JOURNAL OF CAVE AND KARST STUDIES

December 2005
Volume 67 Number 3
ISSN 1090-6924
A Publication of the National Speleological Society

Journal of Cave and Karst Studies
of the National Speleological Society

Volume 67 Number 3 December 2005

CONTENTS

The *Journal of Cave and Karst Studies* (ISSN 1090-6924, CPM Number #40065056) is a multi-disciplinary, refereed journal published three times a year by the National Speleological Society, 2813 Cave Avenue, Huntsville, Alabama 35810-4431 USA; (256) 852-1300; FAX (256) 851-9241, e-mail: nss@caves.org; World Wide Web: http://www.caves.org/pub/journal/. The annual subscription fee is $23 US, $44 US for 2 years, and $65 US for 3 years. Check the *Journal* website for international rates. Back issues and cumulative indices are available from the NSS office. POSTMASTER: send address changes to the *Journal of Cave and Karst Studies*, 2813 Cave Avenue, Huntsville, Alabama 35810-4431 USA.

The *Journal of Cave and Karst Studies* is covered by the following ISI Thomson Services: Science Citation Index Expanded, ISI Alerting Services, and Current Contents/Physical, Chemical, and Earth Sciences.

Front cover: Warren Netherton in Cueva de Villa Luz, Tabasco, Mexico. See Kathleen H. Lavoie, Eugene H. Studier, and Olivia F. Cauthorn p. 182–183; Michael N. Spilde, Laura Crossey, Tobias P. Fischer, H.J. Turin, and Penelope J. Boston, p. 187–188. Photo by Jim Pisarowicz.

SOME SIGNIFICANT MILESTONES FOR THE *JOURNAL OF CAVE AND KARST STUDIES*

MALCOLM S. FIELD

This issue of the *Journal of Cave and Karst Studies* marks a few milestones. First, it marks the close of my second year as Editor which, for me, is a considerable achievement. The quality of papers received for publication and the assistance I have received from the *Journal* Advisory Board, Associate Editors, and Reviewers have had the combined effect of making for an impressive journal and making me look good. For this, I am very thankful. However, I still need to ask that more individuals working on cave and karst studies consider submitting their work to the *Journal* for publication. We are especially looking for papers dealing with conservation and exploration.

A second milestone is the acceptance of the *Journal of Cave and Karst Studies* in the Directory of Open Access Journals which is an on-line Web (http://www.doaj.org) service that lists only those journals that allow full access to their published papers. The *Journal of Cave and Karst Studies* was invited to submit an application for consideration and was accepted immediately. Searching this site using such key words as caves or karst will lead to a listing of the *Journal of Cave and Karst Studies* which is linked to the National Speleological Society Web site where the *Journal* is maintained.

The third milestone deals with a profound collaboration between several karst-related journals as initiated by Jo De Waele, Editor in Chief of the *International Journal of Speleology*. Dr. De Waele recognized that the various karst journals worldwide are complementary and that there should be significant collaboration between the respective journals. As part of this collaboration, this issue of the *Journal of Cave and Karst Studies* lists the titles and authors of the most recently published issues of *Acta Carsologica*, *Cave and Karst Science*, *International Journal of Speleology*, *Subterranian Biology,* and *Theoretical and Applied Karstology*. The current issue of the *International Journal of Speleology* is publishing the contents of the last issue of the *Journal of Cave and Karst Studies* (Vol. 67 No. 2) and will continue to publish the contents of our *Journal* so long as the contents are sent on to them. Hopefully, more cave and karst journals worldwide will begin providing the contents of their journals for publication in each cave and karst journal currently in existence.

The fourth milestone is similar to the second and third. *Speleogenesis and Evolution of Karst Aquifers*, a virtual on-line scientific journal (http://www.speleogenesis.info/), now prominently advertises the *Journal of Cave and Karst Studies* on its web site and lists the contents of the most recent issue with a link to the National Speleological Society web site where our *Journal* is maintained. As with the other milestones, this is a significant achievement because our *Journal* appears with other similar journals in the field and suggests that the *Journal of Cave and Karst Studies* is one of a group of highly respected journals specializing in cave and karst studies.

The fifth and final milestone is perhaps the most significant. In June 2003, ISI Services began formally listing the *Journal of Cave and Karst Studies* (thanks to the efforts of the previous editor, Dr. Louise Hose). A substantial value related to an ISI listing is the calculated impact factors generated for papers published in the *Journal of Cave and Karst Studies* based on cited references to the papers. Well, the year 2005 marks the third year of ISI listing. This means that the 2005 edition of the *Journal Citation Reports* will now begin listing impact factors for our *Journal*. This is a monumental accomplishment for the field of cave and karst studies and something of which the members of the National Speleological Society can be very proud.

I would like to close with a very heartfelt thank you to all involved with the *Journal*. Without the support of those briefly listed at the beginning of this editorial, the accomplishments described would not have been possible. Please continue submitting quality research to the *Journal of Cave and Karst Studies* and please continue making the Journal the best it can possibly be.

J. Judson Wynne and William Pleytez – Sensitive ecological areas and species inventory of Actun Chapat Cave, Vaca Plateau, Belize. *Journal of Cave and Karst Studies*, v. 67, no. 3, p. 148–157.

SENSITIVE ECOLOGICAL AREAS AND SPECIES INVENTORY OF ACTUN CHAPAT CAVE, VACA PLATEAU, BELIZE

J. Judson Wynne[1]

USGS-Southwest Biological Science Center, Colorado Plateau Research Station, Flagstaff, Arizona, 86001 USA

William Pleytez

Chechem-Ha Caving Adventures, Benque Viejo, Cayo, Belize, Central America

Cave ecosystems are considered one of the most poorly studied and fragile systems on Earth. Belize caves are no exception. This paper represents the first effort to synthesize information on both invertebrate and vertebrate observations from a Belize cave. Based on limited field research and a review of literature, we identified two ecologically sensitive areas, and developed a species inventory list containing 41 vertebrate and invertebrate morphospecies in Actun Chapat, Vaca Plateau, west-central Belize. Actun Chapat contains two ecologically sensitive areas: (1) a large multiple species bat roost, and (2) a subterranean pool containing troglobites and stygobites. The inventory list is a product of sporadic research conducted between 1973 and 2001. Ecological research in this cave system remains incomplete. An intensive systematic ecological survey of Actun Chapat with data collection over multiple seasons using a suite of survey techniques will provide a more complete inventory list. To minimize human disturbance to the ecologically sensitive areas, associated with ecotourism, we recommend limited to no access in the areas identified as "sensitive."

Cave ecosystems are one of the most fragile ecosystems on Earth (Elliott, 2000; Hamilton-Smith and Eberhard, 2000; Krajick 2001). Sensitivity of bats and other cavernicoles (cave dwelling organisms) is due to their vulnerability to human disturbance. Roosting bats (Mohr, 1972; Hall 1994, Hamilton-Smith and Eberhard 2000), maternity/nursery colonies (McCracken, 1986, 1988, 1989; Cockrum and Petryszyn, 1991; Brown *et al.,* 1993a, 1993b; Elliott 2000), and bat hibernacula (McCracken, 1988; BCI, 1989, 1992; Humphrey, 1969; Stebbings, 1971; Carlson, 1991; Harnish, 1992; Elliott, 2000) are highly sensitive to human disturbance. Because many troglobitic species (obligate cavernicoles) are endemic to a single cave, have low population numbers (Krajick, 2001), and are K-selected species (Hüppop, 2004), most troglobite populations are considered imperiled (Krajick, 2001). Despite their sensitivity to disturbance, cave ecosystems are poorly understood. Only a small fraction of caves in any region of the world has been assessed at an ecological system level (Culver *et al.,* 2004). While cave roosting bat species are well documented globally, troglobite richness and diversity remains poorly described. Culver and Holsinger (1992) estimate global troglobite diversity at 50,000 to 100,000 species.

The biota of Belize caves is poorly known. There is no overall estimate of cave-obligate species in Belize, but in the adjacent and comparable Yucatan Peninsula, Reddell (1979) identified 565 cavernicoles, including 34 troglobitic species. Reddell and Veni (1996) compiled an invertebrate inventory list of Chiquibul Cave, but most other cave invertebrate reports from Belize are brief accounts of new species discoveries or opportunistic collections (refer to Gertsch, 1973; Muchmore, 1973; Williams, 1976a, b, c, 1987; Reddell and Veni, 1976; Reddell, 1981; Rodriguez and Hobbs, 1989). There are few reports on cave-roosting bats (e.g., B. Miller and C. Miller, unpublished data; Elliott, 2000), even though almost one-third of Belize bats roost in caves during some point during their life cycle (Reid, 1997; BBIS, 2001). Epigean species (those inhabiting cave entrance areas, including reptiles, amphibians, and mammals) have not been addressed in the literature.

Throughout Mesoamerica, caves played a central role in Maya mythology (Bassie-Sweet, 1991). Consequently, activities of the ancient Maya are evidenced in many Belize caves. Because "archaeo-ecotourism" is an important economic resource for the country (Fernandez, 1989) and Actun Chapat (Mayan for "centipede cave") contains modified flowstone and other evidence of Precolumbian Maya use, the cave was targeted for development as a "show cave." However, prior to development, the Belize Institute of Archaeology (IOA) wanted additional information on the cave's large bat roost, as well as other ecological aspects of the cave. Thus, this current research was conducted to provide the IOA with this ecological assessment. The goals of this study were to: (1) identify all ecologically sensitive areas; and, (2) develop a species inventory list of Actun Chapat.

Methods and materials

Study area

Actun Chapat is located on the northern extent of the Vaca Plateau, west-central Belize (Figure 1). Situated in the Maya Mountain foothills approximately 20 kilometers south of the

[1]Corresponding author. Email: jwynne@usgs.gov.

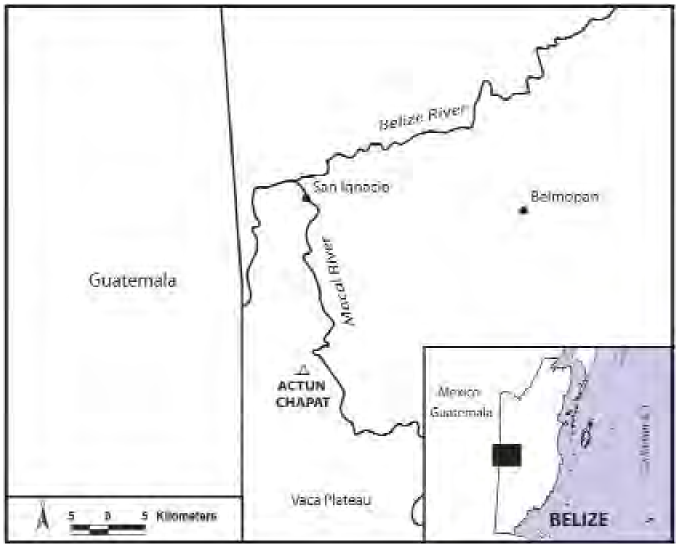


Figure 1. Location of Actun Chapat in west-central Belize situated along the northern extent of the Vaca Plateau.

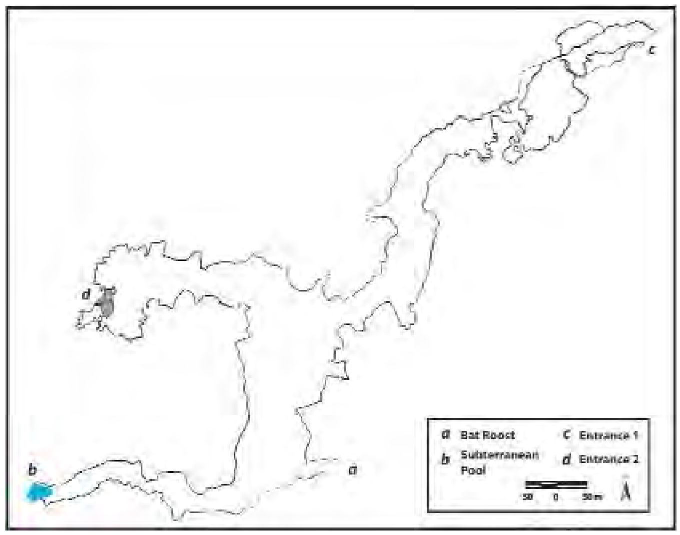


Figure 2. Map of Actun Chapat depicting (a) the multiple species maternity/nursery colony, (b) the subterranean pool, (c) entrance 1, and (d) entrance 2.

town of San Ignacio, this cave has two known entrances (Figure 2). "Entrance 1" is a horizontal entrance situated at the headwaters of an intermittent arroyo. "Entrance 2" is a vertical entrance approximately 10 m deep. Lands within ~1.6 km of Actun Chapat are used for cattle grazing and swidden agriculture. Archaeological research activities have been conducted within this cave since 1999 (C. Griffith, pers. comm.). Currently, this cave is infrequently used as a show cave.

Cave fauna terminology and taxonomy

We divided Actun Chapat cave biota into six cavernicole (cave dwelling organism) groups: troglobites, trogloxenes, troglophiles, stygobites, epigeans and guanophiles. The following definitions of each cavernicole group were derived from Culver and White (2005): (1) troglobites are characterized by no pigmentation, reduced eye development, elongated appendages, and require cave ecosystems for their entire life cycle; (2) trogloxenes spend a portion of their life cycle (e.g., hibernation, roosting, reproduction) in subterranean environments; (3) troglophiles are not obligate cave dwellers and may complete their life cycle either in subterranean or hypogean systems; (4) stygobites are aquatic species that spend their entire life cycle in underground waters; (5) epigean species are surface-dwelling organisms, but may occur as accidentals in caves (usually within cave entrances); and, (6) guanophiles are organisms that feed and/or reproduce in guano deposits, and may occur as both troglobites and troglophiles. Current taxonomy was verified for all vertebrates and most invertebrates using the Integrated Taxonomic Information System (ITIS; http://www.itis.usda.gov). Because taxonomy for most troglobites and stygobites is not yet available within the ITIS database, we used the taxonomy as classified by Reddell (1981).

Literature review

We reviewed published and unpublished literature to summarize prior biological research at *Actun Chapat*. To obtain additional information not available from the literature review, we also contacted researchers who have conducted field investigations in Belize.

2001 Baseline inventory methods

Bat survey

We surveyed for bats both inside and outside the cave. For four days, between 0900 hr and 1500 hr, we captured bats inside the cave with handheld nets (*sensu* Arita, 1996). To minimize disturbance to bats, Wratten #27 red camera filters were placed over the headlamp lights (Kunz, 1982). Dead bats found within the cave were also identified. Bats near Entrance 2 were captured using mist nets (Kunz, 1982) for one night from 1900 to 2330 hr. A net was placed below the vertical entrance, which was the closest entrance to the Zotz Na (Mayan for "bat house"), and the primary entrance used by the colony. Because exiting bats may abandon their roosts after capture (Kunz, 1982), we placed mist nets ~20 meters downslope from the cave entrance. While nets were open, three technicians constantly monitored the nets. Captured bat species were identified using a key developed by B. Miller (Wildlife Conservation Society, Belize), sexed, aged, weighed, evaluated for reproductive condition and photographed (*sensu* Kunz, 1982).

Invertebrate survey

Invertebrates were surveyed within three primary cave zones: (1) light zone, (2) twilight zone, and (3) dark zone. We established three parallel transects within the cave; one along each wall and one at the estimated centerline of the cave. To minimize impacts to invertebrate populations, species were identified in the field when possible. We recorded descriptive information on habitat and behavior for each species encountered. When invertebrates were collected for identification, one to five individuals per species were collected. Due to difficulties with export permits, invertebrates were identified, to the highest taxonomic level possible, using photographs and field information collected on morphology, biomechanics and habitat requirements. Information collected in the field was cross-referenced with existing literature, voucher photos, and consultations with taxonomic experts.

EPIGEAN VERTEBRATE SURVEY

We searched for epigean species using intuitive visual searches (Crump and Scott, 1994). In the light and twilight zones of both entrances, we searched for amphibians, reptiles, mammals, and animal sign in areas containing breakdown, within rock crevices and underneath rocks. All species encountered were visually identified or captured, identified and released. Species were identified using a combination of available literature and local indigenous knowledge.

SENSITIVE ECOLOGICAL AREAS

The majority of the cave was evaluated for ecologically sensitive areas. We considered an area ecologically sensitive if it contained sensitive, endangered or endemic species whose persistence is likely to be threatened by human disturbance. Due to the economic potential of the cave as a show cave, we identified specific zones within the cave as sensitive rather than providing an evaluation for the entire cave. These areas are considered microhabitats specific to sensitive and/or potentially endemic species.

RESULTS AND DISCUSSION

We identified 41 morphospecies in Actun Chapat (Table 1). These included four troglobites, 13 trogloxenes (bats), 13 troglophiles, three stygobites and nine epigean morphotypes (Table 2; Appendix 1). Of these taxa, three were tentatively considered guanophiles.

We identified two sensitive ecological areas: (1) a multi-species bat maternity/nursery roost and (2) a subterranean pool containing stygobites and a semi-aquatic troglobitic crab (Figure 2). The maternity/nursery roost is located below Entrance 2, within a side passage of Actun Chapat and is defined by three chambers, hereafter referred to as Zotz Na. Chamber 1 contained approximately 15 roosting bats and contains at least three *Phyllostomid* spp. The second chamber also contained roosting bats. However, it was difficult to determine if bats were roosting in this chamber or if they moved from Chamber 3 into Chamber 2 due to our presence. A large maternity/nursery colony is located in Chamber 3. This roost contained two primary species: *Natalus stramineus* and *Mormoops megalophylla*. In July 2001, we observed an estimated 7 x 3 m of cluster of hairless pups. This nursery colony

Table 1. Results of the 2001 survey and literature review provided as a summary by cavernicole group.

Cavernicole Group	2001 Survey	Literature Review	Total
Troglobite	3	1[a]	4
Trogloxene (bats)	8	5[b]	13
Troglophile	12	1c	13
Stygobite	2	1	3
Epigean	9	-	9
Total	34	5	41

[a]Troglobite identified by Reddell and Veni (1996).

[b]Bat species were inventoried during field research conducted by B. Miller and C. Miller (pers. comm., 2004).

[c]Photograph of epigean species was taken by D. Billings during a 2005 cave survey expedition.

was located at the approximate center of Chamber 3. Additionally, we identified two important sources of nutrient input into the cave: (1) the multi-species bat roost, and (2) the sinkhole entrance, known as Entrance 2.

The dearth of information on Belize cave biodiversity underscores the need for a national effort to systematically inventory cave biodiversity. Presented here is the first species inventory of a Belizean cave. We identified 41 morphospecies from a variety of systematic groups, including both vertebrate and invertebrate species. Nineteen of these morphospecies were cave-dependent. Also, our findings identified a multi-species bat maternity/nursery roost, and a subterranean pool containing stygobites and a troglobitic crab. Both of these areas should be considered sensitive ecological resources.

Roosting bats are highly sensitive to human disturbance (Mohr, 1972; Hall, 1994; Hamilton-Smith and Eberhard, 2000). To evaluate the importance of the bat roost, we applied the conservation criteria derived from studies conducted by Arita (1993, 1996). Arita suggests that high bat species diversity and the presence of listed (threatened or endangered) or rare species can be used to identify the conservation priority of cave bat roosts. From a study of 36 caves in Yucatan, México, Arita (1996) identified 22 caves (61%) with one to two species, eight (22%) with three to five species and six (17%) with seven to nine species. In México, Arita (1993) suggests that roosts containing multiple species (> 6 species) should receive special management consideration due to their "unusually high species richness." Using this information, we developed a rank system, which identifies < 2 species as low diversity, 3 to 5 species as medium and > 6 species as high diversity. Actun Chapat contains between 10 and 13 roosting bat species (13 if considering the three unidentified individuals to represent distinct species). Therefore, this cave satisfies our high diversity criterion. There were no listed or rare species identified within Actun Chapat. However, the *M. megalophylla* colony is in decline, and is sensitive to disturbance. Although we did not attempt to count this colony, it is considered the largest colony in Belize (B. Miller, pers. comm. 2003). Because Mormoopid bats rarely form large colonies (> 100,000 individuals; Arita 1996) in Yucatan, this colony may

Table 2. Inventory list by cavernicole group of species identified at Actun Chapat. For undescribed invertebrate species, closest taxonomic identification is provided (taxonomic level and common name are provided in parentheses).

Morphotype	2001 Survey	B. Miller and C. Miller (unpublished data)	Reddell and Veni (1996)	Elliott (2000; pers. com., 2005)	Billings (2005)
TROGLOBITE					
Paraphrynus sp./*Paraphrynus raptator*? (whip scorpion)	*		*		
Lithobius sp. (millipede)	*				
Coleopterea (Order; beetle)[a]	*				
Prostigmata (Suborder; mite)	*				
TROGLOXENE					
Peropteryx macrotis	*				
Mormoops megalophylla	*	*		*	
Pteronotus parnellii		*			
Pteronotus personatus		*			
Pteronotus davyi		*			
Phyllostomid sp.	*				
Trachops cirrhosus	*				
Glossophaga sp.				*	
Glossophaga soricina	*	*			
Artibeus jamaicensis	*			*	
Natalus stramineus	*	*			
Myotis sp.	*				
Myotis elegans		*			
TROGLOPHILES					
Gastropoda (Class; snail)	*				
Arachnida (Class; spider)	*				
Loxosceles sp. (recluse spider)	*		*		
Diplopoda (Class; millipede)	*				
Littorophiloscia sp. (pillbug)	*				
Mayagryllus apterus?	*				
Coleoptera (Order; 3 beetle spp.)[a]	*				
Tenebrionid beetle (Zophobas sp.)					*
Tineidae (Family; micro-lepidopteran moth)	*				
Prostigmata (Suborder; 2 mite spp.)	*				
STYGOBITE					
Macrobrachium catonium?	*		*		
Typhlopseudothelphusa acanthochela			*		
Rhamdia guatamalensis?	*		*	*	
EPIGEAN					
Order Araneae (spider sp.)	*				
Citharacanthus meermani	*				
Centruroides gracilis	*				
Blaberus giganteus	*				
Blaberus discoidales	*				
Sphaeroceridae (Family; dung fly)	*				
Eleutherodactylus alfredi	*				
Lepidophyma flavimaculatum	*				
Lepidophyma mayae	*				

[a]Species tentatively considered guanophiles. For a complete inventory list by taxonomic order, refer to Appendix 1.

be unique to the Yucatan Peninsula. Thus, this cave meets one, and potentially both, of these criteria.

Additionally, roosting bats are vitally important to cave ecosystems because they transport organic matter from the outside environment into a cave via guano. The presence of bats and their guano in caves are considered vital to cave productivity (Arita, 1996; Krajick, 2001) and may result in high cavernicole species diversity, large biomass of organisms (Harris, 1970), and endemism (Arita, 1996). Subsequently, if bats abandon a cave, nutrient transport will be suspended, and the persistence of cave fauna may be in jeopardy (Nicholas, 1956). None of the cavernicole species identified within Actun Chapat are considered imperiled, but many invertebrate species identified are likely reliant upon the nutrient load provided by roosting bats. However, proper management of the bat colony will likely insure persistence of other cavernicoles.

Subterranean pools and small watercourses are highly sensitive due to the presence of distinctive and specialized stygobites (Hamilton-Smith and Eberhard, 2000). Stygobites, including salamanders, shrimp, crayfish, and crabs, are often long-lived, have small population sizes and reproduce slowly (Elliott, 2000; Krajick, 2001). Consequently, excessive disturbance to the stygobites in Actun Chapat may severely disrupt population dynamics, so that the population trends towards extirpation or perhaps extinction. However, we have no data to quantify sensitivity thresholds at either an individual stygobite or community level, nor have there been any efforts to develop conservation management criteria for stygobites in either southern México or northern Central America. Thus, we have no comparative framework for assessing the sensitivity of the two stygobite species and the semi-aquatic troglobitic crab, or evaluating the conservation priority of this community.

If protection of biodiversity is a management priority for this cave, the bat maternity/nursery roost and subterranean pool should remain undisturbed. Because declines in roost populations have been correlated to recreational caving activities as well as scientific investigations (Stebbings, 1971; Brown and Berry, 1991; Carlson, 1991; Cockrum and Petryszyn, 1991), the large multiple-species maternity/nursery roost warrants high consideration as a management priority. Activities perceived as minor, such as briefly entering a roost area, or shining a light within a roost, may result in decreased survivorship (McCracken, 1988) or permanent abandonment (McCracken, 1988; Cockrum and Petryszyn, 1991) of the roost. If this were to occur, the removal of the guano nutrient input into Actun Chapat would likely have a negative cascading effect on the entire cave ecosystem. Also, no taxonomic studies on the stygobites and troglobitic crabs have been conducted. Therefore, we do not know if these species are endemic to Actun Chapat. Similar species have been described from nearby caves, so the Actun Chapat stygobites and troglobitic crab may represent subpopulations. If this is the case, we do not know the connectedness of these subpopulations to other cave systems. If this pool is connected to other caves containing these species, immigration and emigration of individuals between caves will likely be possible. Thus, persistence may be driven by hydrologic connectedness to other populations in nearby caves. Repopulation by new individuals to Actun Chapat may then be possible. Conversely, if these species are endemic, or this community is isolated and the potential for repopulation is restricted, then this pool should receive special management consideration. Because the population dynamics of cave catfish, shrimp and crabs in Belize, and specifically Actun Chapat, are unknown, we do not know the impacts on these species of repeated or prolonged human disturbance. Until endemism and/or the connectedness of this pool to other caves are determined, and an understanding of population dynamics of these taxa obtained, we recommend the subterranean pool not be disturbed.

Although likely justified from a resource management perspective, we recognize identifying the entire cave as "no" or "restricted" access will be highly controversial for the owner and local community. Therefore, to provide some protection of the sensitive ecological areas and the cave ecosystem as a whole, we have identified an approach that may assist in the management of these resources. Using a modified ranking system developed by McCracken (1988, 1989), we divided the cave into green, yellow and red zones. Green zones are open to recreational and research activities. Yellow zones are quiet zones for recreational cavers, and research activities should occur only during certain times of the year. Red zones are off-limits to recreational cavers and used by researchers only in special cases.

We have delimited four suggested use zones within Actun Chapat; two green, one yellow, and one red (Figure 3). Green zone 1 extends from Entrance 1 to the entrance of the south-trending passage (the passage containing Zotz Na and subterranean pool). Green zone 2 extends from Entrance 2 to the entrance of this passage. Although we have observed troglobites and other cavernicoles throughout this passage, responsible recreational caving and research within these areas is considered a good compromise between affording some level of protection to sensitive cave resources while supporting regional economic activities. Separating the two green zones is a yellow zone. Because this zone is approximately 100 meters from the entrance to the Zotz Na passage, reducing visitant noise levels while traversing this area will reduce disturbance to bats. Establishment and use of a trail connecting Entrance 1 and Entrance 2 would further reduce impacts to cave biota. From the southern edge of the yellow zone southward is a red zone. This passage contains both sensitive ecological areas. The northern edge of the red zone is approximately 100 m from the passage containing the Zotz Na. Designating this zone as off-limits to recreational cavers is highly recommended. Research activities within this zone should occur only if determined necessary by IOA and Ministry of Natural Resources, Forest Department (MNRFD). To safeguard the persistence of this bat colony, research activities within both yellow and red zones should proceed when the bat roost is least susceptible to disturbance (*i.e.*, after reproductive cycle of a bat colony is complete), and under the direction of MNRFD.

A distinct contrast in nutrient loading exists between the horizontal entrance (Entrance 1) and the vertical entrance (Entrance 2). The configuration of the two entrances of Actun Chapat (one a vertical sinkhole entrance and the other a horizontal entrance), results in a chimney airflow effect (Tuttle and Stevenson, 1978; Pflitsch and Piasecki, 2003; Stuckless and Toomey, 2003). A chimney effect is characterized by seasonal oscillating airflow driven by changes in ambient temperature. During the winter, warmer internal air attempts to equilibrate

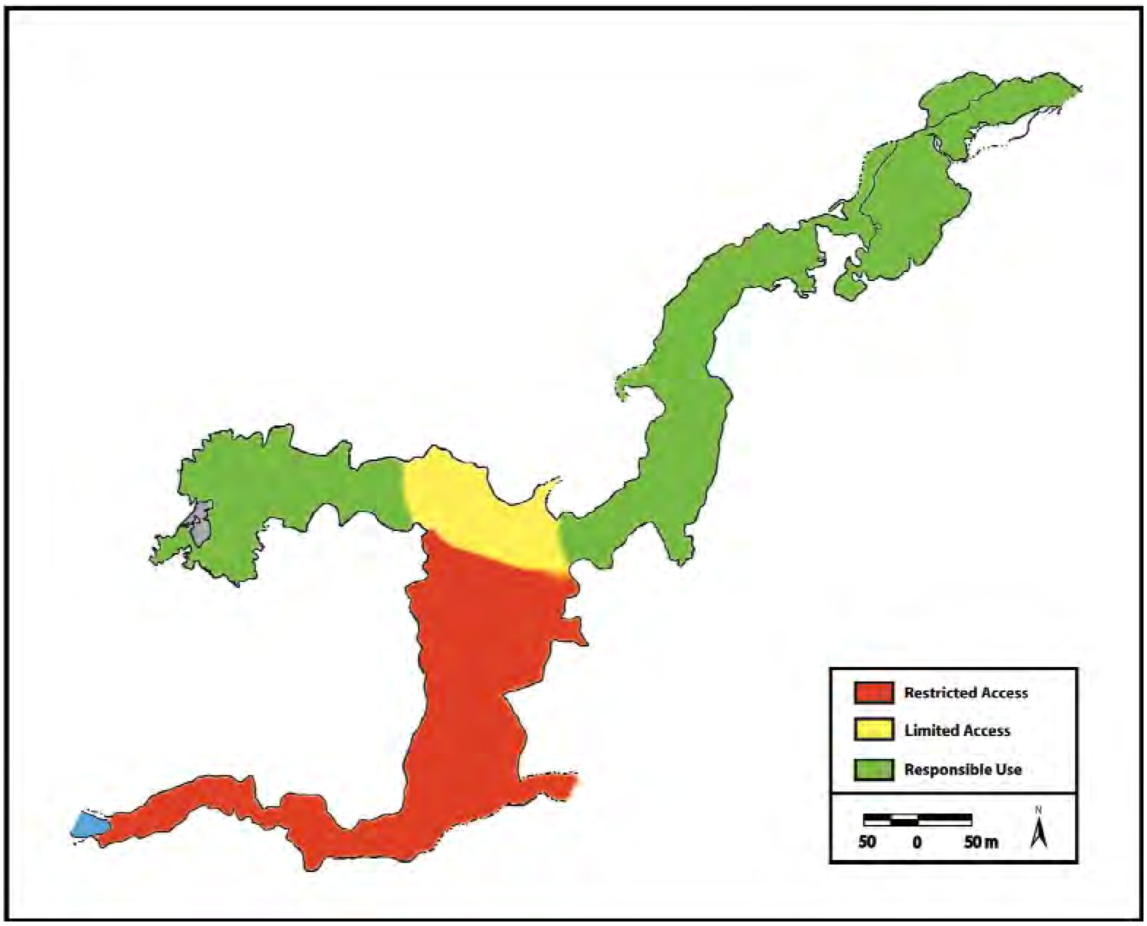


Figure 3. Recommended special use zones within Actun Chapat: Green (responsible use)–open year-round to responsible recreational caving and research activities, Yellow (limited access)–quiet zones for recreational cavers throughout the year with research activities permitted after bat breeding season, and Red (restricted access)–no access permitted to recreational cavers and access to researchers should be granted only in special cases.

with the cooler external air. As a result, warm air is expelled through the chimney entrance and ambient air is inhaled through the horizontal entrance. During the summer, a reverse chimney effect occurs as cooler internal air is expelled through the lower entrance as ambient air is inhaled through the chimney. The intensity of this effect is driven largely by cave structure.

At Actun Chapat, this cave breathing activity appears quite pronounced and may be more dramatic at the vertical entrance. This is tentatively supported by the disproportionate amount of nutrients found at the base of the vertical entrance compared to the horizontal entrance. The nutrient rich-Entrance 2 is likely driving species diversity and abundance. Entrance 1 is characterized by extensive breakdown and cobbles with virtually no organic material on the cave floor. Consequently, during our surveys of this entrance, we did not identify any fauna. Conversely, the cave floor below Entrance 2 contained a substantial amount of breakdown, leaf litter and other forest detritus.

