The field phase of the study included ground-water tracing and the installation of stage recorders in Chenault and Owens Karst Windows and along the main truck of Sinking Creek. Staff gauges were also installed at major tributaries. Discharges were measured at these sites, and rating curves were developed for key stations. Garretts Spring was instrumented and monitored by Dr. Gary Felton, University of Kentucky Department of Agricultural Engineering, who also provided the land-use data for the drainage basin. Other work included development of a simple flow-budget model for the three monitoring stations and Garretts Spring. The potential impact of future land-use changes is currently being investigated using data provided by the U.S. Army Corps of Engineers to model flooding, using the HEC-1 flood hydrograph model.

Data from stage recorders and field observations demonstrate that the stage in Owens Karst Window is controlled by the rate of outflow from Sinking Creek Karst Valley in a complex feed back loop. As the stage in Sinking Creek rises, an overflow conduit to Owens becomes active. The flow from Sinking Creek, combined with quick overland flow from the Owens surface catchment, then exceeds the Owens swallet capacity. This causes an initial rapid rise in the stage in Owens, reducing the head difference with Sinking Creek, which reduces the effective swallet capacity at Sinking Creek. After cresting, the stage in both Owens and Sinking Creek drops at the same gradual rate. The discharge from the overflow conduit eventually ceases, which drastically reduces flow into Owens and causes a precipitous fall in stage in Owens Karst Window. This fall is accompanied by rapid draining of the remaining storage from Sinking Creek.

The parallelism of the hydrographs of the impounded Sinking Creek and Owens Karst Window, and water-budget data for the basin, indicate that the outflow from Owens is nearly the same as the outflow from Sinking Creek. Inflow into Sinking Creek has been measured at over 180 cfs (5.1 cms). Free air-surface swallet capacity at Sinking Creek is exceeded at 25.4 cfs (0.7 cms), and the maximum capacity observed is approximately 36 cfs (1.0 cms). The maximum outflow observed at Garretts Spring is 58.6 cfs (1.7 cms), but is estimated to reach 70 cfs (2 cms). The restriction to flow from Sinking Creek is due to the hydraulic efficiency of the conduit between Owens Karst Window and the confluence of the sub-basins because flow from Sinking Creek into Owens Karst Window matches or exceeds the flow out of Owens.

The implications for future flooding in the basin are serious. The cave conduits developed in equilibrium to peak flows from a wooded basin. Current land use, including residential development, has both increased the peakedness of the hydrograph and the total volume of runoff in comparison to a woodland. A project to increase discharge capacity of Sinking Creek would require a huge standby pumping capacity or long drainage tunnels. Alternative solutions include prohibiting further residential development in the flood plain, limiting land-use changes in the basin that increase or quicken runoff, and requiring construction of retention basins, that have the capacity to retain peak flows for days, before new development is permitted.

APPLICATION OF GEOGRAPHIC INFORMATION FLOW ENERGY AS DETERMINED FROM D_{90} AND D_{50} IN HETEROGENEOUS CAVE SEDIMENTS

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Clastic sediments in caves vary widely in lithologic characteristics from clays and fine silts to boulders of considerable size. Although deposition of clastic sediments tends to be chaotic with a stratigraphy that varies greatly over short distances, the overall distribution of sediment sizes is a function of the energy of the moving water that transported them to their site of deposition. The idea that flow strength or competence can be taken from the maximum and average grain size of a deposit is based upon the use of the critical shear stress for a particular bed. In a cave, the slopes and widths of stream channels change over short distances and flow velocities are constantly varying. For this reason the shear stress for a particular bed was calculated independent of bed shape, flow velocity, stream width and grain density. The critical shear stress, T_{ci}, for a particular grain size (D_i) from a heterogeneous deposit may be calculated by

$$T_{ci} = T_{c50} D_i^{0.35} D_{50}^{-0.65}$$

where D_{50} is the mean grain size and T_{c50} is the shear stress required to move a grain of size D_{50} from the deposit. The maximum shear stress calculated from this equation has units of force and is converted to energy by multiplying the shear stress by the water volume per unit bed area. The relationship was tested by collecting published data on grain size distributions from caves in West Virginia, Kentucky, Minnesota and others. There is a linear relation between energy and maximum grain size (D_{90}) of the form

$$E = 0.022\, d\, D_{90} + 0.014, \quad r^2 = 0.89$$

where d is the flow depth. The relationship allows the energy of a cave depositional environment to be determined from measurements on clastic sediments. The energy parameter then can be used to compare paleoflow regimes between caves or within the same cave as the system evolves through time.