During our research in July 2001, the inflow of air into the sinkhole entrance was so prominent, organisms passing over the entrance were sucked into the cave. This phenomenon gave rise to a myriad of insects flying continuously toward the surface, yet trapped within the air column between the entrance and the cave floor. Upon exhaustion, these insects would retire to the cave floor where we observed Alfred's rainfrog, two lizard species, and several Arachnid species preying upon them. The breakdown and forest detritus provides cover for both predator and prey species with the strong downdraft bringing detritus and organisms into the cave. Thus, cave structure, the breathing activity, and the influx of nutrients is supporting an ecosystem and potentially complex food web of epigean species. Although we do not consider Entrance 2 a sensitive ecological area, this entrance certainly warrants further study due to the unique predator-prey relationships borne-out by this chimney-effect breathing cave.

To date, this paper represents the first species inventory list of a Belize cave. In general, most biological information of Belize caves exists in the form of ad hoc invertebrate specimen collections and/or limited studies of cave roosting bats. None of this information has been synthesized to produce inventory lists on a per cave basis. Furthermore, we encountered no studies addressing wildlife using cave entrances. Although we now have a better understanding of Actun Chapat's biodiversity, ecological research in this cave system remains incomplete. To develop a more comprehensive inventory list, a survey effort consisting of extended duration sampling and sampling taxa using multiple techniques should be undertaken. Also, the epigean ecosystem at Entrance 2 offers a living laboratory for studying predator-prey interactions within a unique system.

These interactions and the cave-breathing phenomenon driving this system should be probed further.

Systematic research to inventory cave biota will not ensure the future of cave-obligate taxa. Currently, Belize has no legislation or programs to manage cave systems or safeguard the persistence of cavernicole populations. Delineating an entire cave system or cave passages within a system as red, yellow or green priority for conservation is only the first step. If land managers wish to manage these delicate ecosystems within a conservation paradigm, we propose the establishment of:

1. A ranking system to evaluate sensitivity for cave ecosystems and karst hydrologic systems;
2. A framework for identifying cave ecosystems for potential inclusion in the International Union for the Conservation of Nature (IUCN) World Heritage Site programme;
3. A listing of cave ecosystems and karst hydrologic systems targeted for restoration, and methods for cave restoration;
4. An education program to heighten awareness of Belizeans and tourists regarding the importance and fragility of cave ecosystems;
5. A training and certificate program for cave eco-tour companies and guides; and,
6. A review process of international and regional cave resource management documentation to obtain the information necessary for drafting cave management protection legislation.

Overall, the lack of information on Belize cave biodiversity and cave resource management programs underscores the need for a national effort to address these issues. Belize has a reputation for rich above ground biodiversity and innovative wildlife conservation practices. An effort to gain a greater understanding of Belize's subterranean fauna while concomitantly developing programs to manage cave ecosystems will bolster knowledge of its natural history, likely lead to new species discoveries, assist resource managers in identifying caves of high conservation priority and potentially provide managers with the infrastructure to manage these fragile systems.

ACKNOWLEDGEMENTS

We wish to thank the Belize Institute of Archaeology and Western Belize Regional Cave Project for their generous support throughout this project. We also thank the Chechem-Ha Lodge for providing field facilities and accommodations. J. Ascot, L. Berlin, B. Block, C. Chambers, C. Drost and K. Thomas donated field equipment. Valuable assistance and support in the field was given by J. Brown, C. Griffith, O. Raul Chi, S. Jacyna, and K. Whittenberg. Bats were handled by S. Jacyna and K. Whittenberg. C. Griffith and C. Helmke developed and provided the base map of Actun Chapat, courtesy of J. Awe and WBRCP. Thanks to D. Billings for providing images of Actun Chapat fauna from a 2005 cave mapping expedition. Also, thanks to C. Drost, J. Ove Rein, S. Peck, X. Prous and J. Reddell for insightful discussions on invertebrates. D. Ashley, C. Drost, B. Elliott, D. Fenn, D. Gillikin, M. Hansen, S. Jacyna, B. Miller, M. Santos, M. Sogge, and R. Toomey offered constructive comments on previous versions of this manuscript.

REFERENCES

Arita, H., 1993, Conservation biology of the cave-bats of México: Journal of Mammalogy, v. 74, p. 693–702.

Arita, H., 1996, The conservation of cave-roosting bats in Yucatan, México: Biological Conservation, v. 76, p. 177–185.

Bassie-Sweet, K., 1991, From the mouth of the dark cave: Commemorative sculpture of the late classic Maya: University of Oklahoma Press, Norman, OK.

Bat Conservation International (BCI), 1989, Conservation success in Czechoslovakia: Bats, v. 7, p. 12.

BCI, 1992, BCI news and notes: protection for critical bat caves in New México: Bats, v. 10, p. 17–18.

Belize Biodiversity Information System (BBIS), 2001, Neotropical Bat Information System, Version 1.5.: Wildlife Conservation Society, Gallon Jug, Belize. http://fwie.fw.vt.edu/wcs/, Date accessed: 11 April 2004.

Brown, P. and Berry, R., 1991, Bats: habitat, impacts and migration, *in* Comer, R.D., Davis, P.R., Foster, S.Q., Grant, C.V., Rush, S., Thorne, II, O., and Todd, J. (eds.), Issues and technology in management of impacted wildlife: Proceedings of a National Symposium, Snowmass Resort, Colorado, April 08-10, 1991, p. 26–30.

Brown, P., Berry, R., and C. Brown, C., 1993a, Bats and mines: finding solutions: Bats, v. 11, p. 12–13.

Brown C., Brown, P., and Berry, R., 1993b, Abandoned mines as habitat for bats and other wildlife in the desert, *in* Proceedings of the 1993 Desert Research Symposium: San Bernardino County Museum Association Quarterly, v. 40, p. 22–23.

Carlson, K., 1991, The effects of cave visitation on terrestrial cave arthropods: National Cave Management Symposium Proceedings: Bowling Green, Kentucky, October 23–26, p. 338–345.

Cockrum, E. and Petryszyn, Y,. 1991, The long-nosed bat, Leptonycteris: an endangered species in the southwest?: Occasional Papers, the Museum Texas Tech University, v. 12, p. 1–32.

Crump, M. and Scott, Jr., N., 1994, Visual encounter surveys, *in* Heyer, W.H., Donnelly, M.A., McDiarmid, R.W., Hayek, L.C., and Foster, M.S. (eds.), Measuring and monitoring biodiversity: standard methods for amphibians: standard techniques for inventory and monitoring: Smithsonian Press, Washington D.C., p. 84–91.

Culver, D. and Holsinger, J., 1992, How many species of troglobites are there?: NSS Bulletin, v. 54, p. 79–80.

Culver, D., Christman, M., Sket, B., and Trontelj, P., 2004, Sampling adequacy in an extreme environment: species richness patterns in Slovenian caves: Biodiversity and Conservation, v. 13, p. 1209–1229.

Culver, D. and White, W. 2005, Encyclopedia of caves: Elsevier Academic Press, Burlington, MA., 654 p.

Elliott, W., 2000, Conservation of the North American cave and karst biota, *in* Wilkens, H., Culver, D.C., and Humphreys, W.F. (eds.), Subterranean ecosystems, Ecosystems of the World, v. 30, Elsevier, Amsterdam, p. 665–669.

Fernandez, J., 1989, Belize: A case study for democracy in Central America: Athenaeum Press Limited, Newcastle upon Tyne, UK, 6 p.

Gertsch, W., 1973, A report on cave spiders from México and Central America: Association of Mexican Cave Studies Bulletin, v. 5, p. 141–163.

Hall, L., 1994, The magic of Mulu: Bats, v. 12, p. 8–12.

Hamilton-Smith E. and Eberhard, S. 2000, Conservation of cave communities in Australia, *in* Wilkens, H., Culver, D.C., and Humphreys, W.F. (eds.), Subterranean ecosystems, Ecosystems of the world, v. 30, Elsevier, Amsterdam, p. 647–664.

Harnish, H., 1992, Protecting the bats of Devil's Den: When endangered bats needed special protection from disturbance, a cave alarm system provided an effective and creative solution: Bats, v. 10, p. 13–18.

Harris, J., 1970, Bat-guano cave environment: Science, v. 169, p. 1342–1343.
Hüppop, K., 2005, Adaptation to low food, *in* Culver, D.C. and White, W.B. (eds.), Encyclopedia of Caves: Elsevier Academic Press, Burlington, MA., p. 4–10.
Humphrey, S., 1969, Status, winter habitat, and management of the endangered Indiana bat, *Myotis sodalis*: Florida Scientist, v. 41, p. 65–76.
Krajick, K., 2001, Cave biologists unearth buried treasures: Science, v. 283, p. 2378–2381.
Kunz, T., 1982, The ecology of bats: Plenum Press, New York., 425 p.
McCracken, G., 1986, Why are we losing our Mexican Free-tailed bats?: Bats, v. 3, p. 1–2.
McCracken, G., 1988, Who's endangered and what can we do?: Bats, v. 6, p. 5–9.
McCracken, G., 1989, Cave conservation: special problems of bats: National Speleological Society Bulletin, v. 51, p. 49–51.
Mohr, C., 1972, The status of threatened species of cave-dwelling bats: National Speleological Society Bulletin, v. 34, p. 33–47.
Muchmore, W., 1973, The Pseudoscorpion Genus *Mexobisium* in Middle America (Arachnida, Pseudoscorpionida): Association for Mexican Cave Studies Bulletin, v. 1, p. 63–72.
Nicholas, B., 1956, Biological aspects of cave conservation: National Speleological Society News, v. 14, p. 30–31.
Pflitsch, A. and Piasecki, J., 2003, Detection of an airflow system in Niedzwiedzia (Bear) cave, Kletno, Poland: Journal of Cave and Karst Studies, v. 63, p. 160–173.
Reddell, J., 1979, Zoogeography of the cave fauna of the Yucatan: NSS Bulletin, v. 41, p. 112.
Reddell, J., 1981, A Review of the cavernicole fauna of México, Guatemala and Belize: Texas Memorial Museum Bulletin, v. 27, p. 1–327.
Reddell, J. and Veni, G., 1996, Biology of the Chiquibul Cave System, Belize and Guatemala: Journal of Cave and Karst Studies, v. 58, p. 131–138.
Reid, F., 1997, A field guide to the mammals of Central America and Southeast México: Oxford University Press, Oxford, UK, 334 p.
Rodriguez, G. and Hobbs, Jr., H., 1989, Freshwater crabs associated with caves in Southern México and Belize, with descriptions of three new species (Crustacea: Decapoda): Proceedings of the Biological Society of Washington, v. 102, p. 394–400.
Stebbings, R., 1971, Bats, their life and conservation: Journal Devon Trust for Nature and Conservation, v. 3, p. 29–36.
Stuckless, J. and Toomey, III, R., 2003, Long-term passive ventilation at Yucca Mountain: Evidence from natural analogues: Radwaste Solutions, September/October 2003, p. 31–37.
Tuttle, M. and Stevenson, D. 1978, Variation in the cave environment and its biological implications, *in* Zuber, R., Chester, J., Gilbert, S., and Rhodes, D. (eds) National cave management symposium proceedings, Big Sky, Montana, 3–7 Oct. 1977, p. 108–121.
Williams, P., 1976a, The form of *Lutzomyia beltrani* (Vargas and Dias Najera; Diptera. Psychodidae) in Belize, Central America: Bulletin of Entomological Research, v. 65, p. 595–599.
Williams, P., 1976b, The Phlebotomine sandflies (Diptera. Psychodidae) of caves in Belize, Central America: Bulletin of Entomological Research, v. 65, p. 601–614.
Williams, P., 1976c, Flagellate infections in cave-dwelling sandflies (Diptera. Psychodidae) in Belize, Central America: Bulletin of Entomological Research, v. 65, p. 615–629.
Williams, P., 1987, Description of *Lutzomyia* (Coromyia) *disneyi*, N. sp. (Diptera: Psychodidae-Phlebotominae) from Belize, Central America: Memorias do Instituto Oswaldo Cruz, v. 82, p. 525–529.

Appendix 1 - Annotated List of Actun Chapat Cave Fauna

PHYLUM MOLLUSCA
Class Gastropoda (snails)
Order, genus and species undetermined. Troglophile? This snail was observed within a chamber, which contained a flowstone formation. This chamber was within the twilight zone below Entrance 2. This species may be cave adapted.

PHYLUM ARTHROPODA
Class Malacostraca
Order Isopoda
Family Armadillidiidae (terrestrial isopods)
Littorophiloscia sp. Epigean. This pillbug was frequently encountered within the breakdown beneath Entrance 2. This species is not cave adapted.

Order Decapoda
Family Palaemonidae (shrimp)
Macrobrachium catonium (Hobbs and Hobbs 1995)? Stygobite. This species was previously collected (Reddell and Veni 1996). We captured two individuals, which may represent the same species.

Family Pseudothelphusidae (crabs)
Typhlopseudothelphusa acanthochela (Hobbs 1986). Troglobite. Reddell and Veni (1996) identified this species within Actun Chapat.

Order Araneae
Family, genus and species undetermined. Epigean. This spider was documented below the sinkhole entrance. This spider was observed moving among the rocks and leaf-litter.

Family Theraphosidae (tarantula)
Citharacanthus meermani (Reichling & West 2000). Epigean. This species was observed within the twilight and transition zone of the cave. This species is not cave adapted.

Family Salticidae?
Genus and species undetermined. Troglophile. This spider was observed within the dark zone. It was observed perched on a rock. This spider was difficult to capture, and was capable of hopping and moving rather fast. This species was found deep within the dark zone and is presumed cave adapted.

Family Loxoscelidae
Loxosceles sp. Troglophile. This spider had a tan cephalothorax, gray abdomen, and red legs. It constructs condominium complexes of webs. It was observed directly below Entrance 1, the sinkhole. These haphazardly constructed webs formed mats on the ground. Thirteen webs were observed within a 1.5 by 5 meter area.

Order Amblypygida
Family Phrynidae
Paraphrynus sp. or *Paraphrynus raptator* (Pocock 1902). Trogloxene. The giant tailless whip scorpion was observed within the dark zone of the cave. This species is not cave adapted.

Order Trombidiformes
Family, genus and species undetermined. Two troglophillic mites. One species was found within the leaf litter below the sinkhole entrance (Entrance 2). The second species was a red-bodied mite, observed within the Zotz Na and within a narrow passageway. The ground of both locations was guano covered. Neither species is cave adapted.
Family, genus and species undetermined. One troglobite. One species was observed within the dark zone and had no pigmentation. This species is cave adapted.

Order Scorpiones
Family Scorpionidae
Centruroides gracilis (Latreille 1804). Epigean. This species was observed within the twilight and transition zone of the cave. This species is not cave adapted.

CLASS Chilopoda (centipedes)
Order Lithobiomorpha
Family Lithobiidae
Lithobius sp. Troglobite. This cave adapted Lithobiid centipede was found within the dark zone of the cave. It was observed within bat guano. This species is tentatively considered a guanophile.

CLASS Diplopoda (millipeds)
Order, family, genus and species undetermined. Troglophile. This species was observed throughout the all light-zones of the cave. This species occurs in high densities throughout all light zones, and is presumably the namesake for the cave. Its body is black and orange striped with red legs and feet. When disturbed, this species coils into a disk. This species is not cave-adapted.

CLASS Insecta
Order Blattaria
Family Blaberidae (giant cockroaches)
Blaberus giganteus (Linnaeus 1758). Epigean. This species was observed within the light zone of Entrance 2. This species was not cave adapted.
Blaberus discoidalis (Serville 1839). Epigean. This species was observed within the light zone of Entrance 2 beneath the leaf litter. Three individuals, 3–5 cm in length, were observed within the leaf litter. This species is not cave adapted.

Order Orthoptera
Family Phalangopsidae (cave crickets)
Mayagryllus apterus (Grandcolas and Hubbell 1994)? Troglophile. This species was observed within the twilight and dark zones of the cave. Elliott (pers. com. 2005) also observed this species during his 1992-93 research. During his research, he observed this species feeding on bat guano. This species is tentatively listed as a troglophile, but may be epigean.

Order Coleoptera
Family Tenebrionidae
Zophobas sp. Troglophile. This species frequently scavenges on guano and bat carcasses in tropical caves (S. Peck, pers. com. 2005). This species was photographed by D. Billings (2005) and tentatively identified by S. Peck (Carleton University, Ottawa, Canada). This species is not cave adapted.
Family, genus and species undetermined. Three troglophiles. Two beetle species were observed within the light zone beneath the leaf litter of Entrance 2. One species was observed within the dark zone of the main cave passage from Entrance 2. Neither species is cave adapted.
Family, genus and species undetermined. Troglobite. One species was observed burrowing into a circular pile of bat guano. This species is presumed to be a cave-adapted guanophile.

Order Lepidoptera
Family Tineidae
Genus and species undetermined. Troglophile? This species was observed within the Chamber 3, Zotz Na. It had a silken cocoon, which formed a protective shell, and it emerged partially from one end to feed. It formed a carpet layer over the guano. W. Pleytez aptly described the ground as "being completely alive" with this species. This species is tentatively considered a guanophile.

Order Diptera
Family Sphaeroceridae (dung fly)
Genus and species undetermined. Epigean. This species was observed within the dark zone. It was dark gray in color with red eyes. This species is not expected to be cave adapted.

PHYLUM CHORDATA
Class Actinopterygii
Order Siluriformes
Family Pimelodidae (catfish)
Rhamdia guatemalensis (Günther 1864)? Stygobite. This species was captured with a handheld net from the subterranean pool within the cave's dark zone. This species has no pigmentation and reduced eye development. Reddell and Veni (1996) and Elliott (pers. com. 2005) also identified this species. Elliott (pers. com. 2005) had this species

tentatively identified by researchers at the Texas Memorial Museum, Austin. This catfish is a cave-adapted species.

Class Mammalia
Order Chiroptera (Bats)
Family Emballonuridae
Peropteryx macrotis (Wagner 1843; Lesser Dog-like Bat). Trogloxene. This species was documented by B. Miller and C. Miller (unpublished data).

Family Mormoopidae
Mormoops megalophylla (Peters 1864; Ghost-faced bat). Trogloxene. We captured this species both within Zotz Na and in mist nets outside the cave. B. Miller and C. Miller (unpublished data) also documented this species.
Pteronotus parnellii (Gray 1843; Parnell's mustached bat). Trogloxene. We captured this species within Chamber 1, Zotz Na and in the mist nets below Entrance 2. B. Miller and C. Miller (unpublished data) also documented this species.
Pteronotus personatus (Wagner 1843; Wagner's mustached bat). Trogloxene. This species was documented by B. Miller and C. Miller (unpublished data).
Pteronotus davyi (Gray 1838; Davy's naked-backed bat). Trogloxene. This species was documented by B. Miller and C. Miller (unpublished data).

Family Phyllostomidae
Phyllostomid sp. Trogloxene. One unidentified Phyllostomid species was captured in the mist nets below Entrance 2.
Trachops cirrhosus (Spix 1823; fringe-lipped bat). Trogloxene. We captured this species within a cylindrical recess in the cave ceiling of Chamber 1, Zotz Na.
Glossophaga sp. Trogloxene. In 1992 and 1993, Elliott (2000) documented individuals to genus level within Actun Chapat.
Glossophaga soricina (Pallas 1766; Pallas's long-tongued bat). Trogloxene. We captured this species within Chamber 1 of the Zotz Na.
Artibeus jamaicensis (Leach 1821; Jamaican fruit-eating bat). Trogloxene. One individual was captured with a handheld net. It was roosting with two other individuals (possibly females) within a cylindrical recess in the cave ceiling of Chamber 1, Zotz Na. Once this species was captured the bats apparently abandoned this roost. In 1992 and 1993, Elliott (2000) also documented this species within the cave.

Family Natalidae
Natalus stramineus (Pallas 1766; Mexican funnel-eared bat). Trogloxene. We observed this bat within all chambers of the Zotz Na. However, it was only observed roosting within Chamber 3, where it is the dominant species of the large maternity roost. B. Miller and C. Miller (unpublished data) also documented this species.

Family Vespertilionidae
Myotis sp. Trogloxene? One unidentified Myotis species was captured in the mist nets below Entrance 2.
Myotis elegans (Hall 1962; elegant myotis). Trogloxene. This species was documented by B. Miller and C. Miller (unpublished data).

Class Amphibia
Order Anura
Family Leptodactylidae
Eleutherodactylus alfredi (Boulenger 1898; Alfredo's rainfrog). Epigean. We captured this frog within the breakdown beneath Entrance 2. This species is not cave adapted and is considered epigean.

Class Reptilia
Order Squamata
Family Xantusiidae
Lepidophyma flavimaculatum (Duméril 1851; yellow-spotted night lizard). Epigean. We observed this species in the breakdown beneath Entrance 2. We observed one lizard capture and consume a wasp. This species is not cave adapted.
Lepidophyma mayae (Maya night lizard). Epigean. We observed this lizard in the breakdown beneath Entrance 2. This species is not cave adapted.

Robert N. Lerch, Carol M. Wicks, and Philip L. Moss – Hydrologic characterization of two karst recharge areas in Boone County, Missouri. *Journal of Cave and Karst Studies*, v. 67, no. 3, p. 158–173.

HYDROLOGIC CHARACTERIZATION OF TWO KARST RECHARGE AREAS IN BOONE COUNTY, MISSOURI

Robert N. Lerch[1]

USDA-Agricultural Research Service, Cropping Systems and Water Quality Research Unit, 269 Agricultural Engineering Bldg., University of Missouri, Columbia, MO 65211 USA

Carol M. Wicks

Department of Geological Sciences, University of Missouri, 308 Geological Sciences Bldg., University of Missouri, Columbia, MO 65211 USA wicksc@missouri.edu

Philip L. Moss

Ozark Underground Laboratory, 1572 Aley Lane, Protem, MO 65733 USA
Current address: 401 S. Church St. Waterloo, IL 62298 USA philipmoss@juno.com

The Bonne Femme watershed, located in central Missouri, is a karst watershed in a rapidly urbanizing area. This study was undertaken to characterize the hydrology of two karst aquifers within this watershed before significant increases in impervious surfaces take place. The specific objectives of this study were to: 1) use dye tracing to delineate the recharge area for Hunters Cave (HC); 2) quantify and summarize annual and monthly stream discharge at the resurgence of HC and Devils Icebox (DI) caves; and 3) characterize the chemical and physical status of the cave streams relative to temperature, pH, specific conductance, dissolved oxygen, and turbidity. The quantity and quality of the water at the resurgence of both cave streams was monitored from April 1999 to March 2002. Both recharge areas were determined to be of similar size (33.3 km^2 for HC and 34.0 km^2 for DI) and were formed in the same geologic strata. Average annual discharge was 55,900 $m^3\ km^{-2}$ at DI and 35,200 $m^3\ km^{-2}$ at HC. Relative discharge, as a percent of annual precipitation, averaged 6.1% at DI and 3.8% at HC. Average monthly discharge was 2,930 $m^3\ km^{-2}$ at HC and 4,650 $m^3\ km^{-2}$ at DI; however, median instantaneous discharge over the three years was about 18% higher at HC (74 $m^3\ h^{-1}$) compared to DI (63 $m^3\ h^{-1}$). Turbidity and pH showed the largest differences between sites over the three years. The higher turbidity and lower pH at DI reflected the greater magnitude and duration of runoff events for this system. The physical characteristics of the two recharge areas explained the observed differences in discharge. The HC recharge area is characterized by limited sub-surface conduit development, small conduits, short flow paths from surface to resurgence, and predominantly allogenic recharge. The DI recharge area is characterized by extensive subsurface-conduit development, large conduits, long flow paths to the resurgence, and autogenic and allogenic recharge.

Introduction

The nature of ground-water recharge in karst aquifers controls speleogenesis over geologic time, and it directly impacts the quantity and quality of water in the aquifer in current time. There are two basic ground-water recharge types in karst terranes: autogenic and allogenic (Shuster and White, 1971). Autogenic recharge can be further separated into diffuse and discrete recharge. Allogenic and discrete recharge modes are especially vulnerable settings for contaminant transport to ground-water. Allogenic recharge to karst aquifers occurs where surface runoff draining large areas of insoluble rock or low permeability soils flows directly to adjacent soluble carbonate bedrock (Palmer, 2000). Recharge to the karst aquifer occurs along sinking or losing stream channels via infiltration of surface water through porous streambed sediments or through fractures in the streambed (White, 1988). In this setting, the karst aquifer displays flow characteristics that are typical of surface streams, with relatively rapid response to precipitation and variations in resurgence discharge over several orders of magnitude. In mature karst aquifers formed by allogenic recharge, the subsurface conduits will be well developed, resulting in relatively short residence time of water in the subsurface. Under such conditions, thermal and chemical equilibrium of the water will not be attained (Wicks, 1997). Cave formation is enhanced by allogenic recharge due to the concentration of surface runoff from large catchments into a few relatively small subsurface conduits and because the surface runoff is typically under-saturated with respect to calcite or dolomite in these settings (Groves, 1992; Wicks and Engeln, 1997).

Discrete recharge to a karst aquifer occurs through openings, such as sinkholes, that drain a small land area. Karst aquifers recharged in this manner typically have numerous inputs of surface water to the subsurface, with water draining along cracks, fissures, and zones of weakness in soluble bedrock. As enlargement progresses by solution and/or corrosion along these flow paths, conduits capable of rapidly transmitting water from the surface to the subsurface are created. However, discrete recharge will typically have longer subsur-

[1]Corresponding author. phone: 573-882-9489; e-mail: lerchr@missouri.edu

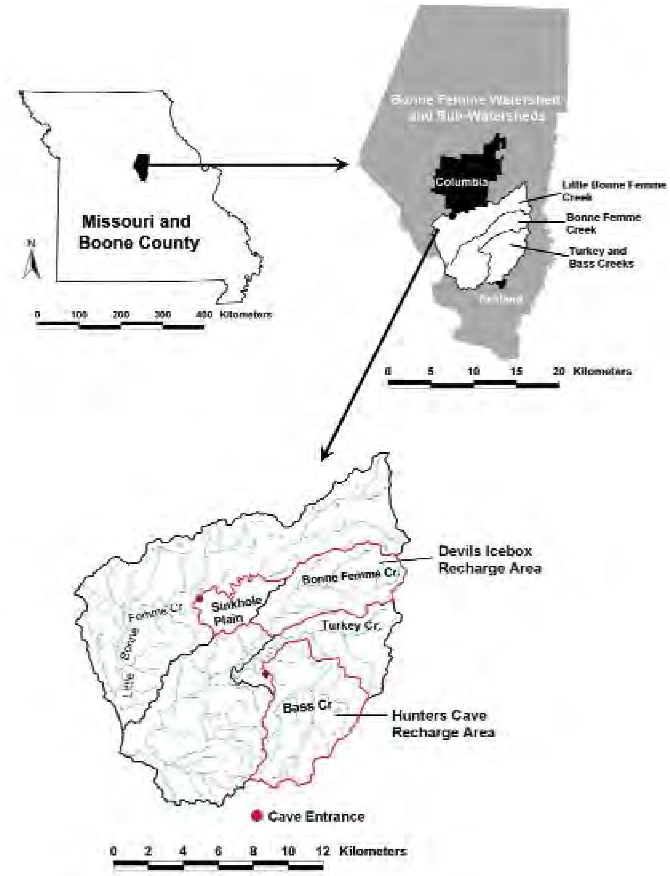


Figure 1. Location and hydrologic setting of the two karst aquifers. For Devils Icebox, the allogenic (upper Bonne Femme Creek) and the autogenic (sinkhole plain) portions of its recharge area are distinguished by the black boundary line shown within the recharge area. Hunters Cave recharge area encompasses allogenic recharge from Bass Creek and two tributaries of Turkey Creek.

face residence time than water transmitted by allogenic recharge, and therefore, thermal and chemical equilibrium of the water are more closely attained in this situation (Wicks, 1997).

Overall, allogenic and discrete recharge modes represent the most vulnerable setting for ground-water contamination because surface water rapidly enters the subsurface with little or no opportunity for contaminant attenuation by surface soils. Contaminant inputs derived from surface land-use activities within the recharge area will have a profound impact on water quality in these karst aquifers. In the Midwestern USA, common land uses or land covers that are a potential threat to karst ground-water quality include urban development, agricultural practices, private septic systems, industrial production, and military activities. These land uses can impact karst aquifers through a myriad of contaminant inputs, such as oil, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, fertilizer, sediment, and fecal coliform bacteria (Ruhe *et al.*, 1980; Boyer and Pasquarell, 1999; Mahler *et al.*, 1999; Lerch *et al.*, 2001).

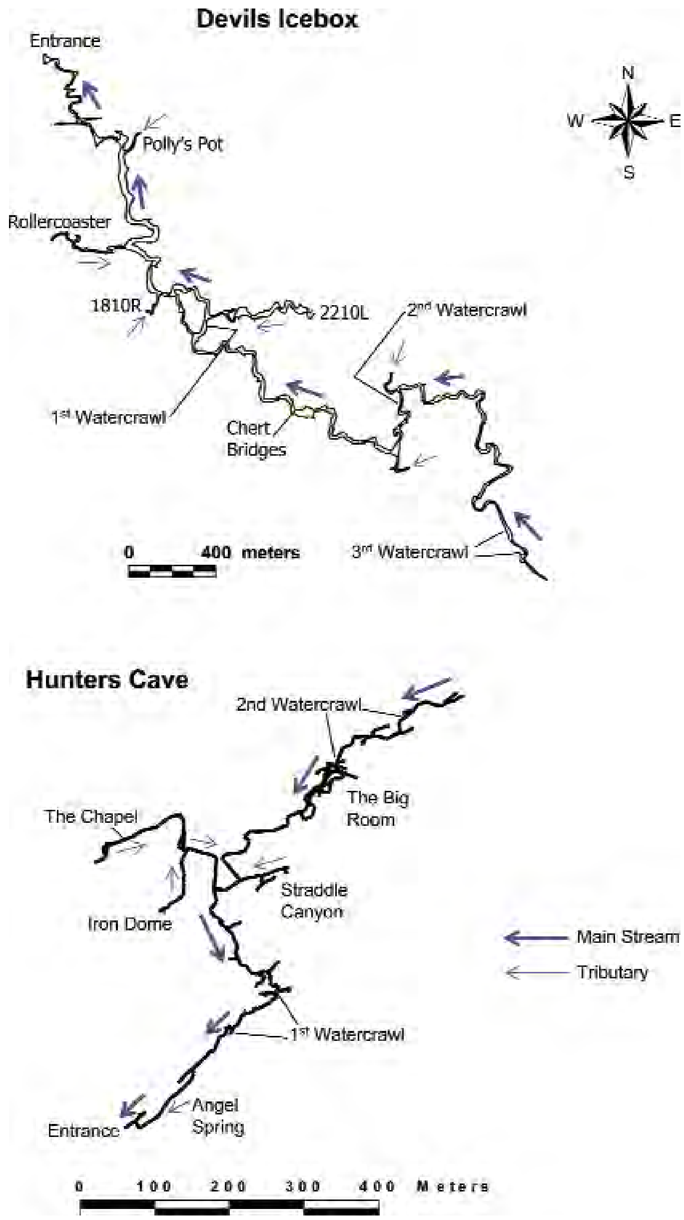


Figure 2. Line plot diagrams of the two cave systems. (Note the difference in scale for the two caves.)

An additional threat to karst ground-water is the increased impervious surface resulting from urbanization. Impervious surfaces, such as roads, building rooftops, sidewalks, driveways, and parking lots, will negatively impact stream hydrology, biology, and channel geomorphology. In surface stream watersheds, impervious surfaces increase discharge velocity and volume of storm water runoff, leading to degraded aquatic habitat and biological health of streams, increased stream bank erosion, and decreased baseflow discharge (Burges *et al.*, 1998; Booth *et al.*, 2002). These hydrologic impacts have also been shown to occur in allogenic recharge karst aquifers (Betson, 1977; Ruhe *et al.*, 1980). Karst systems further complicate the impact of impervious surfaces because inter-basin transfer of water routes storm runoff from one watershed to another. The altered hydrologic conditions caused by impervious surfaces will most profoundly impact allogenic recharge to karst aquifers and their ecosystems, but localized increases to impervious surface could negatively impact the water quality and quantity of discrete recharge to karst aquifers as well. Because of the analogous impacts of impervious surfaces on karst aquifers and surface streams, Veni (1999) recommended the adoption of impervious surface limits designed for protection of surface streams (Schueler, 1994) as a reasonable guideline for karst areas. Limiting impervious surfaces within a recharge area to 15% of the land area should minimize adverse impacts to karst ground-water resources (Veni, 1999). However, implementation of best management practices (BMPs), local geological factors, and restoration of older impervious areas may sufficiently mitigate water resource degradation and allow for more than 15% impervious area (Veni, 1999).