THE MYSTERIOUS BLOWING WELL OF CIBOLA COUNTY, NEW MEXICO

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We are investigating an unusual blowing well located approximately 50 miles west of Albuquerque, New Mexico. The 6-inch diameter well is 623 feet deep and the depth to water is about 465 feet. The well is remarkable because it alternately inhales and exhales large volumes of air in response to fluctuations in barometric pressure.

Volumetric air flow rates monitored over a 2-day period using a Pitot tube revealed air flows of up to 7000 liters/min (250 cfm), with approximately 6000 m^3 (210,000 ft^3) of air exhaled during a 24 hour period. This is equivalent to the volume of air within a cube 60 feet on a side. Falling barometric pressure results in exhalation of subsurface air from the well, while rising pressure causes flow reversal and inhalation of outside air.

The impressive breathing well probably intersects a cave developed in the upper San Andres Limestone (Permian). A huge travertine deposit ($\approx 10^9$ metric tons) that precipitated along extinct fissure spring vents lies adjacent to the well, and the ancient springs were likely hydraulically connected with the cave intersected by the well.

At least 4×10^8 m^3 of San Andres limestone must have dissolved to produce the travertine deposit. Presumably the cave intersected by the flowing well is of similar or greater volume. This is equivalent to a 10m x10m cave passage 4000 km long! A videolog survey of the breathing well is planned to determine if the hypothetical cave really exists.

SYSTEMS IN THE STUDY OF KARST GROUNDWATER FLOW AT THE DRAINAGE BASIN SCALE

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This research concerns the development of new tools and techniques for groundwater research and resource management in the Central Kentucky Karst. The flow patterns within karst drainage systems are closely related to original patterns of secondary porosity and are therefore site specific. In order to make informed management and planning decisions concerning these regions, detailed hydrogeologic investigations of specific drainage systems are required. The main focus of this project is to develop software tools that can be used to store, analyze and make available both spatial and attribute data that result from such investigations. Such data may include physical information on caves, dye traces, geology and topography, as well as cultural information for the surface above a particular flow system, such as land-use and landowner data.

Geographic Information Systems (GIS) computer software may be applied to address this need. GIS programs are capable of storing and manipulating a variety of data types and are ideal for applications such as this which involve highly spatial information.

A GIS database structure was constructed for a "test" karst ground water drainage basin, the Poorhouse Spring drainage basin in northern Warren County. Data necessary for the accurate characterization of this flow system were identified, collected and entered into the database. This system may be implemented to aid decision making in planning and resource management in the area and the methods used in development of the database can be utilized to develop GIS applications in other karst flow systems. An important focus has been to develop menus within the system to make the information accessible to individuals without extensive training in GIS.

GEOLOGY OF THE CUETZALAN CAVE SYSTEM, PUEBLA, MEXICO

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Since 1991, four small SMES (Mexico)–NCC (Great Britain) joint expeditions have been fielded to the

Cuetzalan area in the northern portion of the state of Puebla. Although originally explored in the late 1970s and early 1980s, and described as "one of the finest and most going cave systems in the world," no proper survey was ever published, and interest declined. The four SMES-NCC expeditions have surveyed a total of 75 km of cave passage, 50 percent being made up of new discoveries, and have succeeded in extending all the main systems previously known.

Together, with the exploration and mapping, a lot of effort has been put into research on the geological factors that control this giant karst drainage basin. The Cuetzalan Cave System and associated caves are developed in a sloping monocline, with all beds dipping north at about 8 degrees, breached by surface drainage to create a high-standing, inclined mesa. Cave development is essentially along the contact between the Taman Limestone and the underlying Cahuasas Conglomerate, and is mostly controlled by fractures and small scale normal faults. The Taman limestone is ~80 m thick, and is transitionally overlain by the Pimienta Shales. The caves that open at higher levels tend to drop rapidly to the Cg-Ls contact level, although some extensive caves have developed on carbonated horizons in the Pimienta Shales that overlie the Taman Formation.