The present study was undertaken to characterize the hydrology of two predominantly allogenic recharge karst aquifers in the Bonne Femme watershed of southern Boone County, Missouri (USA) (Fig. 1). The Bonne Femme watershed is rapidly urbanizing due to growth in the cities of Columbia and Ashland, and this study was initiated before significant increases in impervious surface had occurred in either of the karst-recharge areas. Thus, the hydrologic impact of increasing imperviousness and the effectiveness of BMPs that may be implemented as urban growth occurs can be documented. The specific objectives of this study were to: 1) use dye tracing techniques to delineate the recharge area for Hunters Cave (HC); 2) quantify and summarize annual and monthly stream discharge at the resurgence of HC and Devils Icebox (DI) caves; and 3) characterize the chemical and physical status of the cave streams relative to temperature, pH, specific conductance, dissolved oxygen, and turbidity.

Materials and methods

Site Descriptions

The recharge area of the DI and HC are both located within the Bonne Femme Creek watershed located due south of Columbia, Missouri, USA (Fig. 1). The caves were formed in the Burlington Limestone (Osagean Series, Mississippian System) (Wicks, 1997). The total thickness of the Burlington Limestone is approximately 50 m. The Chouteau Group (Kinderhookian Series, Mississippian System) underlies the Burlington Limestone, and is composed of limestone, dolomite, and silty dolomite with a total thickness of approximately 30 m. The Chouteau Group is not conducive to cave development (Unklesbay, 1952); this unit serves as the base of the local flow system in the DI cave. The upper (eastern) portions of both cave recharge areas are covered by clay-rich Pleistocene age glacial and loess deposits (St. Ivany, 1988). These low permeability, fertile soils are generally in the Mexico-Putnam or Mexico-Leonard soil associations (USDA-NRCS, 2001). Lower (western) portions of each recharge area are characterized by residual soils of the Weller-Bardley-Clinkenbeard association (USDA-NRCS, 2001) and correspond to the areas with karst features, such as sinkholes, caves, and springs, including the two cave entrances.

The DI cave length is currently listed as Missouri's seventh longest cave at 10.76 km (6.69 miles) (Gulden, 2005) and includes the primary trunk passage and several smaller side passages (Fig. 2). The main trunk passage is the primary stream conduit, and was surveyed to a length of approximately 6.4 km (4 miles) (Fig. 2) before reaching a sump. The cave system's downstream terminus is a spring located in Rock Bridge Memorial State Park (Missouri Department of Natural Resources, Division of Parks), and water travels along the surface for a short distance before discharging into Little Bonne Femme Creek. This flow path creates an inter-basin transfer of water from the upper Bonne Femme watershed to the Little Bonne Femme watershed (Fig. 1).

As part of this project, HC was re-surveyed to an extent of 2.54 km (1.58 miles) which currently makes it the 34th longest cave in Missouri (Fig. 2). The main passage is also the primary stream conduit, and its flow path extends for approximately 1.25 km, accounting for slightly less than half the surveyed distance of the cave. The largest tributary to the main cave stream is Angel Spring (Fig. 2), located about 70 m into the cave (see additional discussion below). Very small tributaries to the main stream also enter through The Chapel, Iron Dome, and Straddle Canyon side passages. Four other intermittently flowing tributaries have also been observed at various points in the cave, with two of these sources entering through the largest domes in the cave. HC terminates at a spring resurgence discharging directly into Bass Creek located within the Three Creeks Conservation Area (Missouri Department of Conservation).

Delineation of Hunters Cave Recharge Area

The HC recharge area was determined using standard dye tracing techniques (Aley, 1999), involving the introduction of fluorescent dyes into stream channels and their subsequent sorption from the water by activated carbon samplers. These samplers contained 4.25 g of activated carbon, derived from coconut shell charcoal, placed in a fiberglass screening with openings of 1.3 to 1.5 mm (Aley, 1999). The samplers were placed at two locations in the cave stream, and they were also placed downstream from all dye introduction points and in adjacent basins in order to assess the possibility of inter-basin transfer. Before dye injection, two separate sets of samplers were deployed, each for one week, to determine if detectable background levels of any of the dyes were present. Raw water samples were also collected once during the time the background sets were deployed. No dyes were detected in raw water or in the charcoal samplers from these background sample sets. Following dye injection, samplers were typically replaced at weekly intervals for up to 3 months. Dyes used included fluorescein ([sodium fluorescein] Acid Yellow 73;

CAS No. 518-47-8), eosin (Acid Red 87; CAS No. 17372-87-1), and Rhodamine WT (Acid Red 388; CAS No. 37299-86-8). The specific location for dye injections, dye amounts and type, and locations of activated carbon samplers are given in Tables 1 and 2. Dye analysis of the activated carbon samplers entailed elution of the dyes from the charcoal with a mixture of isopropanol in a strongly basic solution (Aley, 1999). Raw-water samples were also collected at each sampler location for direct dye analysis. Dye concentrations were determined by fluorescence spectroscopy using a Shimadzu RF-5301 spectrofluorophotometer. Limits of detection for the charcoal eluants were (in μg L^{-1}): fluorescein, 0.010; Rhodamine WT, 0.275; and eosin, 0.035. Limits of detection for the raw water samples were (in μg L^{-1}): fluorescein, 0.0005; Rhodamine WT, 0.05; and eosin, 0.008.

MONITORING PROCEDURES

Hydrologic, chemical, and physical monitoring of the water was conducted near the resurgence of each cave from April 1999 to March 2002. Discharge and water quality were only monitored for the cave streams; no monitoring of the surface streams was conducted. For the three-year study period, the years reported and discussed below extended from April through March. All instrumentation was placed in stilling wells at both locations for protection against turbulent flow and to reduce data variability caused by very short-term fluctuations in the height of the water column. Hydrologic monitoring consisted of measuring the height of the water column (*i.e.*, stage height) at five-minute intervals with a submerged pressure transducer probe (Hach Co., Loveland, CO). Stage height was then used to compute stream discharge, as detailed below. Pressure transducers were checked for accuracy at least twice per month because thermal drift was a known source of error for these instruments. The pressure transducers were calibrated in the field any time that the known stage height and that recorded by the transducer were more than 5% different. In addition, the transducers were routinely calibrated in the field every three months. Chemical and physical water monitoring included temperature, pH, dissolved O_2, specific conductance, and turbidity measured at 15-minute intervals using a YSI 6920 Sonde (YSI, Inc., Yellow Springs, OH). The Sondes were brought into the laboratory every two months for cleaning and calibration of all probes. In addition, the dissolved oxygen probes were cleaned, the membranes replaced, and the probes calibrated in the field every two weeks. The chemical and physical monitoring allowed for detailed documentation of the response of these systems under both runoff event and prolonged low flow conditions on a year-round basis.

At DI, the monitoring station is located within a large karst window approximately 30 m downstream from the resurgence (Halihan *et al.*, 1998). The stage height was correlated to stream discharge using two independently developed rating curves. In both cases, standard protocols for measuring velocity with wade sticks and current meters were employed (Rantz, 1982). One rating curve was developed by Vandike (1983) under lower flow conditions. A second rating curve was developed by Halihan *et al.* (1998) under consistently higher flow conditions in the spring of 1994, following the record high rainfalls of 1993. Thus, two different equations were used depending upon stage height:

For a stage height < 0.36 m (1.2 ft),

$$Q = 10^{\left[(2.135 S_H) - 1.10\right]} \qquad r^2 = 0.99 \tag{1}$$

and for a stage height > 0.36 m (1.2 ft),

$$Q = \left(124.1 S_H\right) - 131.8 \qquad r^2 = 0.97 \tag{2}$$

where S_H is stage height (ft) and Q is discharge ($ft^3\ s^{-1}$). Because the field measurements for developing the rating curves were recorded in English units, the initially developed rating curve equations computed discharge in $ft^3\ s^{-1}$, which was then converted to $m^3\ h^{-1}$. The need for two equations arises from the log relationship in Equation (1) which accurately predicts discharge at low stage heights, but severely over-estimated discharge above stage heights of 0.36 m. Equation (2) showed that a linear relationship existed between stage height and discharge for stage heights > 0.36 m. Errors associated with stage-height rating curve relationships developed using current meters have been estimated to range from 5–25% (Tillery *et al.*, 2001).

At HC, the monitoring station was located approximately 15 meters into the cave (*i.e.* upstream from the resurgence). A rating curve could not be developed for HC because high-flow conditions in Bass Creek prevented access to the cave. Therefore, flow-velocity measurements at the resurgence could not be acquired for high-flow conditions, a necessity for the development of an accurate rating curve. As an alternative, the stage height data were used in conjunction with Manning's Equation (Manning, 1890) to compute flow velocity. The cave passage immediately upstream from the resurgence is a very uniform width stream channel with extensive amounts of small to medium-sized breakdown in the streambed. The channel slope over the initial 15 meters and a reference cross-section of the stream channel were surveyed to provide needed data for computation of flow velocity. In addition, a relationship was established to relate stage height at the reference cross-section to the roughness coefficient, *n*. This relationship was developed by measuring flow velocity with a wade stick and pygmy meter placed at 40% of the water depth at stage heights ranging from 0.06 to 0.19 m. Manning's Equation and the area of the reference cross section were then used to estimate discharge and these estimates were compared against the field measured discharge. By choosing roughness coefficients that minimized the error between predicted and measured discharge, a series of roughness coefficients for known stage heights could be generated and graphed. This graph showed a log relationship between these two variables, and linear regression of the log transformed stage height data was then used to determine the following equation:

$$n = \left[-0.53 \log(S_H)\right] - 0.02 \quad (3)$$

Equation (3) was valid only for stage heights < 0.19 m (0.62 ft). For stage heights > 0.19 m, the roughness coefficient was assigned a value of 0.10. The inverse relationship between stage height and roughness coefficient suggested that the high degree of streambed non-uniformity caused by the breakdown in the stream channel created a significant impediment to flow under low stage height conditions. To make direct comparisons between the two sites, summaries of annual and monthly discharge from the cave streams were normalized to the size of each recharge area and expressed in $m^3\ km^{-2}$.

Precipitation and other climate data were obtained from two weather stations. The National Weather Service maintains a weather station at the Columbia Regional Airport, located within the HC recharge area, with data available on a daily basis (National Weather Service, 2005). The University of Missouri maintains a weather station at their South Farms research facility, located less than a kilometer north of the DI recharge area. Data at this site are available on both a daily and hourly basis (University of Missouri Extension, 2005).

RESULTS AND DISCUSSION

RECHARGE AREAS AND LAND USES

Previous studies established the hydrologic links between the DI cave stream and upper Bonne Femme Creek (Crunkilton and Whitley, 1983; St. Ivany, 1988) and the Pierpont sinkhole plain (Deike *et al.*, 1960). The initial recharge area delineation was based on these studies in combination with surface water drainage patterns and topography (St. Ivany, 1988; Wicks, 1997). An additional dye trace using 1.4 kg of fluorescein dye injected into the upper Bonne Femme Creek channel immediately south of Missouri Highway 163 (UTM 563,295 east, 4,302,392 north; Zone 15; NAD83 datum) was conducted on December 9, 2003. This dye trace confirmed speculation by St. Ivany (1988) that the losing reach of upper Bonne Femme Creek extends to approximately 213 m above sea level, establishing the southernmost extent of the recharge area (Fig. 1). The DI recharge area is approximately 34.0 km^2, and is comprised of two distinctive hydrologic recharge areas: 1) an allogenic recharge area corresponding to upper Bonne Femme Creek; and 2) a discrete recharge area encompassing the Pierpont sinkhole plain (Fig. 1).

The initial step in the delineation of the HC recharge area was to overlay the survey line plot on the topographic map to determine locations for dye injections and establish the network of charcoal samplers. From this overlay, it could be seen that Bass Creek comes in very close proximity to the cave passage (Fig. 3 and Fig. 4; inset). The estimated distance of this near intersection corresponded to the location of Angel Spring (Fig. 2). In addition, the cave stream beyond the Big Room was shown to be in close proximity to Turkey Creek, located to the north and east of the cave. Therefore, all dye injections were conducted within the Bass and Turkey Creek watersheds (Table 1 and Fig. 3).

Results of the first and second dye injections confirmed the hydrologic connection between Bass Creek and the HC stream (Table 2; Fig. 3). Rhodamine WT injected into Bass Creek on February 25, 2002 resulted in very high concentrations detected in charcoal samplers and raw water samples collected from Angel Spring (Station #3) (Table 2). Visual observation of Rhodamine WT at the HC resurgence was also confirmed within 2 hours of this injection. In addition, a much lower concentration of Rhodamine WT was detected in the cave stream at Station #4. This same result also occurred for the second dye injection in Bass Creek (upstream) in which eosin was detected within the cave at Stations #3 and #4, with higher concentrations at Station #3. These results established that Angel Spring is the discharge point for the major conduit connecting Bass Creek and the HC stream, and this connection establishes a meander cutoff of the large horseshoe bend in the surface stream channel of Bass Creek (Fig 4.; inset). An additional minor flow path from Bass Creek to the cave stream also exists, with an apparently small proportion of Bass Creek discharge entering upstream from Station #4.

Hydrologic connections between the HC stream and two small tributaries of Turkey Creek were also established (Table 2; Fig. 3). Fluorescein dye injected into a small pool of water in the Log Providence tributary to Turkey Creek resulted in

Table 1. Dates, locations, amounts, and type of fluorescent dyes injected to delineate the Hunters Cave recharge area.

Injection Date	Fluorescent Dye	Amount Injected (kg)	Injection Location (UTM Coordinates; Zone 15; NAD83 Datum)	Injection Location Name
2/25/2002	Fluorescein	0.91	563,170 m east; 4,299,020 m north	Log Providence tributary to Turkey Creek
2/25/2002	Rhodamine WT	0.91	562,390 m east; 4,298,412 m north	Bass Creek (downstream)
2/25/2002	Eosin	0.91	562,483 m east; 4,299,331 m north	Turkey Creek (immediately downstream of Log Providence tributary)
5/20/2002	Fluorescein	0.23	564,236 m east; 4,299,462 m north	Equine Center tributary to Turkey Creek
5/20/2002	Rhodamine WT	0.45	562,413 m east; 4,299,686 m north	Turkey Creek (upstream from losing reach)
5/20/2002	Eosin	1.80	564,814 m east; 4,297,259 m north	Bass Creek (upstream)
4/9/2003	Rhodamine WT	0.91	565,533 m east; 4,299,521 m north	Bass Lake tributary to Turkey Creek
4/10/2003	Fluorescein	0.45	568,307 m east; 4,298,434 m north	South Fork Turkey Creek
4/10/2003	Eosin	2.30	568,332 m east; 4,300,763 m north	North Fork Turkey Creek

very high concentrations detected in charcoal samplers and raw water samples at Station #4. There was no flow in the Log Providence stream channel at the time of injection. Furthermore, no fluorescein was detected in charcoal samplers placed downstream from this injection point (Stations #7 and #10), despite a runoff event following 15 mm of rainfall on March 1 and 2, 2002 that occurred after dye injection but before charcoal sampler collection. Thus, all the dye flowed through solution conduits to the cave stream and then traversed nearly the entire length of the cave stream to reach Station #4. The other Turkey-Creek tributary, designated as the Equine-Center tributary (Table 1), showed low-level fluorescein detections at Station #4 following injection into this tributary under high-flow conditions (Table 2). In the 14 days preceding injection, 209 mm of rainfall was recorded. Despite the high-flow conditions and small injection mass (0.23 kg), a 1.6-fold increase in the raw water fluorescein concentration was measured at Station #4. Dye injection at four separate locations in the main Turkey Creek channel failed to establish a hydrologic connection with HC (Tables 1 and 2). Additional injections outside the Bass- and Turkey-Creek watersheds were not conducted. The established hydrologic connections to Bass-Creek and the Turkey-Creek tributaries accounted for the observed discharge at the HC resurgence. In addition, adjacent areas to the west of the Bass-Creek watershed likely drain to the Spring-Cave recharge area, but additional dye-tracing studies are needed to more accurately determine the extent of this recharge area. Creeks to the east and south of Bass and Turkey Creeks (within the Cedar-Creek watershed) are not losing streams, and they drain to the south and east towards Cedar Creek and away from the HC recharge area.

These results established that only the small area drained by the two Turkey-Creek tributaries (2.2 km²) was connected to HC. With the additional drainage area from these two tribu-

Table 2. Sampler locations and detection of injected dyes.

Station Number, Site Description, and Sampler Location (UTM Coordinates; Zone 15; NAD83 Datum)	Dye Injection – 2/25/2002 Fluorescent Dye Detected[a]			Dye Injection – 5/20/2002 Fluorescent Dye Detected			Dye Injection – 4/9 and 4/10/2003 Fluorescent Dye Detected		
	Fluorescein	Rhodamine WT	Eosin	Fluorescein	Rhodamine WT	Eosin	Fluorescein	Rhodamine WT	Eosin
#1, Devils Icebox Resurgence 558,414 m east; 4,302,688 m north	ND	ND	ND	ND	ND	ND	NS	NS	NS
#2, Bonne Femme Creek, upstream from confluence with Turkey Creek 560,595 m east; 4,298,915 m north	ND	ND	ND	ND	ND	ND	NS	NS	NS
#3, Angel Spring in Hunters Cave 562,285 m east; 4,298,393 m north	ND	w, ++++	ND	ND	ND	w, ++	NS	NS	NS
#4, Upstream from Angel Spring in Hunters Cave 562,296 m east; 4,298,404 m north	w, ++++	++	ND	w, +	ND	+	+	ND	ND
#5, Bass Creek upstream from Hunters Cave resurgence 562,188 m east; 4,298,208 m north	ND	+	ND	ND	ND	++	NS	NS	NS
#6, Bass Creek upstream from Station 5 562,454 m east; 4,298,386 m north	ND	ND	ND	ND	ND	++	ND	ND	ND
#7, Turkey Creek upstream from confluence with Bass Creek 561,610 m east; 4,298,678 m north	ND	ND	w, ++	+	w, +++	ND	NS	NS	NS
#8, Turkey Creek upstream from Station 7 562,517 m east; 4,299,533 m north	ND	ND	ND	++	+++	ND	NS	NS	NS
#9, Spring Cave resurgence 560,878 m east; 4,298,346 m north	ND	ND	ND	ND	ND	ND	NS	NS	NS
#10, Log Providence tributary to Turkey Creek 562,634 m east; 4,299,411 m north	ND	ND	ND	NS	NS	NS	NS	NS	NS
#11, Turkey Creek upstream from Station 8 563,002 m east; 4,300,024 m north	NS	NS	NS	++	ND	ND	+	w, +++	ND
#12, Turkey Creek upstream from Station 11 565,073 m east; 4,300,820 m north	NS	NS	NS	NS	NS	NS	+	ND	+
#13, Bass Lake tributary to Turkey Creek 565,258 m east; 4,300,011 m north	NS	NS	NS	NS	NS	NS	ND	w, ++++	ND

[a] w = detected in raw water; maximum concentration detected in eluant from an activated carbon sampler: + < 10 $\mu g\ L^{-1}$; ++ = >10 and <100 $\mu g\ L^{-1}$; +++ = >100 and <1000 $\mu g\ L^{-1}$; and ++++ = >1000 $\mu g\ L^{-1}$. ND = not detected; NS = not sampled.

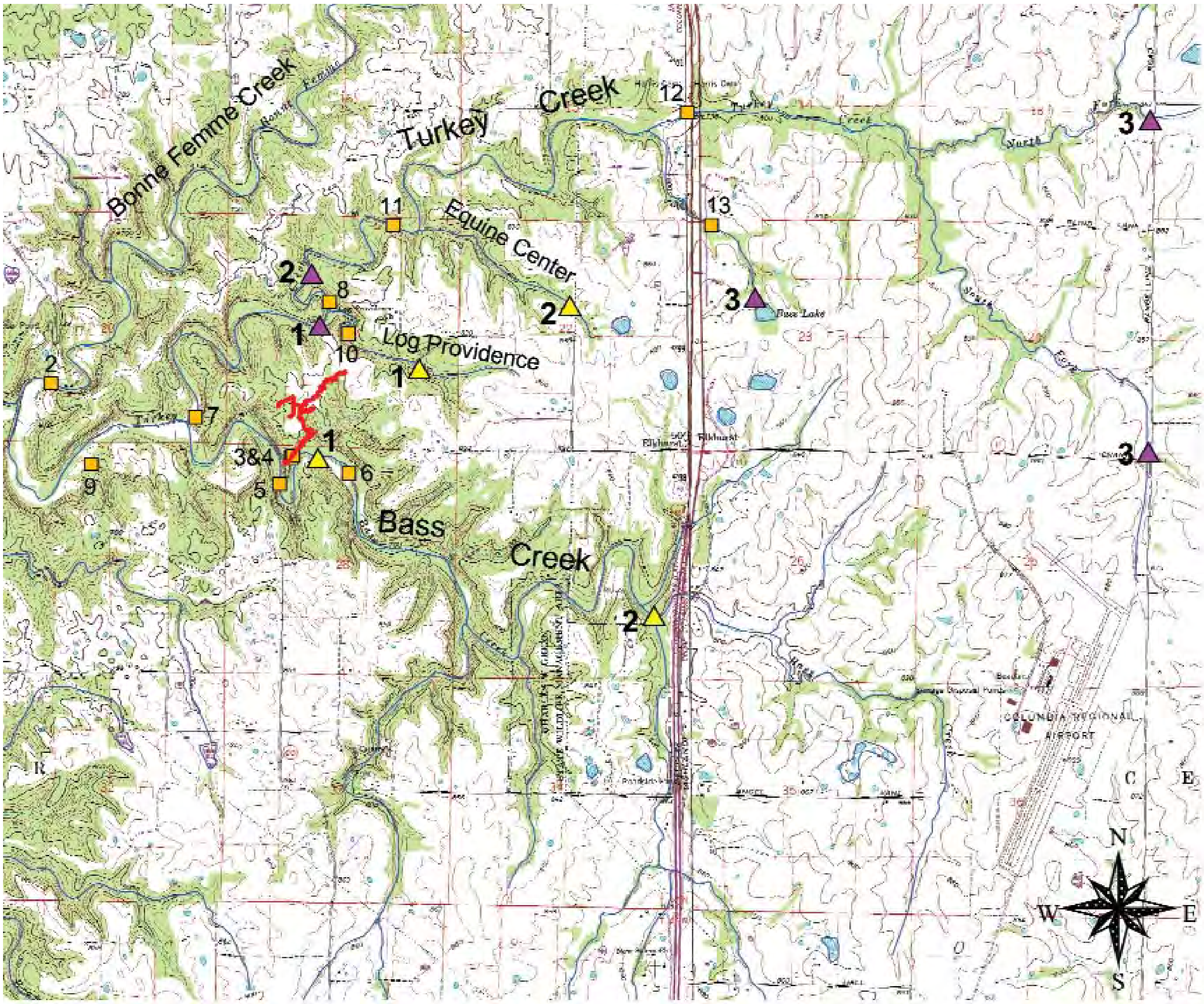


Figure 3. Dye-tracing studies used to delineate the Hunters Cave recharge area. Hydrologic connections were based on dye detection within the cave at charcoal sampler stations 3 and 4 (see Table 2). Large numbers adjacent to triangles represent the round of dye injections and correspond to dates listed in Table 1; 1 = February 25, 2002; 2 = May 20, 2002; and 3 = April 9–10, 2003. Small numbers adjacent to squares represent charcoal sampler stations corresponding to Table 2 (note: station 1 was not located within the view of this figure).

taries, the total recharge area was determined to be 33.3 km² (Fig. 4). The hydrologic connection of the Turkey-Creek tributaries to HC coincides with a fault documented by St. Ivany (1988). The fault intersects perpendicular to the tributaries, upstream from their confluence with the Turkey-Creek stream channel, running along a line from northeast to southwest towards the upper reaches of the cave near the Log-Providence tributary (Fig. 4). This fault is probably responsible for the occurrence of solution conduits connecting these tributaries to the cave stream. The hydrologic connection of the Turkey-Creek tributaries also established that inter-basin transfer occurs between Turkey and Bass Creeks via HC. The importance of these tributaries to the aquatic cave stream ecology is significant because Bass Creek only influences the lower 60–100 m of the stream reach. Thus, these two tributaries are the primary sources of water for the vast majority of the HC stream reach, and the water quality derived from this small area directly impacts stygobites and their habitat. Collectively, the HC and DI recharge areas account for 28% of the area within the Bonne Femme watershed.

Land-use/land-cover data were determined using ArcView GIS (version 3.3) and 1991-93 LANDSAT data with 30 m resolution (Fig. 5). The LANDSAT data were classified by the Missouri Resource Assessment Partnership (Missouri Spatial Data Information Service, 2005). These land-use data are a major improvement over past data in resolution and in the dis-

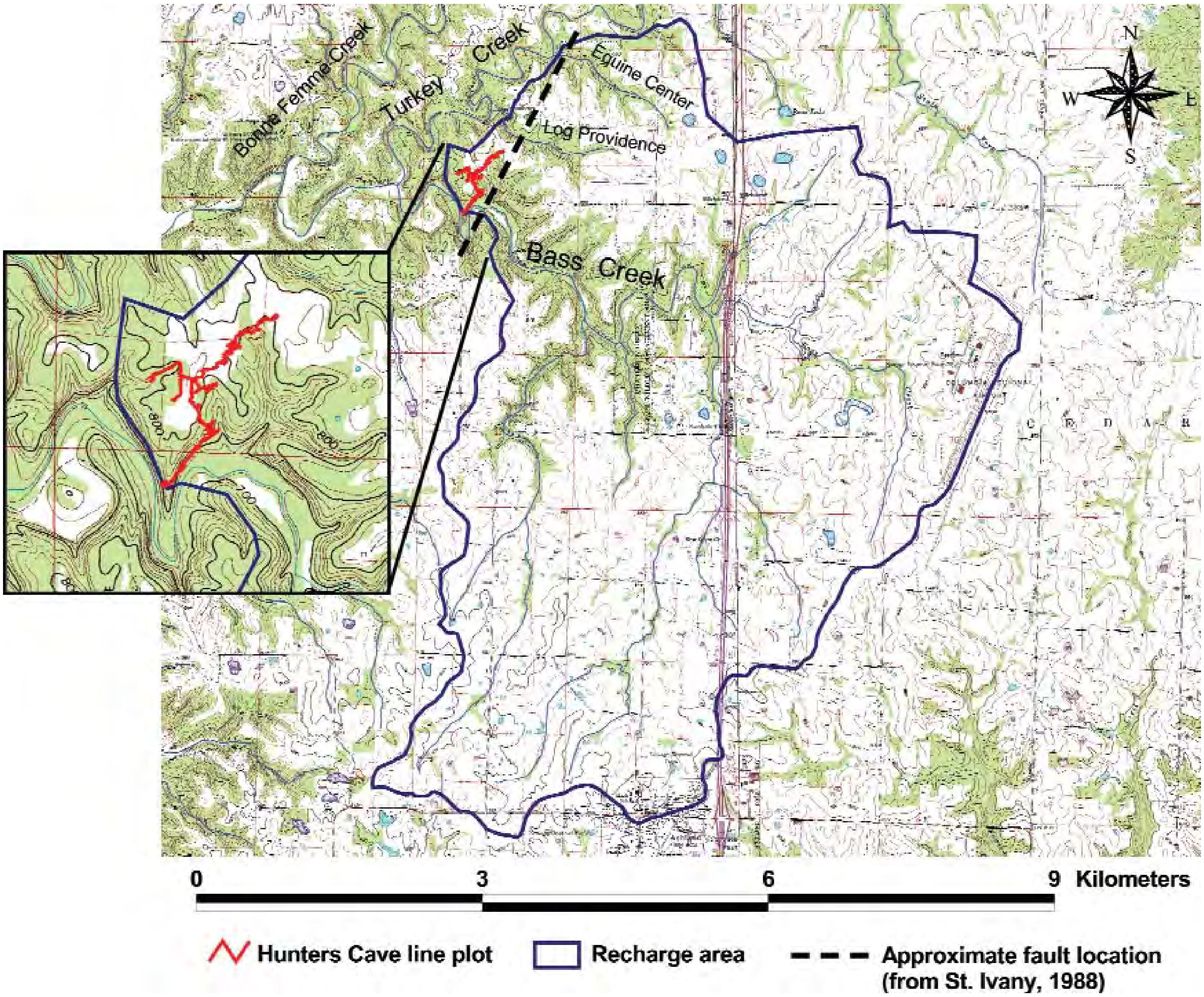


Figure 4. Hunters Cave recharge area delineation. Inset shows the meander cut-off created by the flow path from Bass Creek to the cave stream via Angel Spring. The location of the fault (based on St. Ivany, 1988) creating a likely conduit from the Turkey-Creek tributaries to the upper cave stream is also shown.

tinction between different land-use categories. Most notable is the division between row crop and grassland areas. Because of their close proximity and similarities in geology and soils, both recharge areas had very similar land use/land cover (Fig. 5). About 80% of both recharge areas was comprised of grasslands or row crops. However, the HC recharge area has a higher proportion of grasslands and a lower proportion of row crops than DI. In addition, row crop areas within the DI recharge area were concentrated within the upper Bonne Femme watershed (Figs. 1 and 5). In both recharge areas, row crops were predominantly corn and soybeans, and approximately 40% of the grasslands were range land, with cattle and horses the predominant livestock. The remainder of the grasslands represents forage production for hay. Forested areas lie mostly within public lands (Rock Bridge Memorial State Park and the Three Creeks Conservation Area) and along stream corridors, and these areas were mainly oak-hickory forests typical of the Ozarks region. In addition, the HC recharge area has a small amount of urban impervious area. Urban areas are comprised of commercial and residential development in Ashland, Missouri, and the Columbia Regional Airport in the eastern portion of the recharge area. The DI recharge area currently has no significant amounts of either urban impervious or urban vegetation land cover.

Stream Discharge

On an annual basis, the area normalized discharge from the DI cave-stream resurgence was consistently greater than the

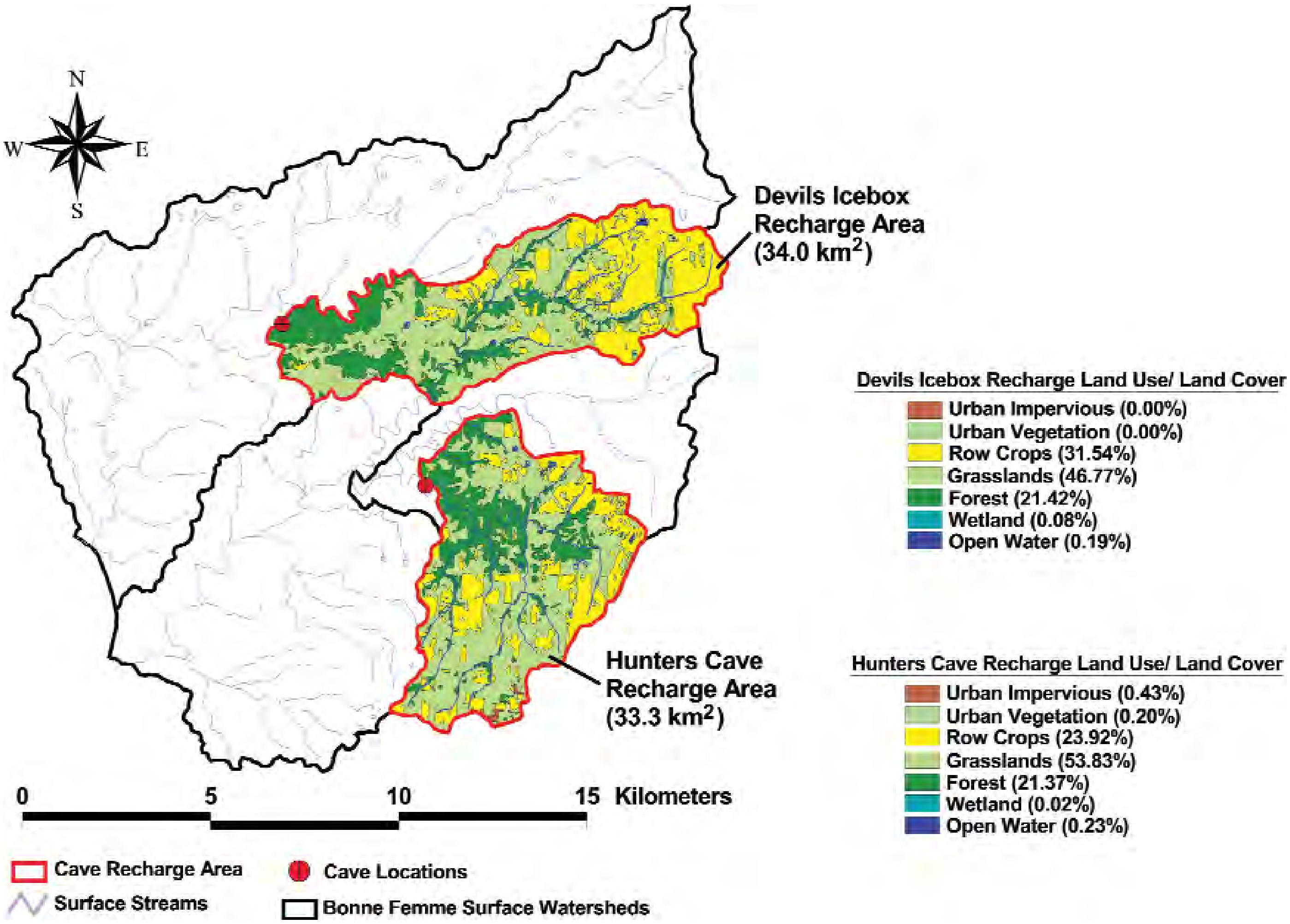


Figure 5. Land use/land cover for Devils Icebox and Hunters Cave recharge areas.