The main Cuetzalan System is made up of 3 separate subterranean rivers several km long (San Miguel, Resistol and Chichicaseapan) which have been joined into a single system through fossil passages (Bochstiegel and Essex Girls passages) and has a length of over 33 km. Two other closely related systems, Zoquiapan (7 km) and San Andres (10 km) come within less than a kilometer from the main system. Apparently (no tracing experiments have been done) the Resistol River joins the Chichicaseapan, receives the Zoquiapan water and enters San Miguel near its bottom, and from the sump that marks the end of San Miguel the water enters San Andres near its terminal choke.

The main resurgence for the system has not yet been located. Two large overflow resurgences, located on both sides of the northernmost spur of the Cuetzalan mesa, and active only in flood, are the only known outlets for the system. One of them, Cueva de Alpazat, has been explored for over 7 km, heading upwards towards the upper systems.

Most cave development is of the drawdown vadose type, although many of the smaller passages show evidence that they frequently function in flood spate conditions, with all limestone surfaces scalloped and conglomerate and chert layers standing out in relief. Surface streams flowing over the Cahuasas Conglomerate flow northwards (downdip) until reaching the base of the Taman limestone, and sink into sumideros. The main entrances to all the caves are these sumideros. As several underground streams join into ever larger passage, larger canyons are excavated into the conglomerate. Ceiling collapse is quite frequent, especially near the lowest levels of the upper caves, where stream size is large, and therefore passage cross sections are too big for the thinly bedded Taman limestone to sustain.

Fossil passages, especially in the Chichicaseapan and Risistol streams, record a complicated downdip migration of the active streams, which open new routes that rejoin the older ones lower down. Since the older passage had been excavated deeply into the conglomerate, the arrival of the water to its old route is usually through impressive cascades.

The morphology of most of the fossil and partially active passages in Alpazat, the overflow resurgence cave, suggest that they formed, at least initially, under shallow phreatic conditions, although certain portions of the cave still function frequently under vadose, flood spate conditions.

ROLE OF GROUNDWATER IN THE DEVELOPMENT OF PSEUDOKARST TERRAIN IN THE PIKES PEAK GRANITE, COLORADO

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Sinking streams, blind valleys, towers, natural arches, steepheads, poljes, underground streams and caves provide the Lost Creek drainage, an area entirely within the Tarryall Mountain batholith of the 1.1 Ga Pikes Peak Granite, with the distinctive appearance of karst. Seven caves, all containing streams, are known within the drainage. The longest is over 600 m. Surfaces are up to 60 m above the cave streams and several of the caves have extensive soil and forest covers.

The granite prominently displays a strong joint system with steep northeast and northwest sets and a sub-horizontal set, resulting in sub-orthogonal joint sets. Differential subsurface weathering by groundwater moving along the joints decomposed the granite forming grus. Near the surface, weathering along all three joint sets resulted in rounded boulders entirely engulfed by grus. At greater depth, and in areas lacking the sub-horizontal sheeting joints, grus formed along the vertical joints. Surface erosion easily removed the grus leaving behind scoured canyons in bedrock with boulder roofs. Through this two-step process of weathering and erosion, caves were formed that easily accommodate sinking and underground streams. Through the same process, blind valleys, towers, natural arches, steepheads, and poljes were formed.

Groundwater weathering occurred primarily from the chemical alteration of biotite to hydrobiotite and vermiculite in the presence of water with an accompanying volume increase up to 40 percent. The physical expansion fractured the surrounding solid rock. Frost shattering during freeze-thaw cycles further disaggregated the granite above the frost line in this alpine setting.

The distribution of caves and pseudokarst features is controlled by joint density, the concentration of biotite in the granite, and the comparative rates of subsurface weathering and surface erosion.

PHOSPHATE MINERALS IN YARIMBURGAZ CAVE

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Yarimburgaz Cave is the oldest archeological site in Turkey. Lower Paleolithic artifacts and the remains of extinct fauna, especially *Ursus deningeri,* have been recovered from the lower entrance chamber of this solutional cave formed in limestone of Eocene age. Diagenesis plays an important role in the development of the stratigraphic sequence, phosphatization is extensive in the entrance chambers where the archeological materials are found and in the cave interior. The site is important because it has the potential to shed more light on the history of human movement through and paleoenvironmental conditions in the Black Sea–Marmara region in the middle Pleistocene.

In the cave interior recent bat guano reacts with the limestone bedrock and clayey fill to form a range of minerals whose components are primarily Ca, S, and P, with variable presence of Al, Si, K, and Fe. Gypsum is common, and is usually closely associated with intermixed Ca-S phosphates. In the lower entrance chamber diagenesis is evidenced by the widespread occurrence of cemented zones. The cements are mostly crandallite and montgomeryite in the lower clayey units, and dahlite or hydroxyapatite in the younger sediments that underlie breakdown-rich layers.

The purpose of this poster is to present SEM photographs of some of the mineral associations and the corresponding EDS (elemental) and XRD analyses in order to trigger discussion about factors controlling phosphate mineral formation and stability. Of particular interest is whether the presence or absence of certain minerals can provide useful information about environmental conditions within the cave.

GOVERNMENT REGULATION OF DYE TRACING: THE FUTURE

Albert E. Ogden

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Due to an increasing use of tracers in the ground water cleanup business, government regulators have become concerned with the potential of cross contamination of traces and the qualifications of those conducting the work. Many facilities, such as Superfund sites, have a number of responsible parties. Often, neighboring facilities with ground water problems hire different consultants who usually keep their investigative techniques and cleanup strategies held under secrecy. If two facilities were to conduct dye traces during the same time period, the results could cause false positives and potentially create economically disastrous results from unnecessary remedial actions. This is more likely to occur in non-traditional karst aquifers where tracers move slowly such as through thick soil mantle or a dolomitic aquifer. In these hydrologic settings, a tracing agent may reside in the subsurface for months or even years. As a result, some states are requiring registration and approval of a ground water trace before it is conducted. In Tennessee, this is handled under the Underground Injection Well Program. Although this process is good for the environmental business, the question is how will it affect cavers? Will the government stop a caver from conducting a dye trace? Will a caver have to establish his qualifications, take tests or pay professional registration fees? This could be the future.

HOW DO TEMPERATURE, HUMIDITY AND CARBON DIOXIDE AFFECT EPSOMITE CRYSTAL GROWTH IN A CAVE?

Rose A Galbraith

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Caves are a delicate environment and have been damaged in the past due to carelessness and lack of ecological awareness about caves. To protect caves, one must understand the relationships between environmental factors and speleothem deposition. This experiment was done to find out how humidity, temperature and carbon dioxide affect epsomite crystal growth and to assess how highways near caves and/or people may be affecting caves.

Samples of angel hair speleothem that were thought to be epsomite crystals were obtained from a cave in central New Mexico. Epsomite crystals were grown in several differing environments to determine growth rate under variable humidity and temperature. Further experiments were done with pieces of the cave crystals to test their reactions to changes in their environment. X-ray diffraction was used to identify the crystals and the affects of the changes.

Variations in temperature and humidity caused change in both the cave sample (which X-ray diffraction showed to be mirabilite rather than epsomite) and the experimental samples. Both mirabilite and epsomite are very sensitive to even slight environmental changes so they can indicate possible early signs of potential danger to a cave, much as indicator species are to other ecosystems.

A HISTORY OF WOODLEE CAVE AND DRY CAVE, GRUNDY COUNTY, TENNESSEE

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Woodlee Cave and Dry Cave have rich and varied histories. Dry Cave was explored by Native Americans in the late Archaic period, while Woodlee Cave was an occupation site in the middle Woodland period. After 1805 both caves were explored by white settlers, although few specifics are known. In the Civil War both were mined for saltpeter, and Woodlee Cave was apparently a significant source. Following the Civil War, the caves were frequently visited by the inhabitants of the valley, Northcutt's Cove, and occasionally by others. More is known about these visitors than previous explorers. Most of these were pleasure trips. The property changed hands over the years and the various owners will be discussed. After the turn of the 20th century both caves were used for utilitarian purposes as well as pleasure trips. Dry Cave was used as a root cellar, while Woodlee Cave contained a moonshine still. This paper will examine the history of the two caves through the 1930s.