HC resurgence during the three years of monitoring (Table 3). Despite similarities in the amount of precipitation received, DI had an average of 59% more annual discharge than HC. The disparity between sites was greatest in Year 1 when annual discharge at DI was 2.2 times greater than that of HC. Annual discharge was most similar in Year 3. Average annual precipitation over the three years of monitoring was below the 30-year running average of 1,024 mm in both recharge areas (Table 3). Year 1 was among the driest 12-month periods on record for this area, with 30–31% below normal precipitation.

Relative discharge was 5.2 to 6.9% of the annual precipitation at DI and 2.8 to 4.6% of the annual precipitation at HC (Table 3). Comparison of these relative discharges to a nearby non-karst watershed, Goodwater Creek, showed that about 33% of annual precipitation could be accounted for as stream discharge in this surface watershed. Thus, relative discharge from the karst-recharge areas accounted for only about one-tenth to one-fifth that of the nearby non-karst surface watershed. Since Goodwater Creek is a lower gradient stream than upper Bonne Femme or Bass Creeks, its relative discharge likely represents a lower limit of the relative discharge for the two losing streams. Hence, the volume of allogenic recharge to the karst aquifers was much more constrained than it was for their corresponding losing streams. The volume of the sub-surface conduits imposes a physical constraint on the discharge conveyed to the cave streams. As stage height increases during a runoff event, there is a decreasing proportion of the surface water conveyed to the subsurface conduits, causing the increased discharge to remain in the surface channel.

DI had greater monthly discharge than HC in 24 of the 36 months monitored (Fig. 6). At HC, average monthly discharge over the three years was 2,930 $m^3\ km^{-2}$, with a range of 11 to 6,890 $m^3\ km^{-2}$. At DI, the average monthly discharge was 4,650 $m^3\ km^{-2}$, with a range of 599 to 16,100 $m^3\ km^{-2}$ (Fig. 6). In general, monthly discharge at both sites followed seasonal rainfall and ground-water recharge patterns for the region. However, these trends were often punctuated by weather extremes that caused widely varying discharge conditions. In Year 1, an extended dry period from July-November 1999 resulted in extremely low discharge at both sites, but especial-

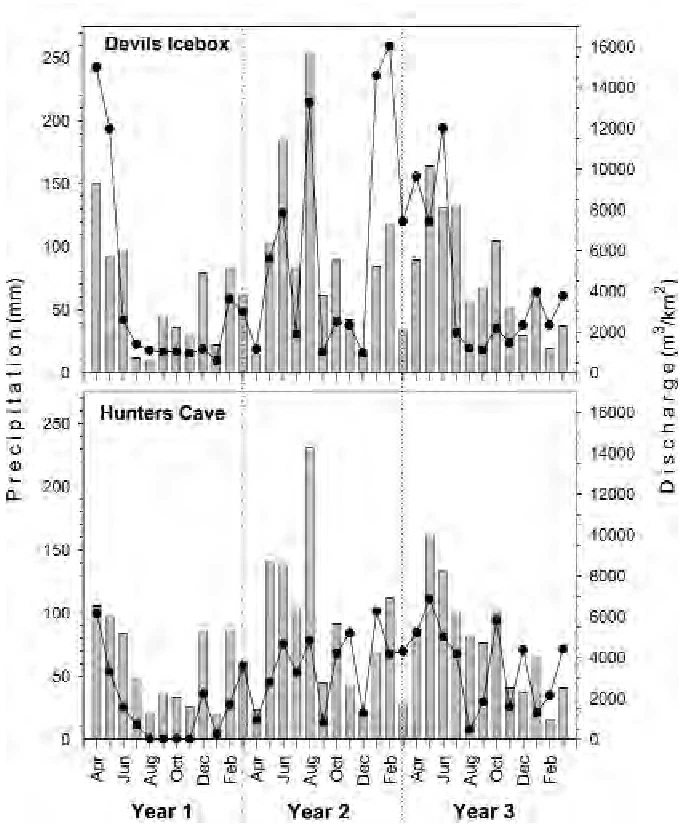


Figure 6. Monthly precipitation (bar graphs) within both recharge areas and monthly discharge (line graphs) for each cave stream at their resurgences.

ly at HC where discharge was <30 m³ km⁻² month⁻¹ from August to November 1999 (Fig. 6). During this dry period, discharge at DI was consistently about 1,000 m³ km⁻² month⁻¹. In Year 2, greater than normal precipitation from June through August 2000 resulted in much higher discharge than observed for this same time period in Year 1. Monthly discharge and precipitation were significantly correlated ($p < 0.01$) for both recharge areas, based on regression analysis for all 36 months (coefficients of determination, r^2, were 0.32 for HC and 0.41 for DI). However, regression analyses within a given year showed that only in Year 1 did precipitation explain more than 50% of the variability in monthly discharge at either site. Thus, factors such as rainfall intensity, duration, antecedent soil moisture, air temperature, and evapotranspiration were also important factors determining the monthly discharge in both systems.

Comparisons between sites for high- and low-precipitation months revealed general trends about the two recharge areas. There were 10 high precipitation months (>100 mm) within the HC recharge area and nine within the DI recharge area (Fig. 6). Monthly average discharge for these high precipitation months was 4,770 m^3 km^{-2} for HC and 9,030 m^3 km^{-2} for DI. HC had greater discharge in only one of these months (October 2001). Relative discharge, as a percent of precipitation, for the high precipitation months was essentially the same as the mean annual relative discharge reported for both recharge areas in Table 3. Because the high precipitation months account for one-third to one-half of the annual discharge, they were representative of the overall trend in which the DI recharge area had greater relative and absolute discharge compared to the HC recharge area. Low precipitation months in summer and fall, particularly July–November 1999, showed that discharge from the HC recharge area could reach very low levels, and even approach zero flow (Fig. 6). The combination of low precipitation, high air temperatures, and high evapotranspiration rates apparently was sufficient to almost completely halt ground-water recharge at the HC resurgence in 1999. In contrast, discharge at the DI resurgence during the same period remained very consistent and much high-

Table 3. Area normalized annual stream discharge and precipitation.

Cave	Year 1[a]	Year 2	Year 3	Mean
Devils Icebox				
Discharge (m^3 km^{-2})	43,500	74,700	49,400	55,900
Relative Discharge (%)[b]	6.1	6.9	5.2	6.1
Precipitation (mm)	719	1085	954	919
Relative Precipitation (%)[c]	–30	6.0	–6.8	–10
Hunters Cave				
Discharge (m^3 km^{-2})	19,600	42,800	43,300	35,200
Relative Discharge (%)	2.8	4.1	4.6	3.8
Precipitation (mm)	702	1047	943	897
Relative Precipitation (%)	–31	2.2	–7.9	–12

[a] Year 1 = April 1999 to March 2000; Year 2 = April 2000 to March 2001; Year 3 = April 2001 to March 2002.

[b] Annual discharge as a percentage of precipitation.

[c] Percent deviation from 30-year running average annual precipitation of 1,024 mm (based on National Weather Service data from the Columbia Regional Airport).

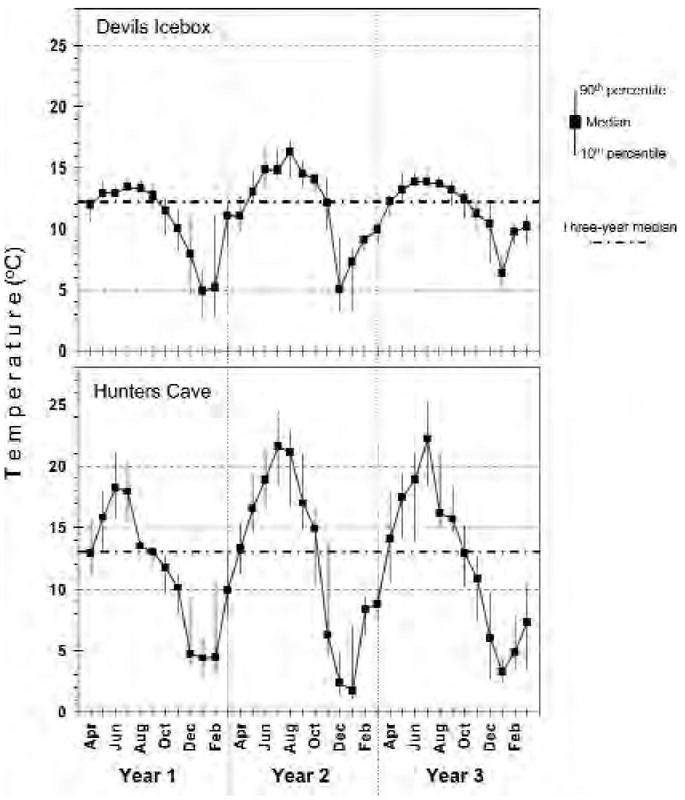


Figure 7. Monthly water temperature at the resurgences to Devils Icebox and Hunters Cave.

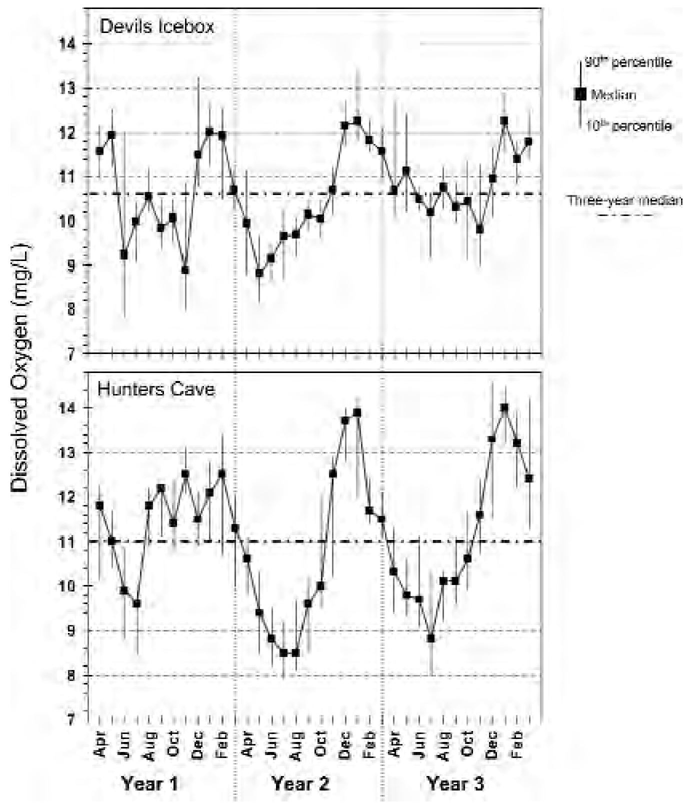


Figure 8. Monthly dissolved oxygen at the resurgences to Devils Icebox and Hunters Cave.

er than at HC. In the six months with precipitation <25 mm, average monthly discharge was 781 m^3 km^{-2} at HC and 1,260 m^3 km^{-2} at DI. For these same months, total precipitation within the DI recharge area was 33 mm lower than in the HC recharge area.

Monthly and annual summaries of instantaneous stream discharge reflected the strong influence of seasonal precipitation patterns (Table 4) over the three years of the study. For instance, in Year 1 low precipitation resulted in the overall lowest discharges at both sites. Increased precipitation in Years 2 and 3 substantially increased discharges at both sites, but the increase was much greater at HC. In Years 2 and 3, median discharge at HC increased by about eight-fold compared to Year 1 whereas median discharge at DI in Years 2 and 3 increased by only 20–30% over Year 1. Comparison of discharge data between recharge areas, summarized over all years, showed that HC had 18% higher median discharge, 13% higher 90th percentile discharge, but 96% lower 10th percentile discharge compared to DI. On a monthly basis, all discharge statistics were highest from February through June at both stream resurgences, reflecting the generally high precipitation during these months (Fig. 6). In addition, the seasonally high rates of ground-water recharge that occur during February and March resulted in high discharge for these months, even when precipitation was low.

Chemical and Physical Characterization of the Cave Streams

The chemical and physical parameters monitored were mainly affected by the magnitude of discharge and seasonal differences in climate (Figs. 7–11). Changes in median monthly temperature (Fig. 7), for instance, were strongly related to seasonal changes in air temperature. The long-term median temperature recorded at DI for this study was only 0.7º C lower than that documented over a two-year monitoring period from 1982-84 by Wicks (1997). The minimum and maximum monthly median temperatures were, however, more extreme than values reported by Wicks (1997). Although the seasonal pattern and three-year median values were similar between systems, HC showed much greater variation in water temperature than DI.

Because of the significant inverse relationship between temperature and dissolved oxygen (DO) (Table 5), the seasonal changes in DO responded oppositely to that of water temperature (Fig. 8). Because of the greater variation in water temperature at HC, a similarly greater variation about the three-year median DO level was observed, with generally higher DO in winter and lower DO in summer compared to Devils Icebox (spelled out in this section to avoid confusing syntax). However, the three-year median DO levels were very similar between the two sites. In general, DO levels were always near

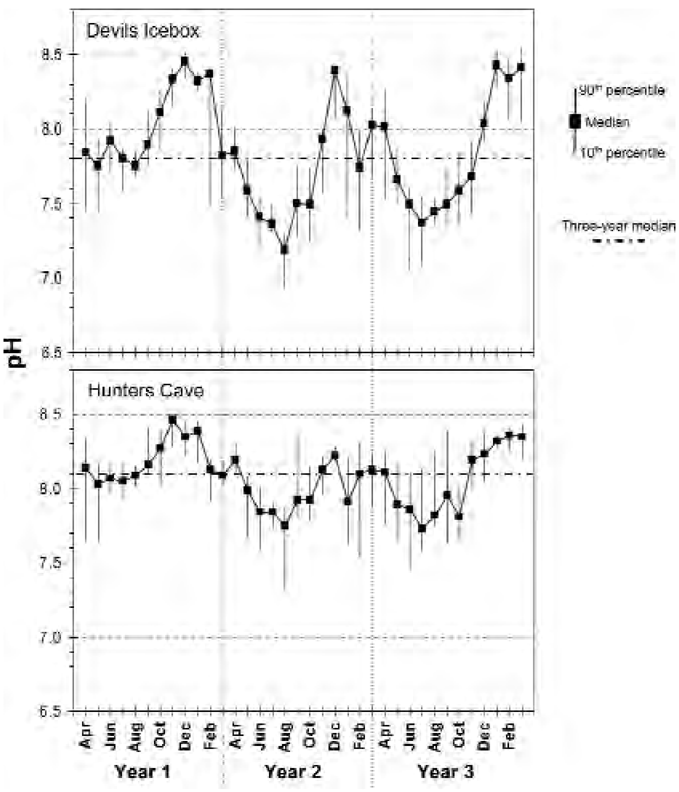


Figure 9. Monthly pH at the resurgences to Devils Icebox and Hunters Cave.

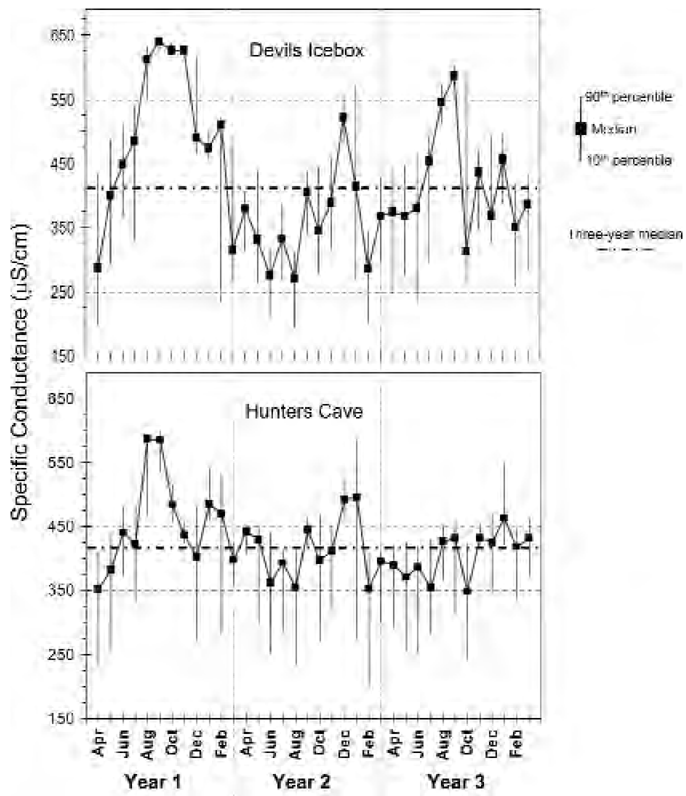


Figure 10. Monthly specific conductance at the resurgences to Devils Icebox and Hunters Cave.

Table 4. Summary of instantaneous stream discharge by month and year.

	Devils Icebox			Hunters Cave		
Month or Year	Median (m^3h^{-1})	90th Percentile (m^3h^{-1})	10th Percentile (m^3h^{-1})	Median (m^3h^{-1})	90th Percentile (m^3h^{-1})	10th Percentile (m^3h^{-1})
January[a]	53	230	24	40	420	11
February	93	570	27	100	210	22
March	140	450	50	180	250	89
April	160	760	43	180	320	29
May	150	790	50	120	480	29
June	110	590	63	120	440	16
July	60	110	41	46	460	6.2
August	53	110	40	15	180	0.59
September	48	55	20	18	70	0.28
October	59	150	42	43	560	0.80
November	59	110	42	27	410	0.41
December	49	120	30	60	450	12
Year 1	54	280	28	13	220	0.41
Year 2	64	430	32	100	450	26
Year 3	72	290	53	110	450	15
All Years	63	320	35	74	360	1.3

[a] Monthly data are summarized across all three years.

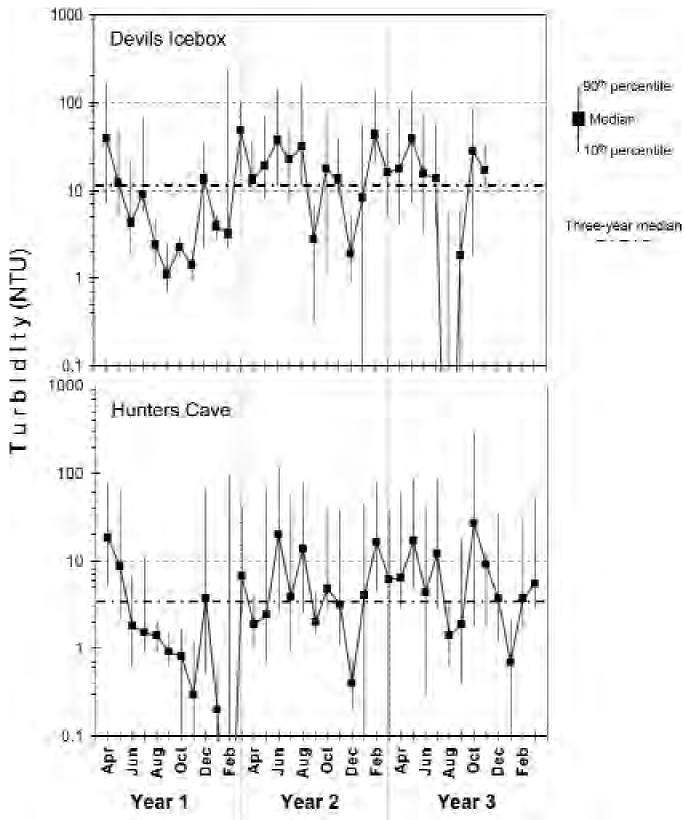


Figure 11. Monthly turbidity at the resurgences to Devils Icebox and Hunters Cave.

or slightly above saturation at both sites. At Devils Icebox, the variation in DO was not as closely related to temperature as HC (Table 5). In Years 1 and 3, Devils Icebox showed changes in median DO levels during the summer and fall months that did not vary inversely with median monthly temperature (Figs. 7 and 8). Typically, increases in DO occurred over the summer months, from July through September, despite increased water temperature. Apparently, the increased DO was associated with photosynthetic activity of algae at the resurgence. The monitoring station at Devils Icebox lies within a karst window, and diurnal fluctuations in DO were observed during these months. Thus, the location of the monitoring station at Devils Icebox resulted in greater variation in the relationship between DO and temperature than at HC, where the monitoring station was underground.

Monthly pH was more closely correlated to water temperature than discharge (Table 5). In general, the winter months had the highest pH, and the summer months had the lowest pH at both sites (Fig. 9). The three-year median pH was slightly lower at DI than at HC. The strong influence of temperature on pH most likely occurred due to the effect that water temperature has on the respiration of aquatic organisms within the surface and subsurface reaches of the recharge areas. The respiration rate of aerobic organisms will be higher when the water temperature is warmer, and this leads to greater evolution of CO_2 and subsequent formation of H_2CO_3, leading to the lower median pH values observed from spring through fall. The poor correlation between pH and discharge was not expected. At shorter time-scales, pH consistently showed an inverse relationship to discharge, and this relationship was especially obvious during runoff events. At the monthly time-scale, the influence of discharge was still apparent, and there was a statistically significant correlation between discharge and pH at HC (Table 5). For instance, one of the lowest monthly median pH values at both sites was observed during August 2000 when monthly discharge was quite high. In addition, the lower three-year median pH at DI most likely reflected the influence of larger and longer duration runoff events, which convey more acidic water, on the long-term pH in this system.

Specific conductance (SpC) was inversely related to discharge and turbidity at both sites (Table 5). Therefore, SpC was greatest during low flow months and lowest during high flow months (Fig. 10). The extended dry period from July-November 1999 resulted in the highest SpC at both sites. The three-year median SpC was nearly identical between sites, but variation about the three-year median was much greater at DI (Fig. 10). The inverse relationship between discharge and SpC has been documented at DI and in other allogenic recharge karst aquifers, but these studies either considered much shorter time scales or less intensive monitoring than reported here (Hess and White, 1988; Ryan and Meiman, 1996; Wicks, 1997). The strong inverse relationship between SpC and turbidity reflected their covariance with respect to discharge. It also reflected that low SpC water from a runoff event more strongly coincided with high turbidity water than high discharge.

Turbidity was directly related to stream discharge and inversely related to SpC at both sites and inversely related to pH at HC (Table 5). Monthly median turbidity at both sites generally varied directly with monthly discharge (Figs. 6 and 11), resulting in high turbidity for the spring and summer months. However, months with one or two very large events, such as March 2000 and February 2001, also resulted in high median turbidity despite modest monthly discharges. The three-year median turbidity at DI was 3.4 times higher than HC (Fig. 11). Median turbidity exceeded 10 NTU for 7 months at HC and for 19 months at DI. Furthermore, DI had 8 months in which median turbidity exceeded 20 NTU compared to only one month at HC (October 2001). Overall, turbidity was greater at DI compared to HC for 30 of the 32 months in which both sites were monitored. Although maximum turbidity levels during runoff events, as reflected by the 90^{th} percentile levels (Fig. 11), were similar between sites, HC consistently returned to very low turbidity levels more quickly following runoff events. As previously noted, DI had greater peak discharge and longer duration runoff events than HC, and this, in part, contributed to its higher turbidity. Another factor that likely contributed to the greater turbidity at DI was the higher relative and absolute amount of row crop acreage within its recharge area (Fig. 5). The rather low correlation of monthly median

Table 5. Correlation coefficients (*r*) between discharge and chemical and physical parameters[a].

	Discharge	Temperature	Dissolved Oxygen	pH	Specific Conductance
			Devils Icebox		
Temperature	0.08	—	—	—	—
Dissolved Oxygen	0.28	–0.70[b]	—	—	—
pH	–0.20	–0.85[b]	0.55[b]	—	—
Specific Conductance	–0.56[b]	–0.23	–0.05	0.34	—
Turbidity	0.54[c]	0.23	0.02	–0.36	–0.82[b]
			Hunters Cave		
Temperature	0.10	—	—	—	—
Dissolved Oxygen	–0.15	–0.93[b]	—	—	—
pH	–0.44[c]	–0.72[b]	0.72[b]	—	—
Specific Conductance	–0.66[b]	–0.37	0.48[c]	0.40	—
Turbidity	0.69[b]	0.29	0.31	-0.46[c]	–0.69[b]

[a] Correlation coefficients determined by correlation analysis of monthly median values for all parameters ($n = 36$, except turbidity for the Devils Icebox, $n = 32$).
[b] $p \leq 0.001$ level of significance.
[c] $p \leq 0.01$ level of significance.

turbidity to monthly discharge (Table 5) was related to the observed dynamics between turbidity and discharge during runoff events. Inspection of hydrographs along with the turbidity data showed that their poor correlation resulted from very short-term fluctuations in turbidity during the rising and peak portions of the hydrograph, and the rate at which the two parameters approached pre-event levels during the receding portion of the hydrograph.

RECHARGE AREA CHARACTERISTICS

Despite similarities in geology, size of the recharge areas, land use/land cover, and climate, there were often major differences in annual, monthly, and instantaneous discharge between DI and HC. Two important characteristics distinguish these recharge areas and explain the observed differences: 1) size of the losing stream drainage areas; and 2) size and spatial extent of the sub-surface conduit systems.

Within the HC recharge area, the Bass Creek watershed encompasses 31.1 km^2, which represents 93% of the HC recharge area. Within the DI recharge area, the upper Bonne Femme Creek watershed represents only 74% of the recharge area, encompassing 25.3 km^2. Thus, on a relative basis, Bass Creek supplies a greater amount of water to the HC resurgence than does upper Bonne Femme to the DI resurgence. At the annual time scale, this difference explains the large change between Year 1 discharge and that of Years 2 and 3 for HC. On a monthly time scale, the strong influence of Bass Creek on HC discharge can be seen by the much greater seasonal changes in discharge and the wider range in 10^{th} to 90^{th} percentile discharge for most months as compared to DI. For instance, the relative increase in discharge between summer and fall months was much greater at HC compared to DI (Table 4). This reflected the proportionately greater influence that seasonal increases in ground-water recharge had at HC due to the larger drainage area of Bass Creek and its dominating influence on discharge at the HC resurgence. The ratio of 90^{th} to 10^{th} percentile flows was also much greater for HC in every month except February, March, and April. This ratio has been shown to be a measure of runoff propensity in larger surface basins (Blanchard and Lerch, 2000). Indeed, HC had more runoff events than DI in every year, with an average of four more runoff events per year. Therefore, because of the greater drainage area of Bass Creek, the HC recharge area was, overall, more runoff prone than DI.

The other key feature explaining the differences in discharge between the two recharge areas was the size and extent of their subsurface-conduit systems. The DI recharge area has a more extensively developed subsurface-conduit system than the HC recharge area based on the following: 1) consistently higher relative discharge at DI on an annual basis (Table 3); 2) greater 90^{th} percentile discharges at DI from February through June (Table 4), reflecting the much greater discharge during major runoff events; 3) greater 10^{th} percentile discharges at DI, especially during low precipitation months (Table 4), indicating greater water storing capacity in the DI recharge area; 4) the DI recharge area encompasses the autogenic 8.7-km^2 Pierpont sinkhole plain, indicating the existence of more numerous conduits and greater spatial extent of the conduit system; and 5) the DI cave system is considerably larger, in length and volume, than the HC system, and it has more numerous tributaries with higher discharge.

The greater relative discharge at DI on an annual basis suggests that a larger and more extensive conduit system exists that is capable of capturing and conveying a greater proportion of precipitation to the cave stream. The higher relative and absolute discharge at DI also resulted in its greater 90th percentile and peak instantaneous discharges during most runoff events. For the nine months in which >100 mm of precipitation occurred in both recharge areas, DI had greater peak discharge for every runoff event in these months. At the other end of the discharge spectrum, DI had greater 10th percentile discharges in 11 of 12 months, and the differences in 10th percentile discharges between DI and HC were most pronounced during low precipitation months in summer and fall (Table 4). The most notable differences in discharge, as mentioned above, were during the July-November drought of 1999 when DI maintained consistently higher discharge than HC despite receiving lower precipitation (Fig. 6). This data showed that the DI recharge area must store more water between rainfall events. Apparently, a portion of the water stored within the DI recharge area can have residence times of weeks to months. Given that discharge ceases in upper Bonne Femme Creek during periods of low precipitation, the greater storage of the DI recharge area was, therefore, associated with the autogenic portion of the recharge area. The high SpC observed during prolonged dry periods (Fig. 10) indicated that water storage occurred within the bedrock matrix or within the epikarst of the autogenic portion of the recharge area. Storage within the bedrock matrix and within epikarst would result in water with the observed high SpC, and differentiation between bedrock matrix storage and epikarst storage is not possible based on values of SpC. A consideration that would undermine this explanation was the possibility of significant anthropogenic inputs, such as irrigation, industrial, or wastewater discharges, to the DI recharge area that only became evident under very dry conditions. However, there are no significant agricultural or industrial inputs, and the quality of the water did not indicate significant inputs of domestic wastewater under these conditions.

The drainage characteristics of the two recharge areas represent another important distinction between these two systems. Unlike the DI recharge area, the HC recharge area has only a few sinkholes (<10 based on topographic map inspection) and minimal internal drainage. Within the HC recharge area, ground-water recharge occurs by allogenic recharge through two main subsurface-conduits: the fault conduit connecting the Turkey-Creek tributaries to the uppermost part of the cave stream; and the conduit connecting Bass Creek to Angel Spring (Figs. 3 and 4). The Bass Creek to Angel-Spring conduit accounted for the overwhelming majority of discharge at the resurgence, especially under runoff conditions. The length of this flow path may be as short as 100 m. The much greater water-temperature fluctuations at HC also provided support for the existence of short flow paths within the HC recharge area (Fig. 7). Overall, the HC recharge area lacks significant autogenic recharge, has only two main surface drained conduits, and the primary conduit to the cave stream extends over a very short distance. Hence, this recharge area is characterized by much more limited subsurface-conduit development than DI, leading to attenuated discharge under runoff conditions and lower discharge during dry periods.

Summary and conclusions

Dye-tracing studies were successfully applied to the delineation of the HC recharge area and for improving the accuracy of the delineated recharge area for DI. These studies facilitated determination of existing land uses and land cover for both recharge areas. The recharge areas were shown to be of similar size, have similar land uses, formed in the same geologic strata, and formed primarily by allogenic and discrete recharge. However, intensive hydrologic and water-quality monitoring revealed distinct differences in the characteristics of these recharge areas. For instance, DI was shown to have greater absolute and relative annual discharge, much greater peak discharge during runoff events, and greater water-storing capacity than the HC recharge area. HC had more frequent runoff events, greater median instantaneous discharge, and more pronounced seasonal changes in discharge, water temperature, and dissolved oxygen than DI. Discharge at the HC resurgence was predominantly allogenic, and the areal extent and size of subsurface-conduits are apparently very limited in this recharge area. In contrast, discharge at the DI resurgence represents both allogenic and autogenic (discrete) recharge, and its recharge area is characterized by a subsurface-conduit system that is both greater in volume and areal extent than HC. Currently, land use within both recharge areas is mainly row-crops, grasslands, and forests. As land use changes from rural to urban in these watersheds, the cave streams will be vulnerable to the hydrologic impact caused by increases in impervious land surface, as well as to water-quality contaminants associated with urban land use *(e.g.*, turf chemicals and oil). As a result of this and other studies, the Boone County (MO) Commission was awarded an EPA 319 Nonpoint Source Pollution Control grant to guide future development in the Bonne Femme watershed. Project objectives include: creation of a watershed land-use plan; recommendation of policies and procedures to local governments for the review and approval of new developments that will provide special protection for the watershed; and implementation of BMPs through allocation of cost-share funds. With documentation of the existing land uses and hydrologic conditions, the impact of urban growth and the effectiveness of new policies and implemented BMPs can be assessed.