A HYDRATED URANYL VANADATE MINERAL FROM SPIDER CAVE, CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

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A hydrated uranyl vanadate has precipitated as decimicron to millimeter-sized crystals in Spider Cave, Carlsbad Caverns National Park. Crystals are canary yellow and plate-like; they commonly consist of laths shaped like "playing cards" standing upright in a botryoidal coating of opal. Metatyuyamunite $[Ca(UO_2)_2(VO_4)_2 \cdot 3\text{-}5H_2O]$ was identified by X-ray diffraction (XRD) and scanning electron microscopy. Data from XRD indicates that Spider Cave metatyuyamunite using the orthorhombic unit cell has dimensions of a = 10.397(4)Å, b = 8.403(2)Å, c = 16.692(12)Å.

Uranium and vanadium compounds may have initially been deposited within siltstones and dolostones in the Permian Yates Formation of the Artesia Group, the same formation in which Spider Cave is situated. Association of hydrated uranyl vanadate crystals with secondary opal on breakdown blocks, floor deposits, and speleothems in Spider Cave suggests that after speleogenesis and subsequent lowering of the water table, hydrated uranyl vanadates have precipitated from vadose solutions enriched with uranium, vanadium and silica. The silica was probably derived from clays and/or clastic silts and sands of the Yates Formation.

This is the first report of uranium mineral deposition within caves of the Guadalupe Mountains.

HISTORY

THE WIND CAVE FEUD

Nancy E. Holler

Turn back the clock for an action-packed ride through the 1890s and 1900s at Wind Cave, South Dakota. Possession of the cave focused on two families—the Stablers and the McDonalds, and their common interest in gaining wealth quickly transformed into a raging feud between them. Numerous accounts of gunfights, publicity stunts, house torching, bitter verbal exchanges, cave specimen collecting, and *lots* of newspaper publicity are just a few events that contributed in the battle for Wind Cave gaining nationwide attention and having such a rich and colorful history.

HISTORY OF THE EXPLORATION OF SISTEMA HUAUTLA

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The caves of the Huautla plateau, Mexico, were suspected from aerial photographs in the mid-60s. Association for Mexican Cave Studies cavers began exploration in 1966 and it continues today.

There have been three phases of exploration. The initial exploration was in 1966-71 by AMCS and McMasters University, Canada, cavers. In 1967, the distinction of deepest cave in the Western Hemisphere came to Huautla and has remained most of the time since.

The second phase began in 1976 with discovery of deeper passages in Sotano de San Agustin. In 1977 the Huautla Project was formed to organize annual expeditions and conduct "full speleology".

The third phase began in 1982 with the split of the Huautla Project into two parallel efforts. One continued the exploration of the vertical caves of the upper end of the cave system. This resulted in the March 26, 1987 connection of Nita Nanta with Sistema Huautla, establishing the cave as the world's third deepest. The other concentrated on the lower end of Sistema Huautla through cave diving.

Sistema Huautla has an abundance of deep routes. There are 15 entrances and deep routes with depths over 600 meters, 700 meters, 800 meters, two over 900 meters, and two over 1,000 meters. Not integrated into the system are caves of 400 meters, two over 500, one over 600, and two over 700 meters in depth.

Published studies on cave science have included archaeology, geology, biology, paleontology and hydrology.

HISTORICAL STUDY AND PERSPECTIVE VIEW OF TOURIST CAVING IN CUBA

Ana Nidia Abraham Alonso
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José Luis Gerhartz Muro
Instituto de Planificación Fisica and Sociedad Espeleológica de Cuba (paper not presented)

The history and development of the tourist caves of Cuba will be discussed, and a diagnosis will be given of the actual situation of these resources through a critical evaluation of the errors committed during the work of adapting the caves and their surroundings, presenting a series of recommendations to better organize trails, lighting, handrails and so on, in order to make the caves more attractive. Also described will be some established tourist areas in Cuba that have exploitable speleological potential. Examples of how, in several cases, these caves can be used will be presented.

Finally, recommendations will be offered for the development of tourism in Cuban caves. [Translated from Spanish.]

PALEONTOLOGY

CAVE VERTEBRATE PALEONTOLOGY IN TEXAS

Rickard S. Toomey III
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Of the many Texas caves from which bones have been recovered, approximately 30 have produced scientifically important vertebrate remains. These thirty caves are all located in central and Trans-Pecos Texas. The remains from these caves provide information both on animals that have lived in the area and on environmental changes the area has experienced. Notable vertebrate finds in Texas caves include well-preserved peccaries, turtles and scimitar cats from Friesenhahn Cave, a partial peccary "herd" from Laubach Cave, sloth dung from the Sloth Caves, and a long vertebrate-bearing sequence from Hall's Cave.

Deposition of most of the well-studied remains from Texas caves occurred during the last 25,000 years; however, one cave contains fossils between 750,000 and 1.5 million years old. The fossil vertebrates found in Texas caves include fish, amphibians, reptiles, birds and mammals. They range in size from small salamanders and mice to elephant-like extinct mammoths and mastodons. Bone in caves occurs in many contexts and gets into caves in several ways. The context in which it is found and the ways it got there are both critically important in evaluating the significance of bone in caves.

With careful collection and further study many other caves will probably produce important fossils. For this reason it is important to always be aware of the potential for significant vertebrate remains when exploring, studying or conserving caves.

THOSE DAMN BONES ARE IN THE WAY

Pat Jablonsky
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As cavers begin to "dig" for caves more and more, they increase the odds that they will encounter bones of various animals. Most of the bones will be of recent vintage, but occasionally, cavers may encounter bones of extinct animals. When this happens what should be done? This presentation will address this issue and provide cavers with basic guidelines on what to do when bones are encountered, especially in regards to caves on Federal lands.

THE BLUE LAKE RHINOCEROS: A CAVER'S PERSPECTIVE

Cato Holler, Jr.
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Approximately 20 million years ago during the Miocene period, vast basaltic lava floods covered over 63,000 square miles of the Pacific northwest. During this time a small rhinoceros of the genus *Diceratherium* died in a pond of water and was subsequently covered by one of the lava flows. As the molten lava poured over the carcass, the water immediately chilled the flow forming a mold of the rhino's body. In 1935 the cavity was discovered high on a basaltic cliff at Blue Lake in east central Washington state. Several teeth and bones were still intact.

Although many cavers had heard of the cavity, it was surprising to learn that few had actually visited the site. An August '93 trip was made to survey and photograph the Blue Lake Rhino Cave, truly one of the world's most unique grottos.

LATE QUATERNARY SIZE, RANGE AND BEHAVIOR CHANGES IN CENTRAL TEXAS BATS

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Different species of bats have responded to the environmental changes of the last 25,000 years in different ways. Bat fossils from central Texas caves indicate that size changes, range changes and possibly behavior changes have all occurred. These changes are interpreted to be responses to changing environmental conditions.

Central Texas *Myotis velifer* have both increased and decreased in size (based on the length of the mandible and length of the lower molars) during the last 25,000 years. About 25,000 years B.P. they were approximately the same mean size as modern bats. By about 15,000 years B.P. mean size had increased by seven percent. During the last 15,000 years their size has gradually decreased to modern size. A preliminary interpretation of these changes is that they are responses to changing cave temperatures.

Pipistrellus subflavus, Eptesicus fuscus and probably *Tadarida brasiliensis* have all changed their geographic range during the last 25,000 years. Changes in *Pipistrellus subflavus* range are a response to changing moisture, especially to drier than modern conditions in the Middle to Late Holocene. Both *Eptesicus fuscus* and *Tadarida brasiliensis* probably changed geographic range in response to changing cave temperatures.

Changes in abundance of *Eptesicus fuscus* remains at Hall's Cave, Kerr County, Texas may indicate a change in bat behavior. This change is probably a result of increasing cave temperature.

DEEP CAVE RECOVERY TECHNIQUES FOR PELONTOLOGICAL SPECIMENS

Patricia L. Jablonsky
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Caves and rock shelters are a rich source of paleontological, anthropological information and other materials of scientific interest. It is estimated that half of all Pleistocene materials in scientific collections are from such sources.

While most specimens are commonly found near entrances and are relatively easy to recover, over time, entrances may be severely altered or may collapse due to surface conditions. When this occurs, significant specimens are frequently moved by natural forces deeper into complex and or difficult to traverse cave systems.

Among items to be discussed will be the special techniques for recovery of deep cave materials utilized in recent excavation and recovery projects at Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico. Due to the fragility of the Chiropteran specimens and the bulk of the larger mammalian specimens recovered, new and modified techniques were developed. Extra care was taken to comply with three major concerns of the Carlsbad Caverns National Park: minimal disturbance to Lechuguilla Cave; prevention of the introduction of alien materials; and full restoration of the sites in the cave.