ACKOWLEDGMENTS

Thanks to the Missouri Department of Conservation and Dr. William R. Elliott for permission to access Hunters Cave, to install a temporary monitoring station, and for restricting public access during the study. Thanks to the Missouri Department of Natural Resources for permission to access Devils Icebox. Special thanks to Nick Genovese for operation and maintenance of the field equipment.

Disclaimer — Mention of specific companies, products, or trade names is made only to provide information to the reader and does not constitute endorsement by the USDA-Agricultural Research Service.

REFERENCES

Aley, T., 1999, Groundwater Tracing Handbook: Ozark Underground Laboratory: Protem, MO, 35 p.

Betson, R.P., 1977, The hydrology of karst urban areas: Proceedings of the Hydrologic Problems in Karst Regions Symposium: Western Kentucky University, Bowling Green, KY. p. 162–175.

Blanchard, P.E., and Lerch, R.N., 2000, Watershed vulnerability to losses of agricultural chemicals: Interactions of chemistry, hydrology, and land-use. Environ. Sci. Technol., v. 34, p. 3315–3322.

Booth, D.B., Hartley, D., and Jackson, R., 2002, Forest cover, impervious-surface area, and the mitigation of stormwater impacts: J. Am. Water Resour. Assoc., v. 38, p. 835–845.

Boyer, D.G., and Pasquarell, G.C., 1999, Agricultural land use impacts on bacterial water quality in a karst groundwater aquifer: J. Am. Water Resour. Assoc., v. 35, p. 291–300.

Burges, S.J., Wigmosta, M.S., and Meena, J.M., 1998, Hydrological effects of land-use change in a zero-order catchment: ASCE J. Hydrol. Engineer, v. 3, p. 86–97.

Crunkilton, R.L., and Whitley, J.R., 1983, Dye trace–Bonne Femme Creek, Boone County. Memorandum, Missouri Department of Natural Resources, 5 p.

Deike, G., Hopson, H., Sturmfels, G., Deike, R., Barnholtz, S., and Lang, K. 1960, Devils Icebox, Boone County, Missouri, 1 sheet, 1:2740 scale. Chouteau Grotto, National Speleological Society, Inc.: Huntsville, AL.

Groves, C.G., 1992, Geochemical and kinetic evolution of a karst flow system: Laurel Creek, West Virginia. Ground Water, v. 30, p.186–191.

Gulden, B. 21 March 2005, NSS GEO^2 Committee on Long and Deep Caves, http://www.pipeline.com/ %7Ecaverbob/state.htm.

Halihan, T., Wicks, C. M., and Engeln, J. F., 1998, Physical response of a karst basin to flood pulses: Example of the Devil's Icebox cave system (Missouri, USA): J. Hydrol., v. 204, p. 24–36.

Hess, J. W., and White, W. B., 1988, Storm response of the karstic carbonate aquifer of southcentral Kentucky: J. Hydrol., v. 99, p. 235–252.

Lerch, R.N., Erickson, J.M., and Wicks, C.M., 2001, Intensive monitoring in two karst basins of Boone County, Missouri: Proceedings of the 15th National Cave and Karst Management Symposium, p. 157–168.

Mahler, B.J., Lynch, L., and Bennett, P.C., 1999, Mobile sediment in an urbanizing karst aquifer: Implications for contaminant transport. Environ. Geol., v. 39, p. 25–38.

Manning, R., 1890, On the flow of water in open channels and pipes: Proceedings of the Institution of Civil Engineers of Ireland, v. 20, p. 161–206.

Missouri Spatial Data Information Service. 21 March 2005, Missouri GAP Land Cover, http://msdisweb.missouri.edu/data/lulc/index.htm.

National Weather Service. 21 March 2005, Climatology and Weather Records, http://www.crh.noaa.gov/lsx/climate.php.

Palmer, A.N., 2000, Hydrogeological control of cave patterns, *in* Klimchouk, A.B., Ford, D.C., Palmer, A.N., Dreybrodt, W. (eds.), Speleogenesis: Evolution of Karst Aquifers; National Speleological Society, Inc.: Huntsville, AL.

Rantz, S.E., 1982, Measurement and computation of streamflow—Volume 1, measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Ruhe, R.V., Clark, D.W., and Epstein, M.L., 1980, Urban hydrology in karst and water quality–Inorganic and organic systems. Report of Investigations, PB80-174303, No. 9. 139 p.

Ryan, M., and Meiman, J., 1996, An examination of short-term variations in water quality at a karst spring in Kentucky: Ground Water, v. 34, p. 23–30.

Schueler, T., 1994, The importance of imperviousness: Watershed. Prot. Techniq., v. 1, p. 100–111.

St. Ivany, G., 1988, Geologic and hydrologic characteristics of the Gans, Bonne Femme, and Clear Creek watersheds and the Pierpont karst plain near Rock Bridge Memorial State Park: MO Geological Survey, Water Resources Report, 22 p.

Shuster, E.T., and White, W.B., 1971, Seasonal fluctuations in the chemistry of limestone springs: A possible means for characterizing carbonate aquifers: J. Hydrol., v. 14, p. 93–128.

Tillery, A.C., Phillips, J.V., and Capesius, J.P., 2001, Potential Errors Associated with Stage-Discharge Relations for Selected Streamflow-Gaging Stations, Maricopa County, Arizona: U.S. Geological Survey. Water-Resources Investigations Report 00—4224.

USDA-NRCS (United States Department of Agriculture-Natural Resources Conservation Service). 2002. Soil Survey of Boone County, Missouri. 318 p.

University of Missouri Extension. 21 March 2005, Boone County Weather Stations, http://agebb.missouri.edu/weather/stations/boone/index.htm.

Unklesbay, A.G., 1952, Geology of Boone County, Missouri. Missouri Geology and Land Survey and Water Resources: 2nd Series, Vol. 33, 159 p.

Vandike, J., 1983, Stream gaging results, upper Bonne Femme Creek–Rating curve, Devil's Icebox Spring. Memorandum, Missouri Department of Natural Resources, 1 p.

Veni, G., 1999, A geomorphological strategy for conducting environmental impact assessments in karst areas: Geomorphology, v. 31, p. 151–180.

White, W.B., 1988, Geomorphology and Hydrology of Karst Terrains: Oxford University Press: New York, 464 p.

Wicks, C.M., 1997, Origins of groundwater in a fluviokarst basin: Bonne Femme basin in central Missouri, USA: Hydrogeol. J., v. 5, p. 89–96.

Wicks, C.M., and Engeln, J.F., 1997, Geochemical evolution of a karst stream in Devils Icebox Cave, Missouri, USA: J. Hydrol., v. 198, p. 30–41.

Gad El-Qady, Mahfooz Hafez, Mohamed A. Abdalla, and Keisuke Ushijima – Imaging subsurface cavities using geoelectric tomography and ground-penetrating radar. *Journal of Cave and Karst Studies*, v. 67, no. 3, p. 174–181.

IMAGING SUBSURFACE CAVITIES USING GEOELECTRIC TOMOGRAPHY AND GROUND-PENETRATING RADAR

Gad El-Qady[1, 2], Mahfooz Hafez[1], Mohamed A. Abdalla[1], and Keisuke Ushijima[2]

[1]*National Research Institute of Astronomy and Geophysics, 11722 Helwan, Cairo, EGYPT gad@mine.kyushu-u.ac.jp*

[2]*Earth Resources Engineering Department, Kyushu University, 6-10-1 Hakozaki, Fukuoka, 812-8581 JAPAN*

In the past few years, construction extended extraordinarily to the southeast of Cairo, Egypt, where limestone caves occur. The existence of caves and sinkholes represents a hazard for such new urban areas. Therefore, it is important to know the size, position, and depth of natural voids and cavities before building or reconstruction. Recently, cavity imaging using geophysical surveys has become common. In this paper, both geoelectric-resistivity tomography using a dipole-dipole array and ground-penetrating radar (GPR) have been applied to the east of Kattamya at Al-Amal Town, Cairo, to image shallow subsurface cavities. The state is planning to construct a new housing development there. The resistivity survey was conducted along three profiles over an exposed cave with unknown extensions. The radar survey was conducted over an area of 1040 m², and both sets of data were processed and interpreted integrally to image the cave as well as the shallow subsurface structure of the site. As a result, the cave at a depth of about 2 m and a width of about 4 m was detected using the geophysical data, which correlates with the known cave system. Moreover, an extension of the detected cave has been inferred. The survey revealed that the area is also affected by vertical and nearly vertical linear fractures. Additionally, zones of marl and fractured limestone and some karstic features were mapped.

Introduction

Delineation of subsurface cavities and abandoned tunnels using geophysical methods has gained wide interest in the past few decades. It has been a challenging problem for exploration geophysics. The problem continues to be relevant today, as the discovery of cavities and tunnels is important to both domestic and military interests.

A variety of geophysical techniques can be used to detect the presence of caves and voids below the surface. All of them are based on a physical contrast between a cave and the surrounding rocks. Because the electrical resistance of the void is higher than the surrounding substrate, 2-D resistivity imaging is used successfully (Noel and Xu, 1992; Manzanilla *et al.*, 1994). But limestone itself has a high resistance, which means that this technique is most likely to be successful if it is used in conjunction with other methods. Palmer (1959) described an early application of the resistivity method. The difference in resistance between an air-filled cavity and the surrounding limestone may be the most outstanding physical feature of a cave, and for this reason the resistivity method has been the most widely used for cave detection (Elawadi *et al.*, 2001; Ushijima *et al.*, 1989; Smith, 1986).

Ground-penetrating radar (GPR) has been a very efficient tool for mapping shallow targets for applications such as geological engineering and environmental management (Fisher *et al.*, 1992). GPR systems detect reflections from short bursts of electromagnetic radiation emitted by a portable radar transmitter (Conyers and Goodman, 1997). Subsurface imaging by radar is possible when the topographic cover is rather smooth, and when the material penetrated is fine grained, no more than a few meters thick, and dry (Reynolds, 1997).

In the eastern part of Greater Cairo, a new housing development is planned, namely Al-Amal Town. It is about 20 km southeast of Cairo on the Cairo-Sukhna Highway (Fig. 1). The area is on the main limestone plateau that contains many intercalations of marl and clay, which are considered hazards for housing developments. Studying these areas could help the future planning for constructing new dwelling zones. Furthermore, delineating the structural patterns, fissures, joints, and faults can greatly help increase the safety factor for buildings at the study area.

The main objective of this paper is to apply both geoelectric-resistivity tomography and ground-penetrating radar to investigate the structure of a cave and to delineate any unknown caverns that might hinder future public development at Al-Amal.

Site of investigation

At Al-Amal Town, the state has projected to build houses for limited-income people to be near an industrial zone. The area is located on the main limestone plateau, which contains lithologic inhomogeneities.

Stratigraphically, the shallow section in the study area and its surroundings is composed of Plio-Pleistocene deposits underlain by Pliocene and Miocene sediments. The Plio-Pleistocene is represented by feldspar-bearing coarse sand in alluvial fans of the wadies surrounding the area. The Pliocene sediments are represented by a series of gravel beds capped by a layer of white to gray, hard, and very dense limestone (Said, 1962). The Miocene section of the Cairo-Suez district increases in thickness toward the east and averages 30 m around the study area. It is divided into two main units, an upper nonma-

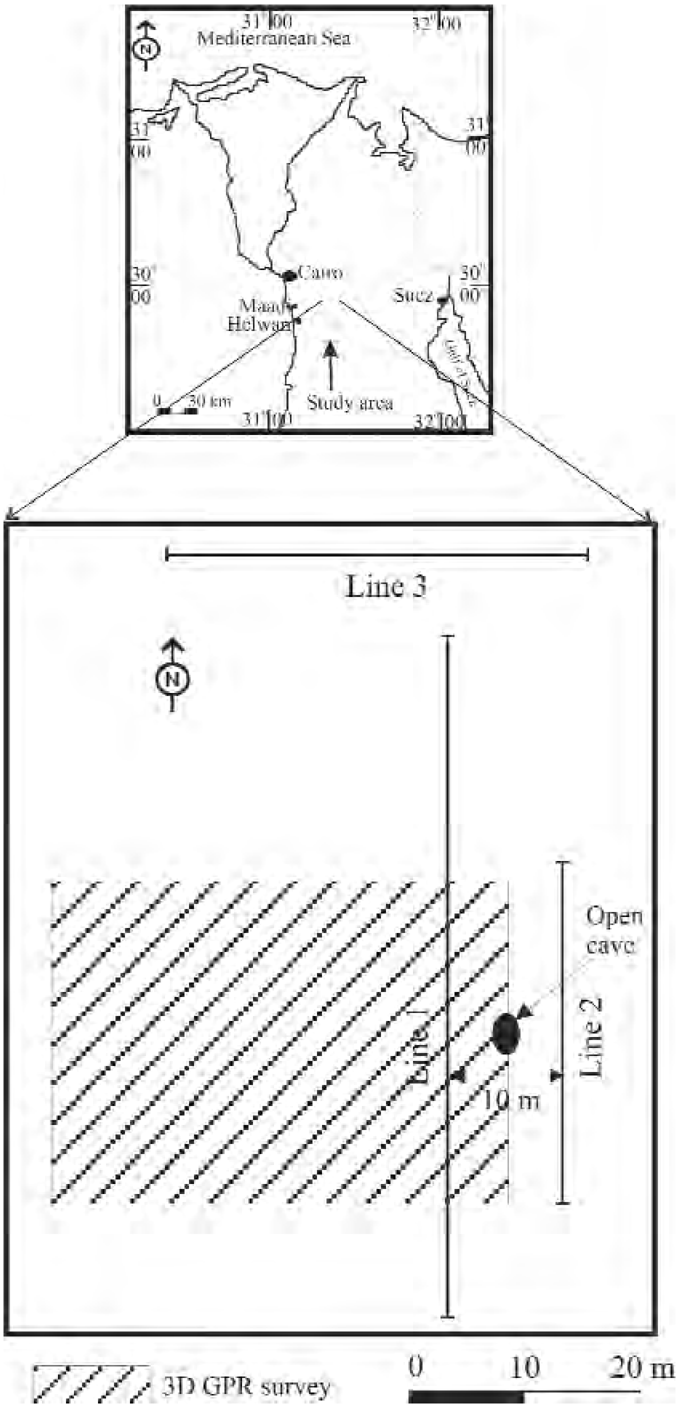


Figure 1. Location map of the study area.

rine unit composed of gravel, and a lower marine unit composed mainly of limestone with interbedded sandstone members.

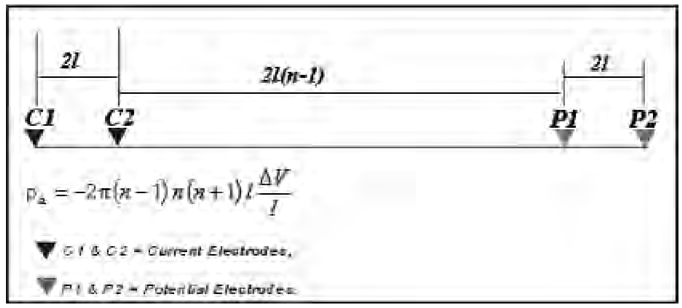


Figure 2. Electrode configurations for the dipole-dipole array for resistivity surveys.

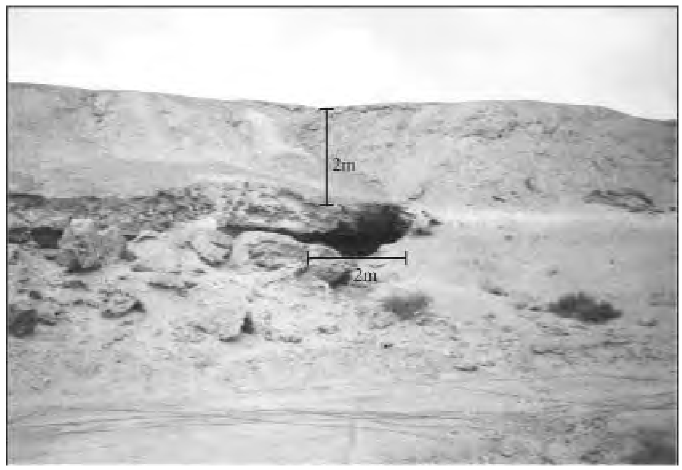


Figure 3. Photograph of the cave outcrop and its dimensions.

GEOPHYSICAL DATA

RESISTIVITY IMAGING

The concepts of electrical imaging are well described in the geophysical literature (e.g. LaBrecque *et al.*, 1996). Resistivity measurements are made for a large number of sets of four electrodes. Given these measurements, it is possible to solve numerically for a resistivity distribution that results in a set of calculated resistivity measurements that best fits with the measured response.

The dipole-dipole electrode configuration was used in this study. Figure 2 illustrates the layout for data acquisition. In this configuration, the apparent resistivity value is calculated according to the formula

$$\rho_a = -2\pi(n-1)\,n\,(n+1)\,l\,\frac{\Delta V}{I} \qquad (1)$$

(see Figure 2 for symbol definitions). The array is widely used in resistivity and induced-polarization surveys, because of the low electromagnetic coupling between the current and potential circuits. Furthermore, this array is very sensitive to horizontal changes in resistivity. Hence it is good at mapping vertical structures such as dikes and cavities.

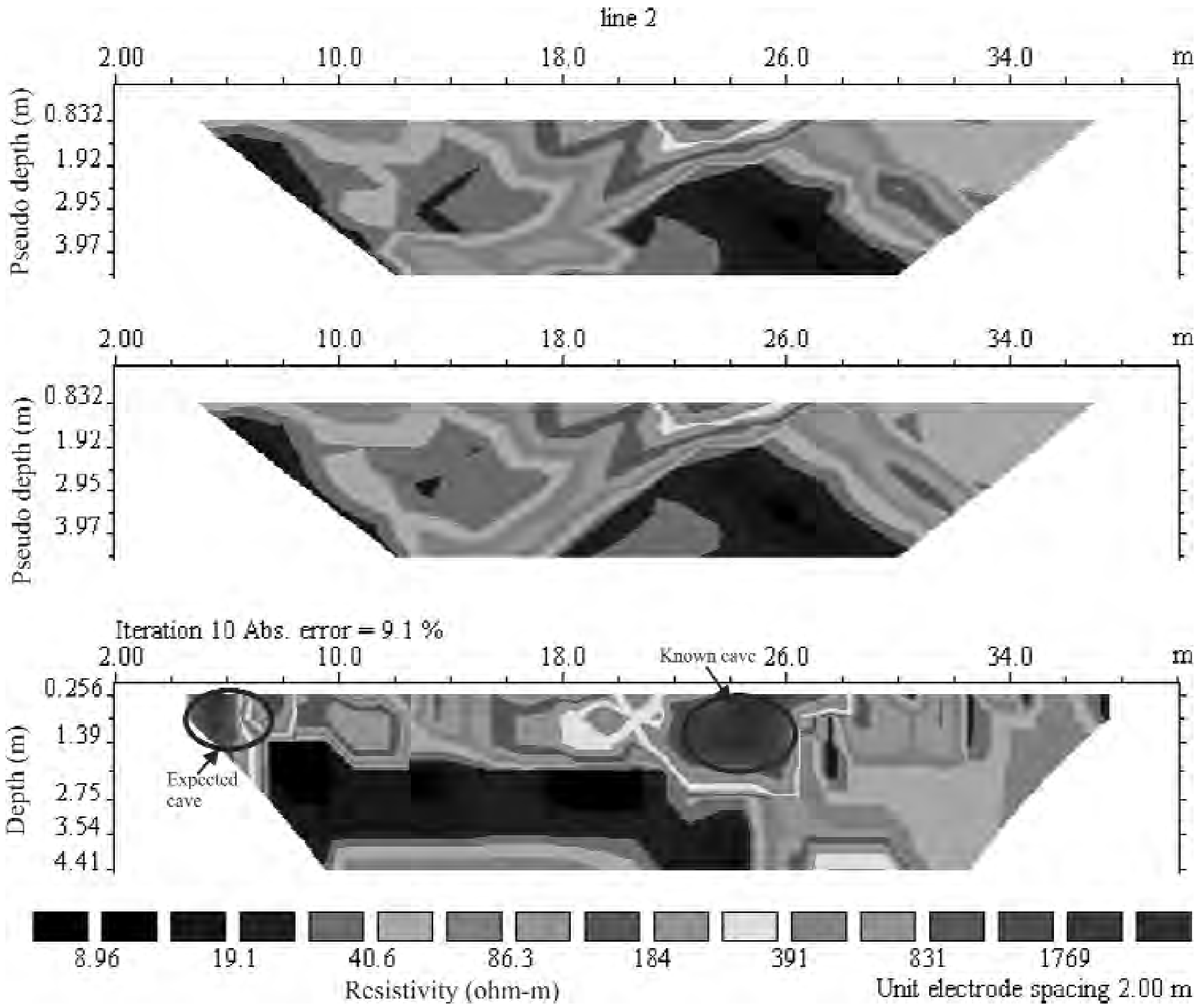


Figure 4. Inverted dipole-dipole resistivity section along survey line L2; (top) measured apparent resistivity, (middle) calculated apparent resistivity, and (bottom) inverted model resistivity section.

The survey was conducted above an exposed cave with unknown extensions (Fig. 3). Resistivity measurements were acquired along three profiles, namely L1, L2, and L3 (Fig. 1). For L1 and L3, the electrodes were spaced 5 m apart, whereas for L2, 2 m. The data were collected using an IRIS Instruments Syscal-R2 system (IRIS, 1998).

The measured apparent resistivity data were inverted to create a resistivity model of the subsurface using iterative smoothness-constrained least squares (Loke and Barker, 1996; Loke, 1998). This scheme requires no previous knowledge of the subsurface; the initial-guess model is constructed directly from field measurements. A robust inversion (Claerbout and Muir, 1973) was used because it is suitable for detecting fractures and faults as well as for sharpening linear features such as faults, dikes, and contacts. The pseudosections of the measured and calculated apparent resistivity and the section of the inverted resistivity model for L2 are displayed in Figure 4 as an example. Figure 5 shows a collective 3-D view of the inverted resistivity models for the three profiles L1 to L3.

Generally, the resultant resistivity sections show that the site is characterized by a relatively moderate resistivity background (19–40 ohm-m). This can be referred to as the lithologic intercalation of marl (calcareous shale) with limestone. The resistivity section of profile L2 (Fig. 4) shows two distinct areas of high resistivity centered approximately at 6- and 24-m horizontal distance. The first anomaly, >830 ohm-m, is at less than 1 m deep, and it appears in L1 at a different horizontal distance. The second one, >1760 ohm-m, extends deeper with a depth ranging from 0.5 to 3 m with a relatively large size. This anomaly also appears in L1. Such anomalies probably reflect cavities distributed in the limestone. Moreover, linear changes in the resistivity distribution that are obvious in section L3 are probably related to contacts between the hard limestone and the marl as well as other linear structures.

GROUND-PENETRATING RADAR

Ground-penetrating radar has become a common component of the standard array of geophysical techniques used to detect voids within limestone. The principles of the method are similar to those of seismic sounding, but in GPR the reflections come from objects and layers within the ground that alter the speed of transmission of the radar signal. Thus, air-filled voids and layers of water-saturated sediment are strong radar reflectors. The depth of penetration of the GPR depends on the frequency of the radar signal, as well as the electrical properties of the substrate.

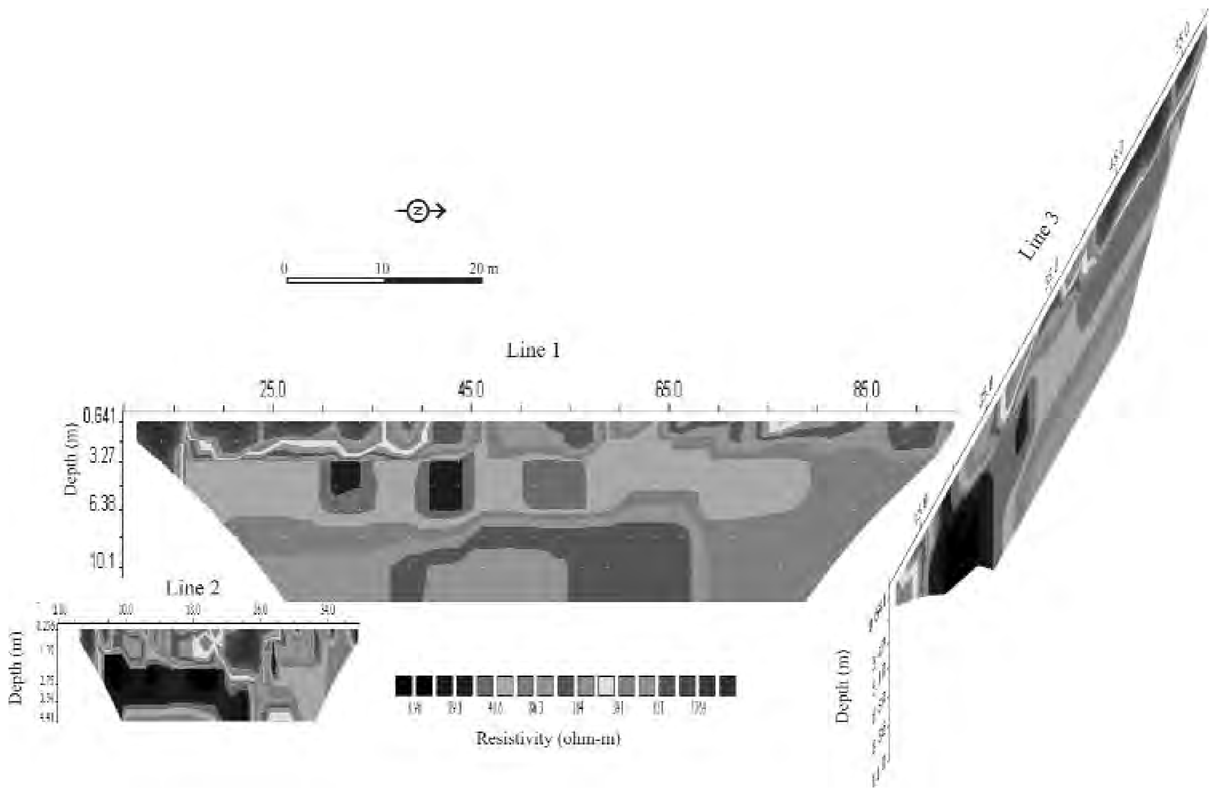


Figure 5. Three-dimensional view of the inverted resistivity sections for the survey lines.

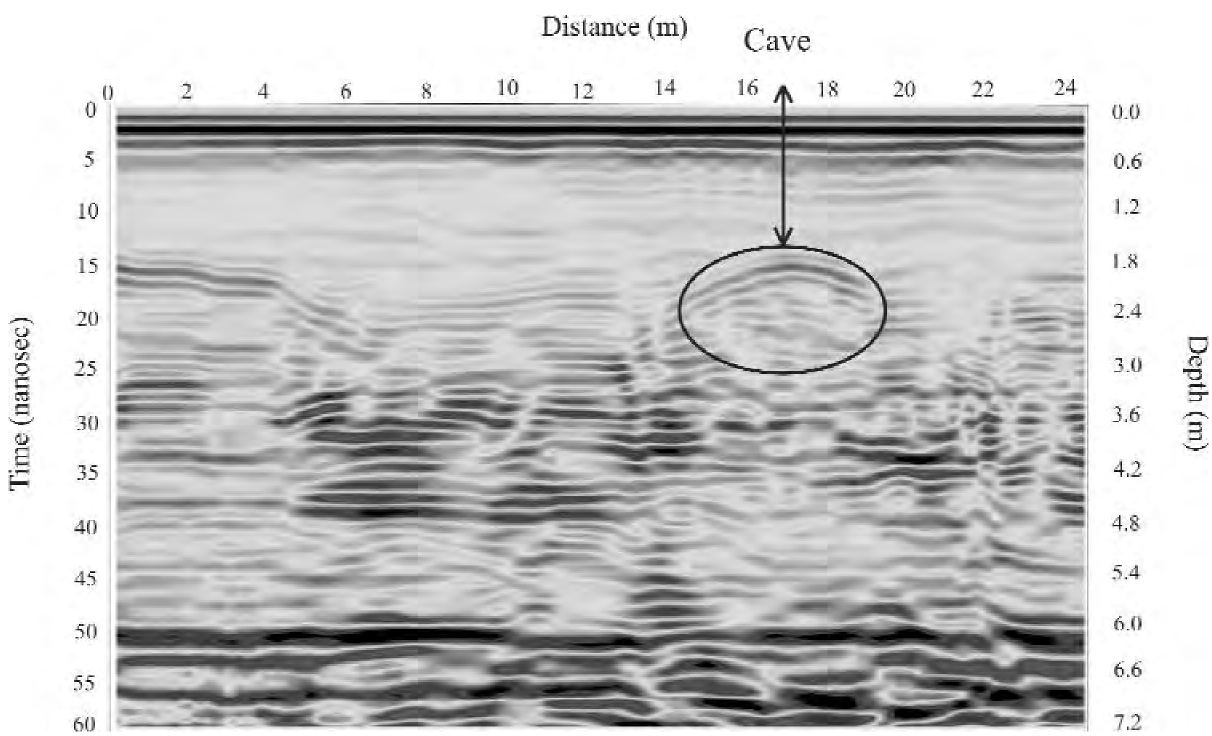


Figure 6. Radar record along resistivity line L2, and over the cave.

GPR uses high-frequency electromagnetic waves to acquire subsurface information. The waves are radiated into the subsurface by an emitting antenna. When a wave strikes a suitable object, a portion of the wave is reflected back to a receiving antenna. Measurements are continuously recorded with a resolution that is significantly higher than most other surface geophysical methods, providing a profile (a cross section) of subsurface conditions.

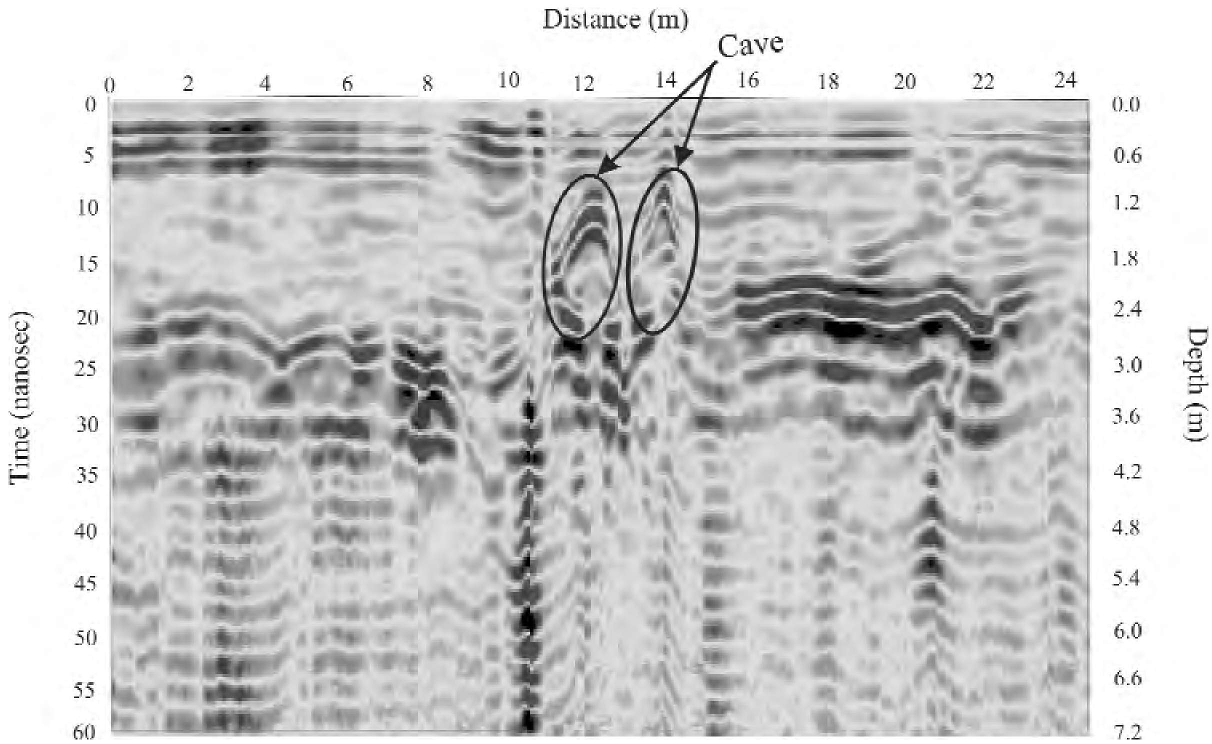


Figure 7. Radar record along resistivity line L3.

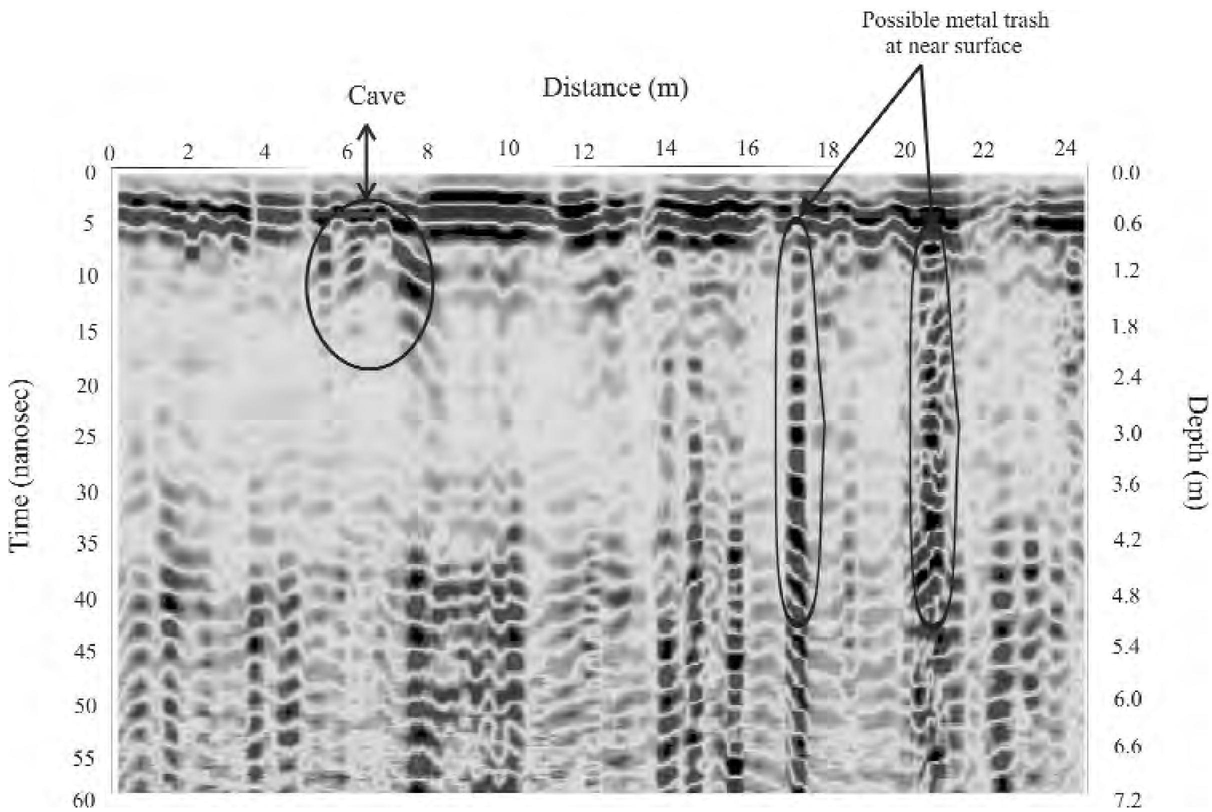
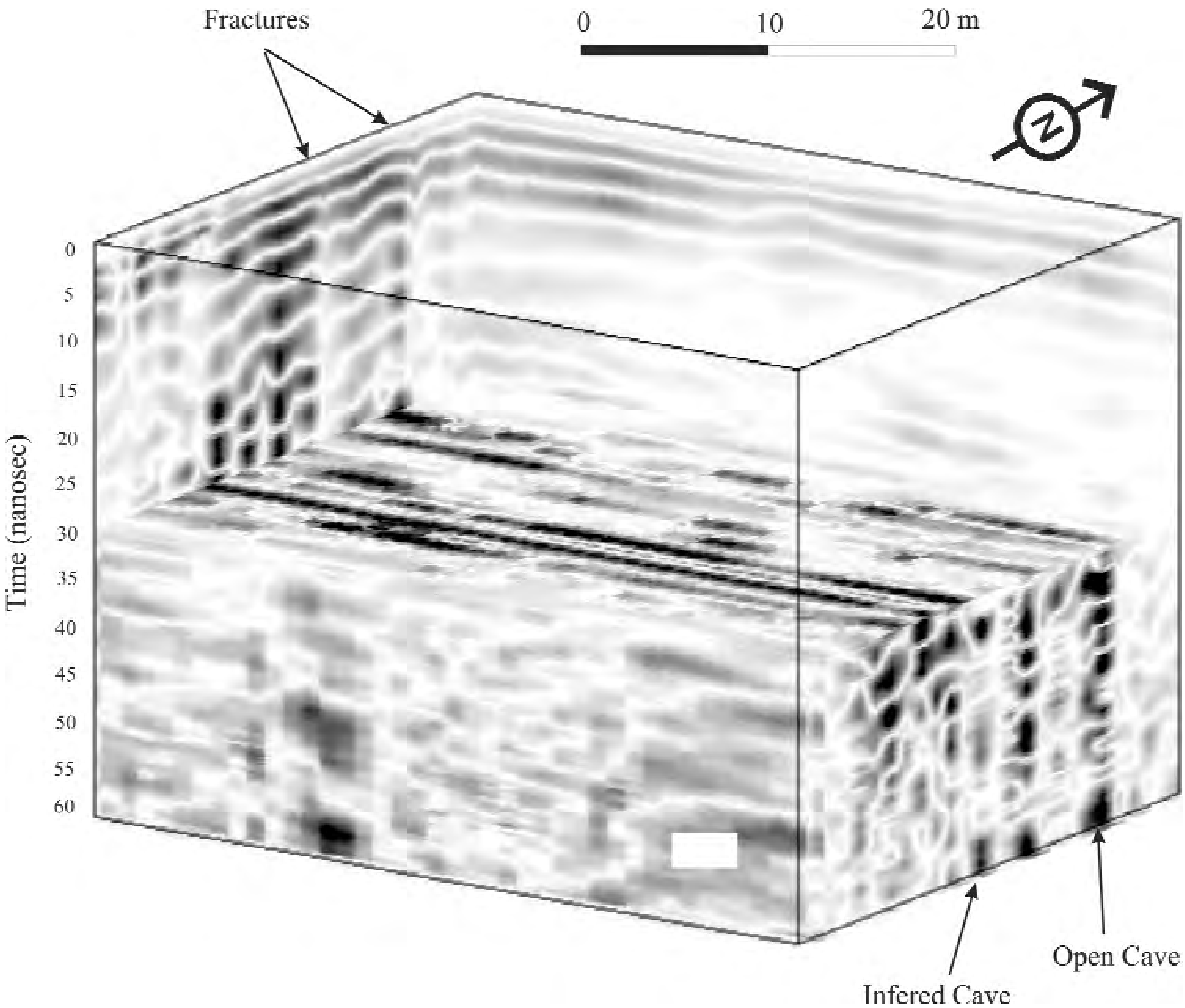


Figure 8. Radar record along resistivity line L1.

In this paper, the GPR survey inspected the uppermost 10 m of the area. The GPR profiles were measured along the same three resistivity profiles (Fig. 1) using an SIR-2000 instrument equipped with a 200 MHz monostatic antenna applying time windows of 120 ns, with 20 scans per meter, and 512 samples per scan. Additionally, 27 parallel profiles 41 m long and spaced 1 m apart extend from east to west for odd profiles, and from west to east for even (zigzag traverse mode). The profiles were measured using the same survey parameters to define the pathway of the cave system. The time over 60 ns was removed

Figure 9. Three-dimensional block depicting the position of the cave system.



where it was noisy. Whereas the data processing was conducted using the Reflex program (version 2.1.1), several processing steps were applied to each radar profile separately, such as background removal, band-pass filters (1- and 2-dimensional), median filter, and automatic-gain control. The band-pass filtering was applied in order to eliminate high-frequency components. The radar survey was conducted directly above a known cave system (Fig. 3) in order to determine its response to the radar signal, which may be used for delineating unknown cave systems in the study area in the future.

Figure 6 represents the processed radar record measured over the cave system along resistivity profile L2. Inspection of this figure shows a hyperbolic arc indicating the existence of the cave; the location and depth of the target can be determined from the vertex of the hyperbolic arc. The velocity of the electromagnetic wave is about 0.121 m ns^{-1}. The depth to the cave system is shown to be about 2 m, which correlates with the true depth of the cave. Keeping in mind the signature of the cave in the radar record, the other radar profiles can be interpreted. Inspection of the GPR section of Figure 7, which is measured perpendicular to the cave system and in line with L3, shows a hyperbolic feature at about 13 m from the starting point of the profile and at a depth of about 1 m. It also shows that around the cave, significant fractures extend through the limestone, which may indicate that the cave system extends further. Moreover, the GPR section in Figure 8, which is measured inline with resistivity profile L1, shows that a substantial radar reflection anomaly is at a horizontal distance of between 5.5 and 7.5 m and about 1 m beneath the ground surface. Based on the shape and geometry of the anomalous radar features and the geologic condition of the study area, we believe that the area is characterized by subterranean voids that may be extensions of the known cave system.

Three-dimensional GPR time-sliced image

Three-dimensional interpretations of ground-penetrating radar have been used to identify burials and other cultural features (Conyers and Goodman, 1997). In the past, the use of 3-D images has been restricted, because of the time required to conduct fieldwork over limited areas and the lack of satisfactory signal-processing software. The recent development of sophisticated software has enabled signal enhancement and improved pattern recognition on radar records. Figure 9 shows a 3-D block diagram of a 41 x 27 m grid area. Horizontal time-

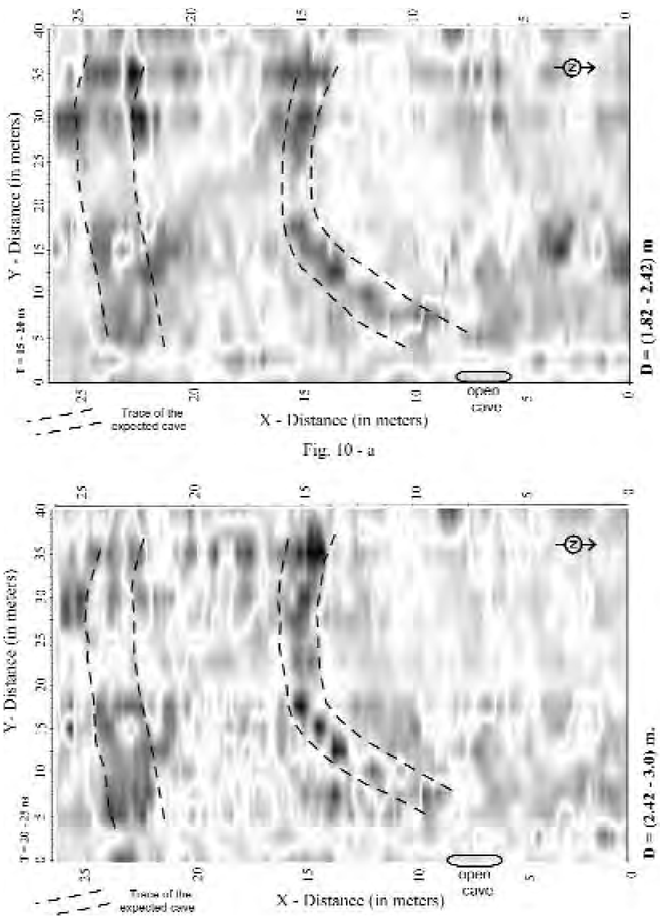


Figure 10. Horizontal time slices of radar data showing the trend of the cave. Figure 10-a depicts a 15–20 ns (1.82–2.45 m) slice and Figure 10-b depicts a 20–25 ns (2.42–3.00 m) slice.

slice maps (Figure 10) were made across the volume at depths ranging from approximately 1.8 m to 3.0 m. These depths were based on an assumed signal propagation velocity through the soil of 0.121 m ns^{-1}.

The top time slices from 15–20 ns (1.82–2.45 m) in Figure 10-a, and 20–25 ns (2.42–3.00 m) in Figure 10-b, show a series of hyperbolic reflectors aligned on adjoining radar records that form a linear pattern of high amplitudes (dark colors) at a uniform depth and orientated east to west. These reflectors are assumed to be the pathway of the cave system.

DISCUSSION AND CONCLUSION

The objective of this study was to investigate the caves and the shallow subsurface setting of the area to outline its geologic structures. Two-dimensional resistivity tomography using a dipole-dipole array and GPR data were collected and interpreted.

As the air-filled cavities have a near-infinite electrical resistance compared to the damp limestone, they produced readily recognizable anomalies. Based on the geophysical signature of the resistivity cross sections, two high-resistivity anomalous areas were detected. Additionally, a group of low resistivity zones were detected and interpreted as pockets of marl embedded in the limestone.

The processed GPR data elucidate a hyperbolic radar signal due to a cave at a depth of about 2 m, with a width of about 4 m, which is in good agreement with the known cave system in the study area. Moreover, some anomalous zones are delineated and are believed to reflect extensions of the cave system and other small karstic features.

Integrated interpretation of the acquired geophysical data along each profile is summarized in a schematic cross section (Fig. 11) showing the interpreted structures and the expected pathway of the cave system. With the existence of such caves, along with frequent large dynamite explosions used in a limestone quarry near the study area, the detected karstic features and fracture zones can be considered as the main risks for the new proposed housing development.

According to the results obtained from this study, we can conclude that ground-penetrating radar and electrical resistivity have proved to be effective tools for imaging subsurface cavities in limestone at shallow depths. On the other hand, natural cavities such as in this study occur in only a few types of rocks, and the rock surrounding natural cavities is often disturbed. This is particularly true in carbonate karstic environments where a cave is formed by the physical and chemical action of groundwater on the rock. In such an environment, fractures and the dissolution of rock surrounding a cave system creates a larger bulk anomalous volume than the cave itself. Fortunately, this helps geophysical methods to detect such caves easily. Consequently, we mainly find that the effective geophysical size of each cavity varies with the geologic environment, but it is usually larger than the real size of the cavity.

Finally, with the frequent massive dynamite explosions in the nearby limestone quarry, the detected fracture zones and karstic features can be considered as the main cause of likely future cracking at this site. Therefore, to increase the safety of homes in the area we recommend controlling the frequency and intensity of the dynamite explosions used at the limestone quarry.

ACKNOWLEDGEMENTS

The staff of the Egyptian National Research Institute of Astronomy and Geophysics (NRIAG) helped acquire the geophysical data using NRIAG facilities; sincere thanks to all of them. We are indebted to the staff of the Exploration Geophysical Laboratory in Kyushu University for their contributions and support during this work. We appreciate the thoughtful comments made by Dr. George Moore of Oregon State University, Dr. Paul Gibson of the University of Maynooth, and Dr. Richard Benson of Technos Inc for their constructive criticism that improved the paper. We appreciate efforts of Dr. Ira Sasowsky, for reading the final text. The Japan Society for the Promotion of Science (JSPS) supported the work of GE.

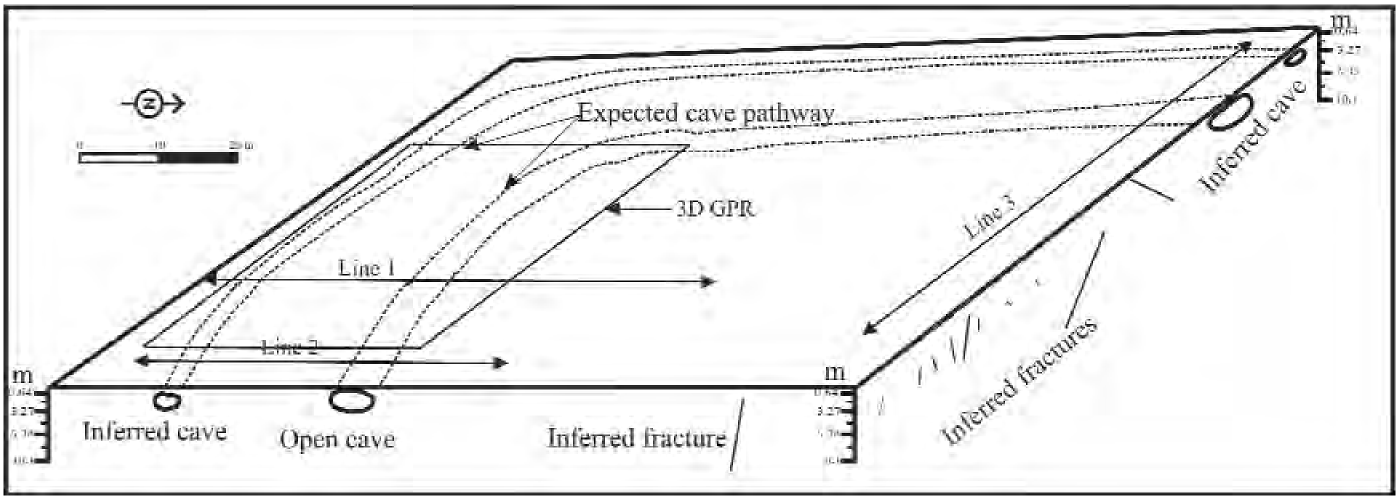


Figure 11. Three-dimensional conceptual view of the interpreted cross sections from the geophysical survey.

References

Claerbout, J., and Muir, F., 1973, Robust modeling with erratic data: Geophysics, v. 38, p. 826–844.

Conyers, L., and Goodman, D., 1997, Ground penetrating radar. An introduction for Archaeologists: Walnut Creek, Altamira Press, 232 p.

Elawadi, E., El-Qady, G., Salem, A., and Ushijima, K., 2001, Detection of cavities using pole-dipole resistivity technique: Memoirs of the Faculty of Engineering, Kyushu Univ., v. 61, p. 101–112.

Fisher, E., McMechan, G., and Annan, P., 1992, Acquisition and processing of wide-aperture ground-penetrating radar data: Geophysics, v. 57, p. 495-504.

IRIS Instruments, 1998, User manual of Syscal Junir-R2, multi-electrode system: Orleans Cedex, 98 p.

LaBrecque, D.J., Ramirez, A.L., Daily, W.D., Binley, A.M., and Schima, S.A., 1996, ERT monitoring of environmental remediation processes: Measurement Science and Technology, v. 7, p. 375-383.

Loke, M.H., 1998, RES2DINV, Rapid 2D resistivity and IP inversion using least-squares methods, User manual: Austin, Tex., Advanced Geosciences, Inc., 66 p.

Loke, M.H., and Barker, R.D., 1996, Rapid least-squares inversion of apparent resistivity pseudo sections by a quasi-Newton method: Geophysical Prospecting, v. 44, p. 131–152.

Manzanilla, L., Barba, L., Chávez, R., Tejero, A., Cifuentes, G., and Peralta, N., 1994, Caves and geophysics: An approximation to the underworld of Teotihuacan, Mexico: Archaeometry, v. 36, p. 141–157.

Noel, M., and Xu, B., 1992, Cave detection using electrical resistivity tomography: Cave Science, v. 19, p. 91–94.

Palmer, L., 1959, Location of subterranean cavities by geoelectrical methods: Mining Magazine (London), v. 91, p. 131–147.

Reynolds, J.M., 1997, An introduction to applied environmental geophysics: West Sussex, John Wiley & Sons Ltd., 796 p.

Said, R., 1962, The geology of Egypt: Amsterdam, Elsevier, 377 p.

Smith D., 1986, Application of the pole-dipole resistivity technique in the detection of solution cavities beneath highways: Geophysics, v. 51, p. 833–837.

Ushijima, K., Mizunaga, H., and Nagahama, S., 1989, Detection of cavities by the pole-dipole resistivity method: Butsuri Tanasa (Geophysical Exploration of Japan), v. 40, p. 324–334.

SELECTED SCIENTIFIC ABSTRACTS FROM THE 2005 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN HUNTSVILLE, ALABAMA

ARCHAEOLOGY

THE ARCHAEOLOGY OF A NINETEENTH CENTURY SALTPETER MINING SITE:CAGLE SALTPETRE CAVE, VAN BUREN COUNTY, TENNESSEE

Sarah A. Blankenship, Department of Anthropology, University of Tennessee, Knoxville, TN 37996 sblanken@utk.edu

Since the foundation of the first colonies, the struggle for both survival and self-sufficiency made gunpowder a critical substance in frontier America. Consequently, the domestic production of saltpeter, the principal ingredient in gunpowder, became an important early industry. A natural and reliable source of saltpeter, the numerous limestone caves throughout Tennessee played a significant role in both the country's military history and the early industrial development of the region. During the nineteenth century, the second war with Britain coupled with the War of the Rebellion led to both large- and small-scale saltpeter mining operations in caves throughout the State. Fortunately, the dry environment of these caves allows for excellent preservation of the material record, thus many of these sites still contain the equipment used in the mining operations, much of it still in context. Despite the high rate of preservation, little scientific research has been undertaken at specific saltpeter-mining sites. Historic documentation of mining activities within these caves is scarce, thus a systematic study of the extant archaeological record can be integral in enhancing our understanding of this early extractive industry. An archaeological examination of extant artifacts and features at one such site, Cagle Saltpetre Cave, in Van Buren County, Tennessee, is focused on providing insight into the production process, the results of which are presented.

TORCHES IN THE DARK: LATE MISSISSIPPIAN EXPLORATION OF HUBBLE POST OFFICE CAVE, TENNESSEE

Joseph C. Douglas, Brian Roebuck, and Lynn Roebuck; Volunteer State Community College, Gallatin, TN 37066

In late 2003, during a Southport Chronic Cavers Grotto survey project, Lynn Roebuck discovered evidence for prehistoric people visiting Hubble Post Office Cave, in the form of cane torch stoke marks. Brian Roebuck confirmed the initial identification. While the cave, located in the middle Duck River drainage, was known to be an important paleontological site, it was not known to contain archaeological material. A subsequent research trip by the authors in early 2004 examined in detail the extant evidence. The locations of cane torch stoke marks and cane charcoal deposits were recorded, a sample of cane torch charcoal was collected, and the site was examined for evidence of resource removal, mortuary activity, or ceremonial use. The results of the research reveal that prehistoric people explored the majority of the cave, but there was no indication of any usage of the cave environment except simple exploration. This conforms to what is known about prehistoric cave use in the region, as exploration-only sites are the most common of all deep cave archaeological sites in Tennessee. A single radiocarbon date was obtained, using AMS technology, which revealed that the exploration of the cave occurred in the early- to mid-15th century, placing the activity in the Late Mississippian period. While comparatively little is known about the Late Mississippian in the middle Duck River drainage, it is clear that the cultural tradition of exploring caves long persisted in the area, despite the relatively light population density at the time.

PREHISTORIC CAVE ART IN 44TH UNNAMED CAVE, TENNESSEE

Jan F. Simek[1], Alan Cressler[2], and Joseph C. Douglas[3]
[1]University of Tennessee, Knoxville, TN 37996-0720
[2]USGS, 579 Barton Way, Decatur, GA 30033
[3]Volunteer State Community College, Gallatin, TN 37066

Recently discovered prehistoric cave art in 44th Unnamed Cave (Tennessee) is discussed. The cave contains more than two dozen pictographs, petroglyphs, and possibly mud glyphs in a dark zone context. The art is associated with a long, intensive, occupation sequence in the vestibule and ritual human interments in the cave interior. The artwork is classically Mississippian in subject matter (ca. AD 1100–1500) and quite resembles certain distinctive design elements found on shell gorgets in the immediate region of the cave. 44th Unnamed Cave brings to fifty the known assemblage of prehistoric art caves. Because it is owned by the State of Tennessee, the site presents a unique opportunity to allow public viewing of prehistoric southeastern cave art under controlled and protected conditions.

WOODLAND AND MISSISSIPPIAN CAVE ARCHAEOLOGY IN FLORIDA: HOW DOES IT FIT INTO THE SOUTHEAST PICTURE?

Amber J. Yuellig, Department of Anthropology, University of South Florida, Tampa, FL 33620

Cave archaeology in the southeast has made monumental contributions to the understanding of prehistoric cultures due to their optimal preservation of organic remains in the subsurface environment. More than four decades of research in caves of the southeast United States demonstrates extensive use by many indigenous groups of the Paleo-Indian, Archaic, Woodland, and Mississippian periods. We know that the range of these indigenous groups was widespread; however, our current perception of archaeological research in caves is based mostly upon studies in south-central Kentucky and surrounding regions, and primarily limited to the Woodland and Mississippian periods.

Less research has been conducted on the periphery of this region despite many of the shared characteristics that these cultures have with other indigenous groups that live on karst terrains during the Woodland and Mississippian time periods. Likewise, little research has been conducted on how cave use in northwest Florida relates to cave use in other regions of the southeast. Florida's younger geology, geographic location, and coastal influences offer archaeologists a unique opportunity to examine variation in underground prehistoric activities. This paper synthesizes previous research conducted in the southeast, reviews prior research in northwest Florida, and explores future research directions for Florida cave archaeology.

BIOLOGY

GUANO INVERTEBRATE COMMUNITIES IN A HIGHLY ACIDIC CAVE

Kathleen H. Lavoie[1], Eugene H. Studier[2], and Olivia F. Cauthorn[1]
[1]State University of New York College at Plattsburgh, 101 Broad St., Plattsburgh, NY 12901
[2]University of Michigan at Flint, Flint, MI 48502

Cueva de Villa Luz in Tabasco, Mexico, is a cave with a complicated energetic base including inputs of sulfur energy from spring and detrital energy from skylights and bats. Sulfuric acid is a waste product of the metabolism of chemoautotrophic bacteria in the cave, and as a consequence, everything in the cave is highly acidic. There are two areas in the cave with large numbers of bats and significant guano accumulations; Casa de los Murcielagos and the Bat House. Guano samples collected from each location were analyzed to determine pH, percent moisture, % organics and % ash. The Kcal/g dry mass was calculated. Guano samples were also assayed for ppt sodium, calcium, iron, potassium, magnesium, and total nitrogen. 100 cc samples of guano were destructively sampled for invertebrates, and smaller 1 cc subsamples for mites. Differences in the types of species found were noted between the two locations, which may be due to proximity to the nearest entrance. Species diversity and abundance were much lower than expected compared to other studies of guano invertebrate community structure. As expected, mites were the most abundant type of invertebrate collected. Three of 12 samples had no invertebrates at all, and two only had mites. The greatest biological diversity was in samples from the Casa de los Murcielagos area which also had the most narrow pH range of 2.2–4.0, and percent moisture ranging from 13.7% to 22.3%. Bat House guano ranged in pH from 1.6 to 4.6. Trying to relate the distribution of species to any of the measured physical characteristics is not simple. In general, samples with very low pH (<pH 2) had the lowest diversity. Samples

with the highest moisture (>50%) also had low diversity regardless of pH. There were no strong correlations between guano pH or percent moisture for any of the minerals or for organic content. In this study, guano pH, percent moisture, and proximity to entrances, are the best predictors of guano invertebrate community diversity.

Preliminary Evaluation of the Invertebrate Fauna of an Artificial Bat Cave in Texas

Kathleen H. Lavoie[1] *and Diana E. Northup*[2]

[1]*State University of New York College at Plattsburgh, 101 Braod St., Plattsburgh, NY 12901*

[2]*The University of New Mexico, MSC2020, Albuquerque, NM 87131-0001*

We began the study of colonization of bat guano in a new environment. The Bambergers have built a man-made bat cave on their Selah ranch in central Texas. Consisting of two large domes 40 ft and 20 ft in diameter, the Chiroptorium has had mixed success in attracting bats. Guano covers the floor in both chambers. A visual census of the guano during January 2005 shows a very minimal fauna in terms of numbers and diversity. The most abundant invertebrates are spiders that are common on the walls of the chambers. Interpretation of results will be complicated by importation of about 100 lbs of guano from Bracken Bat Cave. This project will be conducted over the next five years, in cooperation with a study of the bats.

Macro-Invertebrate Survey of the Timpanogos Cave

Jon Jasper[1] *and Riley Nelson*[2]

[1]*Timpanogos Cave National Monument, RR 3, Box 200, American Fork, UT 84003 jon_jasper@nps.gov*

[2]*Riley Nelson, Department of Integrative Biology, Brigham Young University, Provo, UT 84602 rileynelson@byu.edu*

Under the funding of the National Park Service's Inventory and Monitoring Program, Dr. Riley Nelson of Brigham Young University was contacted to perform a 2-year survey to identify the macro-invertebrate species of the Timpanogos Cave system, Utah. Species were collected in 87 pitfall traps placed throughout the entire cave system. These traps were collected every 2 weeks, sorted, and identified. Preliminary results show that a total of 29 taxa were collected, most from Sciaridae, Mycetophilidae, and Anobiidae. From this study, indicator species will be selected for monitoring the health, or vital signs, of the cave.

Bioinventory of Sequoia, King's Canyon and Yosemite National Park Caves

Jean K. Krejca, Zara Environmental LLC 118 W. Goforth Rd., Buda, TX 78610 jean@zaraenvironmental.com

The goals of this study were to create faunal lists for developing cave management plans, and to provide park staff with the tools to maintain a cave species monitoring system. Thirty-five caves were visited over four field sessions of three weeks each in Sequoia, King's Canyon and Yosemite National Parks. During this investigation, approximately 1600 collections were made and they are being shipped to specialists for identification. Already several taxa have been recognized that represent new species. Additionally, a database is being created with a specialized format for managing in-cave biological survey data. This format links species observations to cave survey stations and searcher effort, in order to facilitate analysis of relative abundance and precise spatial distribution of species over time. The database also incorporates the U.S. Department of Agriculture's Integrated Taxonomic Information System (ITIS) nomenclature and taxon identifiers, and is compatible with the National Park Service's Natural Resource Database Template. This format which is already being used in many parks across the country will allow all of these data to be searchable on the web. The format of the database and field identification aids, including color photographs of live specimens provided in a report, will help park staff maintain long-term monitoring of cave species.

A Biological Survey of Caves at Fort Leonard Wood, Missouri

Steven J. Taylor[1], *Michael E. Slay*[2], *and Steven R. Ahler*[3]

[1]*Center for Biodiversity, Illinois Natural History Survey, 607 East Peabody Drive. Champaign, IL 61820 sjtaylor@inhs.uiuc.edu*

[2]*Arkansas Field Office, The Nature Conservancy 601 North University Avenue, Little Rock AR 72205*

[3]*Illinois State Museum Society, Illinois State Museum Research and Collections Center, 1011 E. Ash Street, Springfield IL 62703*

We surveyed the aquatic and terrestrial fauna of 74 sites, mostly caves, at Fort Leonard Wood, a 71,000 acre (28,700 hectare) military installation located near the northern boarder of the Ozark Plateau (Pulaski County) in central Missouri in 2003 and 2004. All but one of the known caves were sampled, and all taxa, including entrance taxa, accidentals, troglophiles, and vertebrates were noted, thus providing a fairly complete picture of the cave fauna of the northern Ozarks. Using a variety of sampling methods (pitfall trapping, baited aquatic traps, hand collections, vacuum samples, leaf litter samples, and sight records) we recorded more than 2,200 taxon occurrences, representing almost 14,000 specimens. Using species accumulation curves we examined the extent to which our sampling protocol sampled the taxa within the caves. Substrate temperature, relative humidity, and substrate type are correlated with the presence of particular taxa, such as diplurans. Several interesting taxa were recorded including cave-adapted flatworms, terrestrial isopods (*Brackenridgia* sp.), Symphyla, and sometimes quite abundant diplurans. In combination with a concurrent archeological study and cave mapping, the results of this study facilitate informed management of caves by military natural resources personnel.

The Distribution of Amphibians and Reptiles in West Virginia Caves

Michael S. Osbourn and Thomas K. Pauley, Marshall University, Huntington, West Virginia 25755

There are over 4000 caves in West Virginia, which provide potential habitat and refuge for a variety of amphibians and reptiles. In 2002 and 2003 herpetological inventories were conducted in 25 caves in the Greenbrier Valley, resulting in 40 new species encounter records. These inventory results were combined with encounter records from literature, museum collections, and communications with researchers and cavers to produce to most comprehensive account to date. Thirty amphibian and 13 reptile species have been documented in West Virginia cave habitats. Of the over 500 species encounter records, 86% are Plethodontid salamanders. Specifically, Cave Salamanders, Eurycea lucifuga, and Spring Salamanders, Gyrinophilus porphyriticus, are the most frequently documented salamanders from West Virginia caves. This research was supported by grants from the WVDNR Wildlife Diversity Program and the West Virginia Association for Cave Studies.