SOCIAL SCIENCES

THE MARGINELLA BURIAL CAVE PROJECT: A PRELIMINARY REPORT

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A study of the Native American burial caves of Virginia is in progress. Field studies over the past year and a half have documented a number of previously unrecorded Native American burial caves in Virginia. All but one of the Virginia burial caves have been subject to looting. Despite disturbance, important archaeological materials remain and looting continues at these sites and at undocumented sites. In an attempt at utilizing education to protect these resources, articles on their sensitivity and the consequences of their destruction have been distributed to cave owners. A significant objective of the project is to spur enforcement of the laws that protect burial caves from disturbance, which constitutes a felony. Under permits, cosmetic salvage operations at these threatened sites minimizes the attractiveness of these caves to continued damage and provides significant physical information about the individuals interred and their cultural affiliations. Currently, project administrators are working to avert the destruction of one site by highway construction.

THE IMPORTANCE OF CAVES IN NON-KARSTIC REGIONS OF GUATEMALA

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Recent studies in non-karstic regions of the Maya highlands of Guatemala have uncovered the existence of man-made, man-modified and pseudo-karst caves. The caves were excavated from volcanic or volcanically-derived Tertiary and Quaternary age rocks, with construction methods varying according to rock hardness. The caves, which vary in length up to 128 m, are associated with site centers or shrines of particular ritual importance. These features constitute a previously unrecognized form of Maya architecture. Coupled with recent investigations in the Maya lowlands which found natural caves being incorporated into site architecture, the discovery of these man-made features suggests that the presence of a "cave" is absolutely necessary in the process of validating sites.

Guide to Authors

The NSS Bulletin is a multidisciplinary journal devoted to speleology, karst geomorphology, and karst hydrology. *The Bulletin* is seeking original, unpublished manuscripts concerning the scientific study of caves or other karst features. Authors need not be associated with the National Speleological Society.

Manuscripts must be in English with an abstract, conclusions, and references. An additional abstract in the author's native language (if other than English) is acceptable. Authors are encouraged to keep in mind that the readership of *The Bulletin* consists of both professional and amateur speleologists.

For general style refer to the present *Bulletin* and the following guides: "Suggestions to Authors" (U.S. Geological Survey), "Style Manual for Biological Journals" (American Institute of Biological Sciences), and "A Manual of Style" (The University of Chicago Press). For assistance in writing an abstract see "A Scrutiny of the Abstract" by K. Landes, *Bulletin of the American Association of Petroleum Geologists,* vol. 50 (1966), p. 1992. Because good figures are an essential part of any paper, authors are encouraged to see what bad figures look like in the editorial on figures by K. Rodolfo in the *Journal of Sedimentary Petrology,* vol. 49 (1979). p. 1053-60.

Each paper will contain a title with the author's names and address. This will be followed by an abstract and the text of the paper. Acknowledgements and references follow the text. References are alphabetical with senior author's last name first, followed by the date of publication, title, publisher, volume, and page numbers. See the current issue of *The Bulletin* for examples.

Authors should submit two copies of their manuscript (include only copies of the illustrations) to the appropriate specialty editor or the senior editor. The manuscript must be typed, double space on one side of the page. Authors submitting manuscripts longer than 15 typed pages may be asked to shorten them. All measurements will be in Systeme Internationale (metric). Other units will be allowed where necessary if placed in parentheses and following the SI units.

Figures and lettering must be neat and legible. Figure captions should be on a separate sheet of paper and not within the figure. Most figures will be reduced, hence the lettering should be large. Once the paper has been accepted for publication, the original drawings (with corrections where necessary) must be submitted to the editor. Black-and-white photographs must be sharp, high contrast, and printed on glossy paper. Color prints will be printed at author's expense only.

All submitted manuscripts are sent out to two specialists for review. Reviewed manuscripts are then returned to the author for consideration of the referee's remarks and revision (where necessary). Revised manuscripts are returned to the appropriate editor who then recommends acceptance or rejection. Upon acceptance, the author should submit all photographs and original drawings to the editor.

Once the paper has been typeset and laid-out, the senior author will be sent one set of proofs for review. Any corrections other than printer errors will be done at the author's expense. A reprint order form will be sent with the proofs. At this time all authors will be requested to contribute page charges of $25 per page to help defray the cost of publication. The actual cost to the society is about $100 per page. Acceptance of manuscripts for publication is not contingent upon payment of page charges.

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