Biological Inventory of Caves of Tennessee's Cumberland Plateau

Julian J. Lewis, Heather Garland, and Cory Holliday

In 2003 The Nature Conservancy (TNC) of Tennessee undertook a biological inventory of caves associated with the Cumberland Plateau in the east-central part of the state. The Plateau region was chosen for the study because of the high number of caves, previous biological study, and because the area corresponds to TNC's Northern and Southern Cumberlands Project Areas. This large area is a conservation priority for TNC due to the remarkable biodiversity of its forests and aquatic systems. Caves and karst features represent a significant component of the Cumberland Plateau landscape, though the species diversity of the cave systems was not well-known. Building on the pioneering work of Dr. Thomas Barr in the 1950s, Lewis & Associates began conducting bioinventories and gathering data in Tennessee starting with an evaluation of the Rumbling Falls Cave System (Van Buren County) in 2001 and a follow-up project in Van Buren and White counties in 2002. To date 115 taxa classified as obligate subterranean (troglobitic/stygobitic) species have been recorded from over 100 caves sampled. These include 17 crustaceans (3 copepods, 6 isopods, 7 amphipods, 1 crayfish), 22 arachnids (8 spiders, 12 pseudoscorpions, 2 harvestmen), 18 millipeds, 12 collembolans and 41 insects (6 diplurans, 21 carabids, 4 leiodids, 9 pselaphids, 1 dipteran).

Evolutionary History and Conservation Status of Cave Crayfishes Along the Cumberland Plateau

Jennifer E. Buhay[1] *and Keith A. Crandall*[2]

[1]*Brigham Young University, Department of Integrative Biology, 401 Widtsoe Building, Provo UT 84602 crayfish@byu.edu*

[2]*Brigham Young University, Department of Integrative Biology, 401 Widtsoe Building, Provo UT 84602 keith_crandall@byu.edu*

Obligate cave-dwelling crayfish species are found only in southeastern United States, Mexico, and Cuba. Most species are considered to be endangered because of surface pollution threats to ground-water and small geographic distributions, not from in-depth biologic research. As currently recognized, there are three morphologically-similar subterranean species of the genus Orconectes found along the Cumberland Plateau, a worldwide hotspot of cave biodiversity. The objectives of this study are to: 1) delineate species' boundaries using molecular genetic data in a phylogenetic framework, 2) examine evolutionary history of each species using Nested Clade Analysis, and 3) assess conservation status of each endangered cave crayfish species using measures of effective population size and genetic diversity.

This research project has uncovered a new species of cave crayfish along the border of Tennessee and Kentucky, an area previously thought to have "intergrades" between two subspecies of *O. australis*. Additionally, *O. a. packardi* will be elevated to species status, which tallies five stygobitic Orconectes species on the Plateau. It appears that *Cambarus gentryi*, a surface-dwelling burrowing species, is the closest living ancestor to the cave Orconectes assemblage on the Plateau. The origin appears to be Eastern Kentucky around 70 million years ago, with range expansions occuring southward down the Plateau in small leading-edge steps. Although controversial, these cave species exhibit high levels of genetic diversity, especially in comparison to common surface-dwellers. Conservation efforts should focus on protecting 'high-traffic' areas to maintain gene flow and prevent isolation.

Cruising in the Bat-Mobile: Bacterial Endosymbionts and Entomopathogenic Bacteria in Bat-Ectoparasites–Insights to General Trends of Host-Parasite/Endosymbiont-Habitat Relationships

Katharina Dittmar, Richard Trowbridge, and Michael Whiting, Brigham Young University, Department of Integrative Biology, Insect Genomics Laboratory

Symbiotic relationships between bacteria and insect hosts are common, with more than 10% of insect species relying upon intracellular bacteria for their development and survival. These symbionts can stem from an obligatory association [primary (P-) endosymbionts]. Besides P-endosymbionts, most bacteria contain a heterogeneous assemblage of bacteria called secondary (S-) endosymbionts. Usually, little is known regarding the evolutionary role and importance of S-endosymbionts, and the boundaries between an endosymbiontic and a parasitic lifestyle are hard to define. Additionally, there are entomopathogenic bacteria with specific affinities to certain insects, and most of these bacteria are phylogenetically closely related to S-endosymbionts. The main goals of this project are to characterize the diversity of endosymbiont and entomopathogenic fauna within the ectoparasitic batflies and reconstruct a robust phylogeny of all involved bacteria. The resulting topology will be used to address the following questions: (1) What is the position of those bacteria within the Gammaproteobacteria, and what are the phylogenetic relationships between endosymbionts and entomopathogenic bacteria?, (2) What is the strain diversity within discernable groups of bacteria?, (3) Which evolutionary hypothesis (co-evolution vs. horizontal transmission) does the phylogeny support for the different groups?, and (4) Is there a geographical pattern of the bacterial fauna in respect to their hosts (Old World vs. New World batflies) and can this pattern be related to general trends in the evolution of batflies, bats and their habitat? This work will provide insight to the evolutionary events between hosts and bacteria in general, and batflies and bacteria in particular, and increase our knowledge about host-bacterial endosymbiont relationships.

Ultraviolet Radiation Sensitivity in Cave Bacteria Versus Surface Bacteria

Jessica R. Snider and Diana E. Northup, Dept of Biology, University of New Mexico Albuquerque, NM 87131

With no sunlight penetration into the subsurface environment, many cave organisms have experienced the loss of skin pigmentation, a protective trait needed to survive the harmful effects of ultraviolet (UV) radiation, which can cause DNA dimerization, mutation and even death. However, the loss of UV resistance traits has rarely been studied in cave microorganisms. In this study, we build on previous results comparing growth of surface and cave isolates after UV treatment and extend the investigations to the loss of pigmentation, protective cell wall components, and bacterial repair mechanisms. Subsurface bacteria from Left Hand Tunnel of Carlsbad Caverns and surface bacteria were isolated and grown on both high (LB) and low nutrient (R2A) mediums. Samples were exposed to 0 seconds, 50 seconds or 100 seconds of UV light (200 µWatts/cm²), incubated at 15º C for 6 days, and surface area growth was measured to determine the growth inhibition from UV damage. Degree of pigmentation, Gram stain status, and presence or absence of recA, the gene encoding the RecA protein involved in UV repair, were determined. Cave bacteria were more sensitive to UV exposure and less able to repair UV damage than surface bacteria. Subsurface bacteria were equally distributed among high, low, and no pigmentation while surface bacteria were predominately pigmented. Cave bacteria were predominately Gram negative (75%), while surface bacteria were equally distributed between Gram negative and positive. Preliminary results suggest that surface and cave bacteria have both retained recA.

Microbial Community Fingerprinting of Cave Ferromanganese Deposits Using DGGE

Armand E. Dichosa[1], Jodie L. Van De Kamp[1], Donna Pham[1], P.J. Boston[2], M.N. Spilde[3], and D.E. Northup[4]

[1]*Dept. of Biology, Univ. of New Mexico, Albuquerque, NM 87131*

[2]*New Mexico Tech., 801 Leroy Place, Socorro, NM 87801 pboston@nmt.edu*

[3]*Institute of Meteoritics, Univ. of New Mexico, Albuquerque, NM 87131*

[4]*Dept. of Biology, University of New Mexico, Albuquerque, NM 87131*

Geochemical studies of cave ferromanganese deposits (FMD) have shown a good correlation between color of the deposit and the mineral composition; however, limited trends have been observed in the microbial compositions of the Lechuguilla and Spider Cave sites previously studied with molecular phylogenetic techniques. To further elucidate the nature of the FMD microbial community and to search for correlations between FMD color and microbial community composition, we undertook a community fingerprinting study using denaturing gradient gel electrophoresis (DGGE). FMD samples of different colors (pink, red, medium brown, chocolate brown, steel gray on calcite deposits, and black) were taken aseptically from the Grand Canyon area of Spider Cave in Carlsbad Caverns National Park. DNA was extracted from the samples using the MoBio Ultraclean Soil DNA extraction kit and an approximately 550 bp fragment of the 16S rRNA gene was amplified using DGGE primers 338F-GC (bacterial specific) and 907R (universal). The same techniques were also applied to enrichment cultures targeting manganese-oxidizing bacteria that were obtained by inoculating Mn-enriched media with FMD from Lechuguilla Cave. DGGE patterns showed the presence of dominant organisms across all colors of FMD.

Manganese and Iron Interactions: Cave and Surface Rock Varnish Communities and Processes Compared

P.J. Boston[1], M.N. Spilde[2], D.E. Northup[3], J. Bargar[4], R. Carey[5], and K. Mullen[6]

[1]*New Mexico Tech., 801 Leroy Place, Socorro, NM 87801 USA pboston@nmt.edu*

[2]*Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131 USA*

[3]*Dept. of Biology, University of New Mexico, Albuquerque, NM 87131 USA*

[4]*Stanford Synchrotron Radiation Laboratory, 2575 Sand Hill Rd., Bldg 137, Menlo Park, CA 94025 USA*

[5]*Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131 USA*

[6]*New Mexico Tech., 801 Leroy Place, Socorro, NM 87801 USA*

In both arid land caves and surface desert environments, microbial communities appear to interact extensively with iron and manganese, yielding deposits of intimately associated Fe and Mn oxides. In many cases, the geological context and bedrock composition of caves and overlying surficial outcrops are similar, but the differences between surface and subsurface environmental conditions are significant, e.g. humidity levels, or presence or absence of weathering. The manner of microorganism interaction with the rock environment may reflect these differences and be reflected in the resulting mineral deposits, although the underlying biological oxidation mechanisms of Mn and Fe may be similar.

We are analyzing the Mn and Fe deposition in the rock mineral coatings in caves and in surface rock varnish, identifying minerals that are potentially biogenic, and isolating organisms capable of mediating some of these processes. Synchrotron XRD and EXAFS measurements have revealed differences in the coating mineralogy (*e.g.* u-XAS and u-EXAFS measurements have revealed the presence of layer- (birnessite) and tunnel-structure (todorokite) Mn oxides in both environmental samples and cultured isolates). Electron microprobe analysis has revealed differences in trace element composition.

We are examining biodiversity in these communities by molecular phylogenetic techniques and have successfully induced production of biominerals similar to those found in caves, by laboratory isolates. The ultimate goal is to determine the degree of microbial responsibility for the secondary mineral deposits observed and the potential role of these communities in both dissolution of bedrock and deposition of surface oxide coatings in caves and rock varnish on surface materials.

Cave Restoration Forum

High Guads Restoration Project

Aaron Stockton, HGRP astockton@dncu.org, highguads@yahoo.com

The High Guads Restoration Project (HGRP) is a monthly volunteer project on the Guadalupe Ranger District of the Lincoln National Forest (LNF) in Southeastern New Mexico. The project provides restoration in caves on the district that have suffered impact from 40-plus years of use. In the mid-1990s, the United States Department of Agriculture Forest Service (USDA-FS) stopped issuing recreational permits to most of the popular caves on the Guadalupe District. They took this action after recognizing significant negative impact in these caves from both regular overuse and intentional vandalism. A stipulation evolved from the closing-the caves would receive large scale restoration work before being reopened to recreational cavers. Due to lack of funding, the FS proposed charging fees for caving tours and permits. Recognizing the dangers and increased negative impacts that wild cave tours would incur, cavers proposed to provide the restoration work themselves in lieu of fees. A figure of $100,000 annually in volunteer work was negotiated between cavers and USDA-FS officials. This number includes work done by caver volunteers annually on both the LNF in New Mexico and the Coronado Forest in Arizona. HGRP formed in 1998 and has donated over $350,000 in volunteer value and materials to the USDA-FS on the LNF alone. In 2005, 70 volunteers from eight states donated $60,000 in work and materials. In addition to restoration work, volunteers also survey, prepare step logs, and monitor recreational caves for visible negative impact. The group meets the last weekend of every month except December.

Cave Conservation & Management

The Caves of Sinking Valley

Larry Simpson, Larry.Simpson@cincinnati-oh.gov

The Caves of Sinking Valley have been surveyed and studied by hydrologists for over 30 years, yet new caves have been found within the last year. The 33-mi² drainage basin is not only a mother lode of caves, but during flood surges it can also be a force of nature. With the possible routing of I-66 over the most vulnerable section of the master conduit, it is imperative to understand how the road and other development could affect the cave and how the cave could affect the road.

Finding the Lost River of Onondaga Cave

Ben Miller, Department of Natural Resources, Missouri, Division of State Parks, Onondaga Cave State Park, 7556 Hwy. H, Leasburg, MO 65535 caverben@yahoo.com

Bob Lerch, USDA-Agricultural Research Service, Cropping Systems and Water Quality Research Unit, 269 Agricultural Engineering Bldg., University of Missouri, Columbia, MO 65211

Onondaga Cave State Park is located in the north central portion of the Ozarks near Leasburg, Missouri. The park is known for two extensive cave systems, Onondaga Cave and Cathedral Cave. Both of these cave systems have large streams (1–2 cfs at baseflow) which have unknown recharge areas. As a management consideration, a series of dye traces has been initiated to delineate the recharge areas of the caves. The project was started in winter 2003, with coordination between state and federal agencies. Standard dye tracing techniques were followed using three different dyes in order to maximize the number of potential injection points per round. It was necessary to work with surrounding landowners and other agencies in order to properly conduct the dye traces, as most of the recharge area lies outside the boundaries of the State Park. To date, Onondaga Cave has had three successful hydrologic connections to surface injection sites. A conservative estimate of the size of the Onondaga recharge area is about 8–10 mi², but dye-tracing work is on-going and will likely change this estimate. However, Cathedral Cave has eluded all attempts to connect it hydrologically to nearby surface streams. Information found thus far is now being incorporated into a cave management plan for the park to potentially aid in future management and possible future land acquisition.

Studying Cave Visitation Trends at Timpanogos Cave National Monument & Nutty Putty Cave

Jon Jasper, Resource Management Specialist, Timpanogos Cave National Monument, RR 3, Box 200, American Fork, UT 84003, Jon_Jasper@nps.gov

Visitation data is vital for properly managing the use of caves. This presentation will show how visitation information has been collected, organized, and analyzed for the tours at Timpanogos Cave National Monument, as well as for uncontrolled visitation problems of nearby Nutty Putty Cave.

Size, time, and date for each tour are recorded at Timpanogos Cave National Monument. The data was used to graph tour size frequency, seasonal and daily visitation fluxes, and the variability between tours sold and tours given.

At Nutty Putty Cave, a StowAway light intensity datalogger was used to record the maximum light exposures over 15-min intervals. This method collected high-resolution visitation data used to graph visitation by season, week, days of the week, and time of day.

At Nutty Putty Cave, a surface register was used to collect visitation demographics. The data showed that local Boy Scouts troops were the largest visiting group with 17% of the total visitation and that NSS grottos were the smallest visiting groups of 1% of the total visitation.

Visitation data is a useful tool that can drive management decisions and policy changes. At Timpanogos Cave National Monument, we are currently associating resource violations (such as touching formations, littering, and leaving tours) with visitation trends to reduce visitation impacts. At Nutty Putty Cave, visitation information helped convince the Utah State Trust Lands that better management practices are needed. Visitation information is vital toward creating valuable management data to support conservation decisions for these two heavily used caves.

Missouri Caves and Karst Conservancy

Joseph Walsh and Chandra Lawler, joe41641walsh@hotmail.com

The Missouri Caves and Karst Conservancy (MCKC) was founded in 1993 on the mission statement of cave conservation through ownership, management, and education.

The MCKC purchased Skaggs Cave, a 5,895-ft cavern in Pulaski County, in 1995. This cave is known for its speleothem displays, and is home to rare cave dwelling creatures. MCKC assisted the Ozark Regional Land Trust (ORLT) with the purchase and management of Sarcoxie Cave in Jasper County. Sarcoxie is home to the Ozark cavefish (*Amblyopsis rosae*) and the endangered Arkansas darter. Crystal Cavern, in Barry County, was leased by MCKC in 1996. The cave was once commercialized, and is now located in the center of a 125-ac parcel of land that has been logged. It is now almost surrounded by development. Plans for the cavern include improving the entrance and walkways, and developing it as an educational resource. MCKC manages 6,000-ft Dream Cave in Ozark County, in cooperation with ORLT and Ozark Highlands Grotto. Dream features unique geology and a significant population of rare bats.

MCKC continues its goals by helping other karst conservancies such as the Carroll Cave Conservancy, and assisting the USDA-FS in gating and patrolling other important Missouri caverns. Perkins and Bruce Caves are two others recently adopted by the MCKC. Future goals include the purchase of at least one additional significant cave, and the realization of our educational program in Crystal. You can help by becoming a member and/ or helping us find that special cave in need of preservation.

Karst Education: Working with Developers to Protect Natural Resources

Kriste Lindberg, Indiana Karst Conservancy, Director Education and Outreach Committee, lindberg@kiva.net

Development is expanding into more and more sensitive areas; the more difficult areas have been left for later because they pose additional challenges to engineers. Karst is included. There is tremendous need for conservation and development communities to work together in protecting natural resources. The gaps between the two must be narrowed. Education can be vital to the process; it can be seen as nonthreatening and balanced. A good place to start is on middle or common ground where both sides can agree and strike a balance between environmental, social, and economic concerns to achieve sustainability. Once the parties come to terms, all can move forward from recommendation to implementation. The City of Bloomington, Indiana is engaged in the karst education endeavor through their Environmental Commission and related commissions, agencies, and community partners. Their example can be used as a model for other areas. During the presentation, an overview of developer education will be discussed along with a few success stories.

Considerations for Cave Rescue Planning: A Case Study of the 2004 Rescue Preplan for Lechuguilla

John Punches, National Coordinator NCRC
Anmar Mirza, Central Region Coordinator NCRC
Stan Allison, Carlsbad Caverns National Park
Tom Bemis, Carlsbad Caverns National Park

Resource managers, cavers, and caves benefit from rescue planning by cave rescue experts. Rescue plans address personnel and equipment needed, management structures, interfacing with cavers, rigging challenges and obstacles. Plans identify sensitive areas of the cave to mitigate damage. Effective rescue planning prioritizes main routes and hazards, and identifies and prepares for high probability scenarios. A cave rigged with rescue in mind is easier and safer to travel, and in the event of a rescue incident, vastly improves evacuation time while minimizing resource damage. Lechuguilla presents unique challenges for cave rescue planning due to the sensitive physical and biological environments. We offer it as a case study on rescue planning and rigging for contingencies.

Cave and Karst Resources of the Virginia Department of Conservation and Recreation Natural Area Preserve System

Joey Fagan, Larry Smith, Mike Leahy, and Wil Orndorff, Virginia Department of Conservation and Recreation, 6245 University Park Drive Suite B, Radford, VA 24141 joseph.fagan@dcr.virginia.gov

The Virginia Natural Area Preserve System serves to protect 45 natural areas, covering more than 38,500 ac across the Commonwealth of Virginia. The Virginia Natural Areas Preserves Act, passed in 1989, directed the Department of Conservation and Recreation (DCR) to establish a nature preserve system to ensure the permanent protection of these unique assets. Acquisition, dedication, and stewardship of natural areas in the Virginia Natural Area Preserve System are the responsibility of the DCR Natural Heritage Program. A wide variety of natural communities and habitat are represented in the system, including nine natural area preserves in Virginia's Ridge and Valley Physiographic Province containing significant caves and other karst resources.

Unthanks Cave and the Cedars Natural Area Preserves in Lee County support several species of cave-dwelling fauna that are federally listed as endangered or are globally rare species of concern. It should be noted that the Virginia Chapter of The Nature Conservancy generously gave the Unthanks Cave Preserve to DCR. Stay High Cave, in the recently purchased Clover Hollow Natural Area Preserve in Giles County, contains several globally rare cave obligate invertebrates that are species of concern. Unique soils and moisture conditions associated with karst provide habitat for globally rare flora and fauna species. Cleveland Barrens and Pinnacle Natural Area Preserves (NAPs) in Russell County, Pedlar Hills NAP in Montgomery County, Mount Joy Pond and Folly Mills Creek Fen NAPs in Augusta County, and Deep Run Ponds NAP in Rockingham County are all situated on karst terrane.

Tourism, Drought, and Climate Changes at Kartchner Caverns (Arizona, USA)

Rickard S. Toomey, III and Ginger Nolan, Kartchner Caverns State Park, PO Box 1849, Benson, Arizona, 85602, USA rtoomey@pr.state.az.us

Kartchner Caverns is a recently developed show cave in southeastern Arizona. One tour opened to the public in November 1999 and another opened in 2003. These openings followed more than 11 years of work in predevelopment studies, planning, and construction, carried out by the Arizona State Parks. Monitoring was initiated during the earliest studies and continues today.

The monitoring includes cave microclimate parameters (temperature, humidity, evaporation, CO_2, and radon), surface climate, and groundwater levels in adjacent aquifers. Some changes in temperature and humidity have been detected. Mean temperatures have risen by up to 2° C, and mean relative humidity has decreased by up to 2.5%. The amount of change varies within the cave, but generally, changes are most extreme in the most intensively developed areas. Comparison of the changes at Kartchner Caverns with some undeveloped caves, with local and regional surface climate data, and with groundwater data in the vicinity suggests that much of the change seen at Kartchner can be attributed to regional changes in climate; however, data show that development and tourism are also factors. Arizona State Parks continues to study and monitor Kartchner Caverns both to better understand the interaction of the various factors in the cave's climate and to be able to respond to changes as needed.

Protecting Underground Cultural Resources: Cagle Saltpeter Cave, Tennessee

Joseph C. Douglas and Kristen Bobo, Joe.Douglas@volstate.edu

In 2003 cave resources specialists and the management of Fall Creek Falls State Park decided that proactive protection of the historic cultural resources in Cagle Saltpeter Cave might be needed. The cave is a well-preserved antebellum industrial landscape, and historical consultants verified its importance and vulnerability. While investigating the cave's historic resources it was discovered to be an important prehistoric site as well. To facilitate its preservation, partnerships were established between the Park (the State of Tennessee), the University of Tennessee Cave Archaeology Research Team, Friends of Fall Creek Falls, The Nature Conservancy, the Upper Cumberland Grotto, and individual cavers. Caver and conservationist Kristen Bobo agreed to design and build an appropriate gate for the site, funds were raised, supplies acquired, and site preparation was undertaken throughout the spring and summer of 2004. In designing protection for the site, consideration was also given to the cave's important biological resources, including significant new biological research on site. In the fall of 2004 the various partners came together and constructed a bat (and invertebrate) friendly gate, using standard ACCA specifications, thus dovetailing the protection of underground historic, prehistoric, and biological resources.

The Evolution of the BeCKIS Project for Cave Inventory and Conservation in Bermuda

Bernard W. Szukalski, Cave Research Foundation bszukalski@esri.com

The Bermuda Cave and Karst Information System (BeCKIS) project has been an ongoing project for three years, and serves to increase public awareness of Bermuda's caves and cave life, increase awareness of negative impacts on these resources, and promote the scientific study of Bermuda caves. A countrywide GIS database has been established to serve these goals, and to maintain an inventory of locations, field observations, cave survey data, and maps. This system incorporates data collected over 25 years, and has been used to examine changes in various measured cave parameters over time, the effects of development and land use practices, and as a communications tool for public awareness and scientific study. A workshop in February brought scientists and cavers from across the globe together with government agencies and local research organizations to examine progress thus far, and to leverage these experiences forward to new project areas and goals.

Hualalai Ranch – A Cave to Be Conserved for All and All Time

John Rosenfeld and John M. Wilson, john@wilsonj.org

The size and significance of Hualalai Ranch Cave in Hawaii County, Hawaii is becoming more and more evident with each expedition. It appears to be a world class cave in many respects, and it merits protection and management appropriate to its importance as a significant cave.

Nevin Davis has reported that the cave has 15.72 mi of mapped passage, as of January 2005. This qualifies it as the longest cave in west Hawaii. Besides length and depth, it exhibits unique, significant geology, aesthetics, biology, and archaeology. Hualalai Ranch Cave is a multi-level maze with many parallel branching and braided passages. One can find all the usual lava formations found in other lava caves. It has an abundance of puka entrances, so one can enter the system at many different places. Fountain grass, a nonnative species, dominates the surface at lower elevations, and goats have destroyed most of the native plants. However, a few pukas have such steep walls that the threatened native plants in them have so far survived. The higher elevations have a dryland forest composed of a mixture of native and introduced species. It is home to several threatened bird species, including the Hawaiian hawk and owl.

Several areas of the cave are exceptional for their secondary mineral deposition. These areas of HRC are not awe-inspiring in the way that portions of Lechuguilla Cave can inspire with massive formations, but rather in an understated aesthetic way that requires one to stop and get close. A person who is not paying attention to detail might go through Puffball Hall and not think anything more about it than that it is whiter than most lava caves. Closer examination has revealed numerous unusual minerals, such as gypsum beards. In addition, a portion of the cave contains a wide exposure of xenoliths in the cave wall. The cave also has significant archaeological sites. Portions of the cave were used for short-term occupation, refuge, and possibly for ritual purposes.

Geology and Geography

Geology and Geography Poster Abstracts

Commonwealth of the Northern Mariana Islands

T. Monty Keel[1,2], John Jenson[2], John Mylroie[1], and Joan Mylroie[1]
[1]Department of Geosciences, Mississippi State University, Mississippi State, MS 39762
[2]Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao, Guam 96923

Rota, like the other islands in the Mariana Arc in the western Pacific, was created primarily by Late Eocene to Early Oligocene volcanism. Rota is mantled by limestone, but has some outcrops of volcanic rocks. The interactions of highly permeable eogenetic limestone, low permeability volcanics, tectonically-driven uplift, and eustatic sea level changes have created an assemblage of caves on Rota distinct from the cave assemblages documented on Guam, Aguijan, Tinian and Saipan, the other islands in the Mariana Arc on which caves have been investigated. As predicted by the Carbonate Island Karst Model, Rota has a large number of flank margin caves, developed by mixing dissolution under diffuse-flow conditions at the edge of the fresh-water lens. Rota also has a significant number of mixing-zone fracture caves developed by mixing dissolution as water from the lens discharged along pre-existing fractures (*i.e.* sea level springs). Rota has a few hydrologically important contact caves. Two extensive zones of vertical fissures were also found on Rota, among them is the deepest cave on the island. Although caves have been found on Rota from sea level to within a few meters of the summit at 496 m, fewer caves have been found at higher elevations. This is probably the result of a combination of more difficult exploration at higher elevations due to thick jungle cover, and destruction of older/higher caves by dissolution and mass wasting of the hill slopes and cliffs that contain the caves.

The Speleogenesis of Large Flank Margin Caves of the Bahamas

Ioan Lascu[1] and John E. Mylroie, Department of Geosciences, Mississippi State University, Mississippi State MS, 39762 [1] nono_acu@yahoo.com

Flank margin caves are abundant in the Bahamas, where they are believed to have developed by mixing dissolution during the last interglacial sea-level highstand, Oxygen Isotope Substage (OIS) 5e. The tight spatial and temporal controls that govern their genesis and evolution–formation in the margin of a freshwater lens, under the flank of the enclosing landmass, in approximately 12,000 years–explain for the most part their size and location, 2–7 m above modern sea level. Several large flank margin caves on Eleuthera, Long, Crooked and San Salvador islands stretch these constraints to the limit. These voids have areal footprints between 1,000 and 10,000 m², some have phreatic dissolutional ceilings that are well over 10 m in elevation, and often show evidence of reinvasion by a freshwater lens. Here we investigate whether these incongruities with the current model can be explained as effects of local geological and hydrological conditions, or if a more widespread mechanism needs to be invoked. Their large size can be explained by the intersection of small or medium-sized voids, the high phreatic ceilings can be caused by perching of the water table by relatively impermeable paleosol calcretes, and the speleothem etching could have occurred intra-OIS 5e. The alternative is formation during a pre-OIS 5e highstand, the most likely candidate being OIS 11, a prolonged period of warmth and possible very high sea level. This would address the problems, but the evidence of such a highstand is scarce and uncompelling throughout the Bahamas and the world.

Geologic and Hydrologic Observations from Wanhuayan Cave, Hunan, China

Andrea Croskrey[1], Pat Kambesis[1], Ben Tobin[1], Mike Futrell[2], Kevin Downey[3], Johanna Kovarik[1], Chris Groves[1], Jiang Zhongcheng[4], and Jiang Guanghui[4]
[1]Hoffman Environmental Research Institute, Western Kentucky University, Bowling Green, KY 42101
[2]1580 Oil Well Road, Blacksburg, Virginia 24060
[3]21 Massasoit Street, Northampton, Massachusetts 01060-2043
[4]Karst Dynamics Laboratory, Guilin, China

Wanhuayan Cave is a world-class show cave located just outside of the city of Chenzhou in Hunan Province. Our group to Wanhuayan was sponsored by the Hoffman Environmental Research Institute, Karst Geology Institute Guilin, and Wanhuayan Cave Company to do a detailed resource inventory and resurvey of the developed section of the cave, determine the recharge area of the system, and to make in-cave geologic observations and measurements. In order to accomplish the task of delineating the recharge area, two dye traces were completed that linked Songja (6 km away) and Zhenyan caves (1 km away; both are major insurgences) to the main stream in Wanhuayan Cave. Structural geology measurements were taken in the cave that identified four joint sets and a bedding plane that strikes to the southwest and dips to the north. A sample of the bedrock was also taken to make a thin-section to identify the lithology and petrology of the Mississippian-aged carbonate, since the rock may be marble instead of limestone. Also, granite boulders greater than 1 m in diameter are located in the cave stream, indicating a source for allogenic recharge in close proximity. This is also interesting considering that the presence of numerous speleothems, and cave streams with a pH of 8, are indicative of autogenic recharge. A final interesting note is the grussy floor, weathered granite, and elevated temperatures found in Zhenyan Cave, which is located on the northern end of Wanhuayan's groundwater basin.

Multi-Tracer Approach for Evaluating the Transport of Whirling Disease to Mammoth Creek Fish Hatchery Springs, Utah

Larry Spangler, U.S. Geological Survey, Salt Lake City, Utah spangler@usgs.gov

The Utah Division of Wildlife Resources has been concerned about the vulnerability of selected spring-fed fish hatcheries to whirling disease, caused by a microscopic parasite that infects species of trout and salmon. Whirling disease can potentially migrate along underground pathways in areas where aquifer permeability is high, such as in volcanic and karstic terrains, and where ground-water movement is rapid enough to allow passage and survival of the spores. Mammoth Creek fish hatchery in southwestern Utah tested positive for whirling disease in 2002. Because a nearby losing stream also tested positive, a study was begun to evaluate potential hydrologic connections between the stream and the hatchery springs.

Fluorescent dye-tracer studies indicate that water lost through the channel of Mammoth Creek discharges from the hatchery springs. Ground-water time of travel through the basalt aquifer was about 8 hours over a distance of 3,000 ft, and well within the two-week timeframe of viability of whirling disease spores. However, results of studies using soil bacteria and club moss (Lycopodium) spores as surrogate particle tracers to simulate the size (up to 100 µm) of the parasite indicate that the potential for transport through the fractured basalt may be low. Substantial losses of particles occurred during streambed infiltration and within the aquifer. Bacteria concentrations were generally below reporting limits, and club moss spores were recovered from only a few samples. However, peak concentrations for the bacteria and club moss spores in water from the east hatchery spring coincided with peak dye recovery.

Possible Source of Hydrogen Sulfide Gas in Cueva de Villa Luz, Tabasco, Mexico

Michael N. Spilde[1], Laura Crossey[1], Tobias P. Fischer[1], H.J. Turin[2], and Penelope J. Boston[3]
[1]Department of Earth & Planetary Science, University of New Mexico, Albuquerque, New Mexico 87131
[2]Los Alamos National Laboratory, Los Alamos, New Mexico 87545
[3]Dept of Earth & Environmental Science, New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801

Cueva de Villa Luz, in Tabasco, Mexico, is an active hypogenic cave system producing prodigious quantities of hydrogen sulfide (300–500 mg/L) from many of its more than twenty springs. Sporadic and rapid gas outbursts exhibit concentrations of H_2S rising from <30 ppm to >200 ppm within a few minutes. Three potential sources exist for spring water H_2S: 1) the Villahermosa petroleum basin, ~65 km to the north, 2) the El Chichon volcano (~50 km to the west), or 3) microbial sulfate reduction taking place in Cretaceous evaporite beds below the cave. Water analyses from four cave springs yield remarkably similar results, despite clear differences in oxidation/reduction potential of discharge water. A spring gas sample contained CO_2, H_2S, N_2, He, and CH_4, minor Ar, H_2 and O_2, but no measurable CO. The N_2/He (4500) and He/Ar (0.9) of the sample indicate a mantle component. Helium isotope ratios (R/R_A = 1.8 where R_A = $^3He/^4He$ of air) are significantly higher than crustal values (~0.02–0.05 RA) but lower than pure magmatic gas (8 RA), suggesting that a mixture containing about 22% magmatic He is discharging into the cave. Comparison of cave water with hydrothermal fluid derived from El Chichon yields a mixture of mostly meteoric water with a hydrothermal contribution of 16%. Light sulfur isotopic values of H_2S and high sulfate content of the water suggest that much of the H_2S could be derived from microbial sulfate reduction taking place along the flow-path before water enters the cave.

CAVES AND MESOCAVERNS AS SHELTERS DURING THE END-CRETACEOUS EXTINCTION

William R. Halliday, Hawaii Speleological Survey, 6530 Cornwall Court, Nashville, Tennessee 37205 bnawrh@webtv.net

Writing in GSA Bulletin Volume 116 (2004), Robertson *et al*. proposed natural cavities as one of two principal mechanisms of vertebrate survival during the end-Cretaceous (K-T) extinction. Yet these investigators almost completely excluded caves and mesocaverns in their reasoning. Further, they focused their considerations on birds. Present knowledge of small Cretaceous and Paleocene mammals and of distribution of late Cretaceous karsts and potentially cavernous pseudokarsts are reviewed in the context of subsurface habitats of modern analogues and relevant genetic concepts. It is hypothesized that late Cretaceous mammals included important spelean populations likely to have survived the K-T extinction. Further study of Cretaceous/Paleocene paleokarsts and of crevice fills and breccias is proposed to test this hypothesis. Biospeleologists should be included in interdisciplinary teams studying such survivals.

GEOLOGY AND GEOGRAPHY ORAL SESSION ABSTRACTS

CHINESE KARST TERMINOLOGY

Dwight Deal, P.O. Box 61228, Denver, Colorado 80206 DirtDoc@Comcast.Net

Many things about Chinese culture are confusing to westerners (and vice versa), and their karst literature is no exception. Western descriptions of tropical karst focus on hill and depression morphology distinguishing between the steepness of hillside slopes. Tower karst has steep, cliffy slopes while cone karst has lower slope angles. Classic Chinese descriptions distinguish on the basis of the degree of separation of the adjacent hills.

Two end-members are defined in the Guilin-Yangshuo area as:

1. Fenglin (pronounced fung-lin), peak-forest karst, where isolated peaks rise from a flat plane. Isolated, near-vertical towers rise like tree trunks in a forest from the surrounding fields. These landforms appear very similar to tower karst in Western literature, but the concept behind the classification is different. Foot caves in tower bases are characteristic of fenglin karst.
2. Fengcong (pronounced fung-sung), peak-cluster karst, is formed by clustered towers with a common base. The bases of adjacent steep-sided (usually cone-shaped) hills merge to form clusters of hills. These landforms appear very similar to cone karst or cockpit karst in Western literature, but the concept behind the classification is different.

Most of the high-relief karst in the world falls into the Chinese category of fengcong karst. In contrast, 90% of the fenglin karst in the world occurs in China, and most of that is in the Guilin-Yangshuo area. The Chinese have defined numerous subcategories of these two karst types that translate as margin-type peak-forest plain karst, peak-cluster gorge karst, intervalley peak-cluster karst, and many more.

THE GEOLOGY OF NATURAL STONE BRIDGE & CAVES, POTTERSVILLE, NEW YORK

Thom Engel, 16 Equinox Court #2A, Delmar, New York 12054

Natural Stone Bridge & Caves is a series of hydrologically-related caves formed in highly metamorphosed, crystalline, Grenville-age marble. The caves result from the sinking and resurgence of Trout Brook. The drainage area upstream from the sink is 230 km² (90 mi²). The water is almost entirely allogenic in origin.

The caves are well adjusted to the local drainage. Presumed derangement by Pleistocene glaciation would suggest that the caves are post-glacial in age. The basin relief ratio and water chemistry seem to support this conclusion. The caves have large cross-sections by New York standards, though they are short. The largest cave in the group has an entrance 50.5 m (166 ft) wide by 10 m (32 ft) high.

GEOLOGY OF OREGON CAVE REVISITED

William R. Halliday, 6530 Cornwall Court, Nashville, Tennessee 37205 bnawrh@webtv.net

No refereed report on the geology of Oregon Cave has been published, and much misinformation is in print. My 1969 *NSS Bulletin* account of the cave contained an accurate account of its geology in terms of then-current concepts. But knowledge of western caves in marble and of the geomorphic history of such marbles has expanded vastly. Oregon Cave now is seen as a fairly small example of a dissolution cave of the Lilburn Cave type, characterized by an extraordinarily rapid dissolution rate and by development of a complex three-dimensional braided network of passages in a limited vertical range below steep feeder routes. The marble is part of a melange which may represent subduction metamorphism of a continental fringing reef or part of the process of accretion of a terrane or "string continent". This is irrelevant to speleogenesis, and discussions of the geology of the cave must be differentiated from those of the geology of its surroundings in Oregon Caves National Monument. As in many of the marble caves of the Klamath Mountains and Sierra Nevada, the cave extends to the edge of its marble body. The non-calcareous rocks exposed by such speleogenesis are not part of the cave.

SPELEOGENESIS WITHIN AN ANTICLINAL VALLEY: HELLHOLE CAVE, WEST VIRGINIA

Dan Zinz and Ira D. Sasowsky, Office for Terrestrial Records of Environmental Change, Dept. of Geology & Center for Environmental Studies, University of Akron, Akron, OH 44325-4101 Tractorboy52@msn.com; ids@uakron.edu

Hellhole is an extensive (32 km) cave system developed within Germany Valley (Pendleton County, West Virginia) on the flank of the Wills Mountain Anticline. It is the most extensive of several mapped caves in the area (others include Memorial Day Cave and Schoolhouse Cave). Hellhole is the deepest cave in the valley (158 m). The upper bounding lithology is the McGlone Limestone. The cave penetrates through the Big Valley Formation and into the New Market Limestone, a high purity unit that tends to form large rooms. Faulting and folding are prominently exposed in several passages, but did not affect passage development in a noticeable way. The entrance sinkhole opens into a large room, but the catchment for the sinkhole is limited, suggesting that the room formed the entrance by collapse. Passage orientation and strike of the bedrock are nearly identical (025°). Lower passages are generally down dip from upper (older) passages. Three hundred measurements of wall scallops show that paleowaters in the historical section flowed north and west (2.5 m³/s). Paleoflow from the southern portion of the cave flowed northward (2.3 m³/s), and flow in the northern section flowed southward (1.4 m³/s). Most passages are 50 to 100 m below the present land surface. Most of the cave appears to have formed under phreatic conditions, but the presence of thick clastic sediments in some locations attests to vadose invasion.

THE CAVES AND CONE KARST OF ABACO ISLAND, BAHAMAS

Lindsay N. Walker, Adam D. Walker, John E. Mylroie, and Joan R. Mylroie, Department of Geosciences, Mississippi State University, 108 Hilbun Hall E. Lee Blvd., Mississippi State, MS 39762

Flank margin caves are a common feature of the Pleistocene eolianite ridges of Abaco Island, Bahamas, where they are proxies for past interglacial sea-level highstands. It has been accepted in the tectonically-stable Bahamas that the highest cave-forming sea-level highstand of the Pleistocene was the +6 m of the last interglacial, OIS5e ~125 ka. Southern Abaco, however, has an eolianite ridge with a series of apparent flank margin caves at an elevation of ~15 m, calling earlier dogma into question.

Abaco also has landforms that bear a striking resemblance to tropical cone karst, features not known from other Bahamian islands. These hills are symmetrical in shape, range in height from 6–20 m, and are formed from the erosional dissection of eolianite ridges. One slope of the hill follows the dip of the foreset beds while the other slopes are formed by truncation of the beds to form a nearly symmetrical cone. The absence of surface streams on Abaco implies that meteoric subaerial dissolution is the dominant process. One element of meteoric dissolution is pit cave formation, which causes slope failure on the periphery of the hills. The land surface is further mobilized by forest fire-induced exfoliation of the eolianites. As eolian ridges initiate with high relief, rock loosened by fire and epikarst processes mass-wastes downslope to create the relative symmetry of the hills. Abaco is the only Bahamian Island that has both the high eolian relief and climate with a large positive water budget necessary for the observed erosion.

Anthropogenic Exhumation of Karst: Residual Ore Mining in Southwest Virginia

David A. Hubbard, Jr., Department of Mines, Minerals and Energy, P.O. Box 3667, Charlottesville, Virginia 22901 david.hubbard@dmme.virginia.gov

Recent work inventorying and classifying mine features for a GIS-compatible mineral resource database has resulted in a reappraisal of the origin and nature of mineral resource deposits in Virginia karst. The exhumed pinnacles and subsoil karren forms comprise the most significant assemblage of the normally covered karst features known in the state, and the distribution of the mines and prospects conveys much about the nature of the deposits and the evolution or succession of karst geomorphology. Some of the barite deposits are true residual ore deposits concentrated in small karst traps as the barite is freed from its carbonate host. Most of the iron and manganese deposits located in Virginia's karst are essentially replacement ores that were concentrated in the active karst belt. The karst-associated lead and zinc ores are even more interesting and result from the dissolution of carbonate rocks hosting Mississippi Valley sulfide deposits. Alteration and secondary formation of lead and zinc deposits as rinds on carbonate pinnacle surfaces were mined by open-pits and by shafts, which were sunk through cover sediments to the secondary ores mantling karst pinnacles. Miners stripped the secondary ores from the flanks of the covered bedrock pinnacles. The resulting karst is one modified by anthropogenic exhumation of normally covered karst and sinkholes formed by the collapse of karst cover into mined voids overlying ancient karst. In some cases, the mining appears to have allowed ore-clogged karst to reactivate and once again take water.

Rare Cave Minerals and Features of Hibashi Cave, Saudi Arabia

John J. Pint, PMB 014-185, 413 Interamerica Blvd. WH1, Laredo, TX 78045 USA thepints@saudicaves.com

Ghar Al Hibashi is a lava tube situated in a field of vesicular basaltic lava flows located east of Makkah, Saudi Arabia. The cave has 581 m of mainly rectilinear passages containing a bed of loess up to 1.5 m deep, optically stimulated luminescence-dated at 5.8±0.5 ka BP at its lowest level, as well as many bones and the desiccated scat of hyenas, wolves, foxes, bats, etc., well preserved due to a temperature of 20–21° C and humidity of 48%. Phytoliths have been found inside plant material preserved in samples of this scat. A human skull, 425 years old, and the remains of an old wall indicate a potential for historical or archaeological studies. The loess bed is under study for testing microrobotic designs to navigate inside lava tubes on Mars.

Nineteen minerals were detected in samples collected, mostly related to the biogenic mineralization of bones and guano deposits. Three of them, pyrocoproite, pyrophosphite and arnhemite are extremely rare organic compounds strictly related to bat guano combustion, observed until now only in a few caves in Africa. Hibashi Cave may be one of the richest mineralogical shelters of the Arabian Peninsula, and has been included in the list of the ten mineralogically most important lava caves in the world.

Secondary Minerals in Volcanic Caves: Data from Hawai'i

William B. White, Materials Research Institute and Department of Geosciences, The Pennsylvania State University, University Park, Pennsylvania 16802

Lava tube caves contain a surprising variety of secondary minerals formed by seepage waters extracting components from the overlying rock and depositing them as crusts, crystals, and small speleothems in the underlying tube. Some 50 specimens were collected in the course of a reconnaissance of a selection of caves on Hawai'i. Many of these were from caves at low elevation near the coast where the cave environment is wet and at ambient temperature. Some were from a cave at 2900 m on Mauna Loa where conditions were much drier. Minerals in hot fumarole caves in the Kilauea Caldera were observed but not sampled. Mineral identifications were made by X-ray diffraction with some assistance from a scanning electron microscope with energy dispersive X-ray detector for bulk chemistry analysis. Calcite is surprisingly common, appearing in the form of small coralloids and other crusts and coatings. Gypsum is common as crusts and as "puffballs." Other sulfate salts such as thenardite and mirabilite were identified. Two unusual occurrences were the transition metal ions vanadium and copper. The vanadate ion was responsible for yellow-green patches on the floor of Lama Lua Cave, and copper salts formed the bright blue-green coatings on lava stalactites in the Kapuka Kanohina System.

Physics-based Micrometeorological Modeling of Idealized Caves: Predictions and Applications to Carlsbad Cavern, NM, USA

P.J. Boston[1,2], S. Shindo[1,2], P. Burger[3], and J.L. Wilson[1]

[1]*Department of Earth and Environmental Sciences, New Mexico Institute of Mining and Technology, New Mexico, pboston@nmt.edu*

[2]*National Cave and Karst Research Institute, Carlsbad, New Mexico*

[3]*Carlsbad Caverns National Park, New Mexico*

Cave micrometeorological processes may contribute to the formation and subsequent enlargement of caves and control some of the details of secondary mineral deposition. For example, airflow has been suggested as a possible factor controlling occurrences of cave popcorn, and convective-cell-driven condensation hypothesized as the cause of Fe/Mn corrosion residue deposits in caves like Lechuguilla Cave, New Mexico.

We have modeled the internal fluid-thermal dynamics of geometrically idealized air-filled caves (focusing on buoyancy and natural convection due to geothermal heating) by creating two-dimensional computer models using FEMLAB multiphysics computer software. Thermal properties of limestone and air and geothermal flux were incorporated. The models couple the incompressible Navier-Stokes equations with the thermal energy convection and conduction equation using the finite element method. We have developed a variant Rayleigh number for this application.

Although the constructed models are limited in scale and have highly simplified geometries compared to real caves, they have identified important factors that may influence internal cave dynamics. Predicted phenomena include natural convection cells, insulation effects of air-filled cavities, thermal effects of speleothems, effects on airflow patterns resulting from chamber and passage aspect ratios, effects of size of entrance passage, and modifications of all of these with the presence of multiple entrances especially at different elevations.

Using Carlsbad Cavern as a test case, we have applied model predictions in an attempt to explain permanent airflow, temperature, and humidity data. These experiments show that modeling can be a powerful tool to understand the internal dynamics of caves.

Quantitative Evaluation of Data Quality in Electronic Data Logging of Karst Flow Systems

Chris Groves[1], Carl Bolster[2], and Joe Meiman[3]

[1]*Hoffman Environmental Research Institute, Western Kentucky University, Bowling Green, Kentucky 42101*

[2]*USDA ARS Animal Waste Management Research Unit, Bowling Green, Kentucky 42101*

[3]*Division of Science and Resource Management, Mammoth Cave National Park, Mammoth Cave, Kentucky 42259*

A characteristic of many karst flow systems is rapid variation in the flow and water chemistry conditions that govern system evolution and function. Recently progress has been made with the use of electronic probes and digital data loggers in understanding the details of these processes. Some parameters can be measured directly, while others can be statistically related to direct observations, and from these a variety of useful quantities can be derived. A challenge in this work, however, lies in the quantitative evaluation of data quality.

We report here our effort underway within Cave Spring Caverns, Kentucky to rigorously define the practical limits of reported precision (associated with the reproducibility of a result) and accuracy (conformity with the true value of the measured parameter) in karst water monitoring by working under essentially ideal conditions of easy access, equipment security and available electricity. After measuring flow through a tipping bucket rain gauge to develop a rating curve, water from an underground waterfall is monitored for temperature, pH, and SpC by three independent probe/data logger (Campbell CR10X) systems with two-minute resolution. This redundancy reduces the probability of data loss by equipment malfunction and allows calculation of a standard deviation to quantify measurement precision. Early results show that data can be obtained within one standard deviation of <0.2° C for temperature, <4 µS/cm at 25° C for specific conductance, and <0.01 unit for pH. We continue to evaluate accuracy issues, especially for pH with highly precise measurements complicated by instrument differences and carbon dioxide degassing.

Geological Factors Affecting the Distribution of Cave-Dwelling Species and Their Implications on the Evolution of Karst Landscapes

George Veni, George Veni and Associates, 11304 Candle Park, San Antonio, Texas 78249-4421 gveni@satx.rr.com

Karst and some non-karst cavernous areas provide habitat to species adapted to spending their entire lives underground. Many of these species are rare and some endangered. These areas occur across diverse biomes, climates, topographies, and geologies, and have even more complex ecological, climatic, and geological histories. These factors are usually intertwined in how they impact and sometimes dictate the distribution and evolution of cave- dwelling species. Six basic geological factors influence and determine subterranean biodiversity: lithology, structure, burial, hydrology, climate, and landscape evolution. Their overall effect is to provide potential habitat for cave-dwelling species, connectivity between populations, and restrictions and barriers to gene flow. Speciation often results when populations become isolated. Genetic isolation can be complete, a barrier to species' distribution, or partial, a restriction to their distribution. In the case of restrictions, gene flow occurs through relatively small areas and/or areas traversable only for relatively short periods of time. While geological factors can be used to predict species distribution, species distribution can also be used to reconstruct past landscapes and groundwater hydrologies. Areas with genetically identical populations suggest geologic continuity. However, the degree of difference between populations may show not only geological discontinuities, such as erosion or faulting separating areas of cavernous rock, but reflect when those discontinuities developed. Studies of aquatic fauna are particularly useful in assessing current and previous hydrological connections in karst aquifers.

Stygobite Phylogenetics as a Tool for Determining Aquifer Evolution

Jean K. Krejca, Zara Environmental LLC, 118 W. Goforth Road, Buda, TX 78610 jean@zaraenvironmental.com

The use of aquifer-dwelling organisms (stygobites) for learning about past and present subterranean hydrologic connections was evaluated in the Edwards (Balcones Fault Zone), Trinity, and Edwards-Trinity (Plateau) aquifers of Texas and adjacent areas in north Mexico, an area with complex karst groundwater flow and sociopolitical problems stemming from overuse and contamination. Using likelihood and parsimony based comparisons, *Cirolanides* (Isopoda: *Cirolanidae*) were found to have a phylogenetic history congruent with *a priori* predictions of subterranean hydrogeologic history in its terminal nodes. Branches of the phylogenetic tree originating from basal nodes had similar terminal taxa, but their placement was not as predicted by hydrogeologic history, a phenomenon that may be indicative of a lack of hydrogeologic understanding of the area. *Lirceolus* (Isopoda: Asellidae) had a phylogenetic history congruent with an alternate hypothesis, patterns of surface drainages. This difference of patterns for two species that both live in the aquifer is probably related to their evolutionary history, with *Cirolanides* having invaded the cave habitat as a single marine population and *Lirceolus* invading the cave habitat as a freshwater migrant with possible pre-existing genetic structure determined by surface drainages. This study pioneers the testing of *a priori* biogeographic hypotheses using phylogenies of aquifer organisms and the creationof hydrogeologic histories in a karst setting, and supports the use of similar methods to aid in understanding biogeography and aquifer evolution.

Tracing Flowpaths in the Balcones Fault Zone Section of the Edwards Aquifer in South-Central Texas

Geary Schindel[1], Steve Johnson[1], and George Veni[2]
[1]*Edwards Aquifer Authority, 1615 N. St. Mary's, San Antonio, Texas 78215*
[2]*George Veni and Associates, 11304 Candle Park, San Antonio, Texas 78249-4421*

The Edwards Aquifer Authority performed a series of tracer tests in the Edwards Aquifer Recharge Zone in northern Bexar County, south-central Texas. The tests were performed as part of the Authority's Focused Flow Path Studies to determine: ground-water flow paths, the effect of major faulting in controlling groundwater flow in the recharge zone, the relationship between recharge and discharge/monitoring sites, and to determine ground-water velocities. Tests were performed in the Panther Springs Creek ground-water basin. Panther Springs Creek, a small ephemeral stream, flows north to south across the width of the recharge zone.

Seven tracer tests were performed in the northern Bexar County area. Sixteen monitoring, irrigation, and municipal water supply wells, completed in the Edwards and underlying Trinity Aquifer, were sampled for dye. Dyes injected into both the Edwards Limestone and Upper Glen Rose Limestone moved from north to south toward the Edwards Aquifer Artesian Zone. The dyes from the tracer tests crossed as many as six major faults, some with displacements of over 30 m. Ground-water velocities ranged from 24 to more than 4,000 m/day, and tracer test distances ranged from 600 to more than 7,600 m. Tracer test data showed that groundwater from the Glen Rose Limestone (Trinity Aquifer) is flowing into the Edwards Limestone (Edwards Aquifer) where the formations have been juxtaposed by faulting. These data have important implications related to the Edwards' water budget as well as protection of water quality.

Digital Compilation of Tennessee Ground Water (Dye) Traces

Albert E. Ogden, Josh R. Upham, and Brandon S. Walsh, Department of Geosciences, Box 9, Middle Tennessee State University, Murfreesboro, Tennessee 37132 aogden@mtsu.edu

It is estimated that more than 300 ground-water (dye) traces have been conducted in Tennessee, but the results are scattered throughout many reports and publications and thus, not readily assessable to State agencies that need to respond immediately to a hazardous materials spill or toxic release. Such tracing data are also needed by consulting firms working on new sites, counties experiencing sinkhole flooding problems, and cavers looking for caves. Through a grant from the TDEC-Ground Water Management Section, over 250 ground-water traces have been placed, to date, onto a digital GIS database with topographic overlays. The ground-water tracing results were gathered from personal interviews, in addition to publications.

The traces were digitized with a Summagraphics digitizing table, Arc/Info GIS, and ArcView GIS 3.3 software. Delorme 3-D Topo Quads 2.0 software was used to find the latitude and longitude for each point in decimal degrees. Attributes for each point include the following: 1) record (trace) #, 2) type of point: injection or detection, 3) topographic map of the trace, 4) geologic age and formation of the trace, 5) reference to the source of information (if published), 6) county of trace, and 7) latitude and longitude of the injection/detection points. After attributes were added, the traces were registered to real world coordinates. Digitizing and attribute errors were eliminated, and spatial accuracy was assessed. The tracing information will soon be placed onto the State's server for easy access by all potential users.

Preliminary Analysis of a Dye Trace in the Unsaturated Zone Above Carlsbad Cavern, Carlsbad Caverns National Park, New Mexico

Paul Burger, Carlsbad Caverns National Park, 3225 National Parks Highway, Carlsbad, New Mexico 88220 Paul_Burger@nps.gov

In early 2001, over 94,000 L of water containing fluorescein dye (80 ppm) was poured into Bat Cave Draw, a small valley overlying Carlsbad Cavern at the edge of the Visitor Center parking lot. For four years, activated charcoal traps have been collected periodically from 23 sites throughout the cave, ranging from every two weeks to every three months. Traps placed prior to the test showed that there was some fluorescein in the system prior to the test, likely the result of antifreeze contamination from the Visitor Center and Bat Cave Draw parking lots. The data show distinct concentration spikes rather than smooth breakthrough curves. In order to differentiate the injected dye from the existing fluorescein in the system, the concentration data were treated as flow data and analyzed using stream baseflow analysis. The data show good correlation between periods of relatively intense rainfall and spikes in dye concentration, but not necessarily individual rainstorms. These analyses will help to estimate travel times and identify flowpaths for dye as an analog for contaminants from the Bat Cave Draw parking lot for contaminants from the Bat Cave Draw parking lot.

HYDROLOGIC CHARACTERIZATION OF TWO KARST RECHARGE AREAS IN BOONE COUNTY, MISSOURI

R.N. Lerch[1], C.M. Wicks[2], and P.L. Moss[3]
[1]*USDA-Agricultural Research Service Cropping Systems and Water Quality Research Unit, 269 Agricultural Engineering Bldg., University of Missouri, Columbia, MO 65211*
[2]*Department of Geological Sciences, University of Missouri, 308 Geological Sciences Bldg., University of Missouri, Columbia, MO 65211*
[3]*Ozark Underground Laboratory, 1572 Aley Lane, Protem, MO 65733 current address: 401 S. Church St. Waterloo, IL 62298*

The Bonne Femme watershed, located in central Missouri, is a rapidly urbanizing area, and this study was undertaken to characterize the hydrology of two karst aquifers within this watershed before significant increases in impervious surface occur. The objectives of this study were to: 1) delineate the recharge area for Hunters Cave (HC); 2) quantify stream discharge at the resurgence of HC and Devils Icebox (DI) caves; and 3) characterize the chemical and physical status of the cave streams. The quantity and quality of the water at the resurgence of both cave streams were monitored from April 1999 to March 2002. Both recharge areas were determined to be of similar size (33.3 km^2 for HC and 34.0 km^2 for DI) and were formed in the same geologic strata. Average annual discharge was 1,900,000 m^3 at DI and 1,170,000 m^3 at HC. Average monthly discharge was 97,700 m^3 at HC and 158,000 m^3 at DI. However, median instantaneous discharge over the three years was 18% higher at HC (74 m^3/h) compared to DI (63 m^3/h). Turbidity and pH showed the largest differences between sites, reflecting the greater magnitude and duration of runoff events and the higher row-cropping intensity in the DI recharge area. The HC recharge area is characterized by limited sub-surface conduit development, small conduits, short flow paths from surface to resurgence, and predominantly allogenic recharge. The DI recharge area is characterized by extensive sub-surface conduit development, large conduits, long flow paths to the resurgence, and autogenic and allogenic recharge.

GEOLOGY OF TAG CAVES

KARST HYDROGEOLOGY OF LOOKOUT MOUNTAIN, A SYNCLINAL MOUNTAIN IN THE FOLDED APPALACHIAN MOUNTAINS OF SOUTH-CENTRAL TENNESSEE

Brian Sakofsky, Kent Ballew, and Nicholas Crawford, Center for Cave and Karst Studies Applied Research and Technology Program of Distinction, Department of Geography and Geology, Western Kentucky University, Bowling Green, KY 42101

The objective of this research is to investigate the hydrogeology of Lookout Mountain, Tennessee, funded by the National Park Service to better understand karst ground-water under its 12 km^2 park and the possible effect of nearby urban development on karst and groundwater quality. Major karst flow routes under Lookout Mountain have been identified, and the drainage basins for the major cave streams and springs have been delineated. If a major spill of toxic material were to occur on Lookout Mountain, as happened in 1996, the NPS must be able to track the contaminant movement. Lookout Mountain is a synclinal mountain in the folded Appalachians with the same stratigraphy as the Cumberland Plateau. Caves are mainly oriented along the strike, with vertical shafts where cave streams drop through resistant strata. Dye tracing and cave exploration and mapping were used to investigate the hydrogeology. A hydrologic inventory was conducted on and around the base of Lookout Mountain, and charcoal dye receptors were placed at all springs and streams, and at several locations inside caves. Four different dyes were simultaneously injected into karst sinks on three separate occasions. The results show that cave streams are trapped by the synclinal structure of Lookout Mountain and flow along the strike. Cave streams have a stair-step pattern as they breach perching layers and descend through the Pennington, Bangor, and Monteagle Limestones. The deepest vertical shaft, Mystery Falls (85.6 m), was formed as a cave stream dropped off the perching Hartselle Formation into the Monteagle.

GEOLOGY AND HYDROGEOLOGY OF TUMBLING ROCK CAVE, JACKSON COUNTY, ALABAMA

Bill Varnedoe, 5000 Ketova Way, Huntsville, AL 35803 billvar@comcast.net
Pat Kambesis, Hoffman Environmental Research Institute, WesternKentucky University, Bowling Green, KY 42101 pat.kambesis@wku.edu

Tumbling Rock Cave is a valley-wall conduit that has developed along the Cumberland Plateau Escarpment of northeast Alabama. Recent dye tracing confirms that the cave functions as a drain for Round Cove, a closed depression at the head of Mud Creek Valley. However, only a small percentage of the injected dye was recovered, which suggests that the cave and surrounding area are hydrologically more complex than originally thought. The main stream passage in Tumbling Rock trends subparallel to and within the eastern wall of the Mud Creek Valley, which suggests that flow paths were guided by stress-relief fracturing. The cave contains multiple levels of passage development. Some of those levels are associated with the allogenic paleo and modern stream within the cave. Higher passage levels, including the Topless Dome, which reaches 120 m in height, are associated with an epikarst aquifer.

PERCHING LAYERS, VADOSE TUBES, AND EXPLORATION IN MAMMOTH CAVE, KENTUCKY

James Wells, 120 Gouge Hollow Road, Oliver Springs, TN 37840
Jim Borden, 2032 NE Katsura Street, Issaquah, WA 98029

While the Mammoth Cave area is famous for being ruled by river-controlled phreatic tube levels, many parts of the cave are heavily controlled by the path that vadose water takes from its point of entry to some far-off base level destination. A big factor affecting these pathways is the presence of perching layers, which may be chert or dolomite. Vadose water flowing on these perching layers results in the formation of vadose tubes, or vadose passages which have a surprisingly significant tube aspect to their shapes. Vadose tubes can be many thousands of feet long, and form an important backbone of the connected cave system. Many passages that are considered to be base level are well above the true regional base level, and owe their continuity to perching layers. A poster-child example of a vadose tube is Canis Minor and Canis Major in Sides Cave. These passages, which start as two branches and then merge into one, originally took water from Cooper Spring Hollow on a horizontal journey of approximately 900 m, finally dumping into a dome at its far east end. The passage later experienced up to six successive piracies, working gradually west toward its origin. Vadose tubes make us look at exploration prospects differently: (1) Upstream is as good as downstream; (2) Leads at the tops of domes are often very promising; and (3) Major passages can exist independently at each level, with little interaction between levels. The same principles apply to many caves throughout the Southeast.

AN OVERVIEW OF KARST DEVELOPMENT ALONG THE CUMBERLAND PLATEAU ESCARPMENT OF TENNESSEE, ALABAMA, AND GEORGIA

Nicholas C. Crawford, Center for Cave and Karst Studies, Applied Research and Technology Program of Distinction, Western Kentucky University, Bowling Green, KY 42101

Surface streams flowing off the sandstone caprock of the Cumberland Plateau onto the underlying carbonates tend to invade the subsurface, creating caves that take a stair-step route to resurge as springs at the escarpment's base. Surface streams usually sink upon flowing onto the Bangor Limestone. They then tend to drop down vertical shafts until they hit the Hartselle Formation, which is primarily sandstone and shale. Bangor cave streams often resurge along the Hartselle Bench about half way down the escarpment and drop as spectacular waterfalls into large sinkholes in the underlying Monteagle Limestone. The cave streams then tend to take a stair-step route down through the Monteagle and St. Louis Limestones to finally resurge in the upper Warsaw Formation near the escarpment base. Many cave streams in the Bangor breach the Hartselle Formation behind the escarpment along stress-relief fractures, thus creating the deep vertical shafts and spectacular underground waterfalls for which TAG caves are noted. In places, even relatively large rivers (such as the Caney Fork and Cane Creek) sink into the Monteagle and St. Louis Limestones, creating large caves (such as Camps Gulf Cave) and then resurge further downstream. Also, large karst valleys (such as Grassy Cove) have formed where surface streams have breached the sandstone caprock, often along structural highs, several kilometers from the edge of the escarpment. As the sandstone caprock is removed by slope retreat, it leaves behind a sinkhole plain that follows the retreating escarpment.

STRUCTURAL CONTROLS ON KARST DEVELOPMENT AND GROUNDWATER FLOW, REDSTONE ARSENAL, HUNTSVILLE, ALABAMA

Tom Zondlo, Sr. Hydrogeologist, Shaw Environmental & Infrastructure, Knoxville, TN tom.zondlo@shawgrp.com

Redstone Arsenal covers 154 km^2 in Huntsville, Alabama and contains 424 identified springs, 1886 mapped sinkholes, a highly evolved epikarst, solution cavities in ~70% of bedrock boreholes, and 26 mapped caves. It is situated on the south flank of the Nashville Dome where geologic structure is usually assumed to consist of gently southward-dipping beds of Mississippian-age carbonates overlying the Chattanooga Shale. Five distinct hydrogeologic regimes have been identified, and a generalized network of subsurface conduits is inferred from a structural-stratigraphic model. Recently the Army completed nearly 50 km of reflection seismic surveys, nine dye traces, and 32 deep coreholes, documenting significantly more complex structure than previously imagined, with block faulting superimposed on the regional dip. Faulting apparently played a significant role in development of shallow karst aquifers, as shown by dye tracing, and may also have facilitated deep karst development. Drilling revealed transmissive solutional voids up 6 cm thick below the Tennessee River base level in the lower Tuscumbia limestone and Fort Payne formations. These strata host natural hydrocarbons that are probably related to block faulting. Ground-water in deep strata is rich in $Na\text{-}SO_4$, grading into Na-Cl water downward toward the Chattanooga Shale. Pyrite and gypsum infilling in deep cores, H_2S and methane at depth, and the distinct water chemistries may suggest a hypogenic origin for the deep karst development. The faulting may be responsible for the juxtaposition of all of these conditions, and for the karst and caves as well.

Speleogenesis in the Cumberland Plateau of Northeastern Alabama

Chris Smart, Department of Geography, University of Western Ontario, London, Ontario, N6A 5C2, Canada csmart@uwo.ca
Warren Campbell, School of Engineering, Western Kentucky University, Bowling Green, KY 42101 warren.campbell@wku.edu

Caves are numerous along the Highland Rim Section of the Cumberland Plateau Province, but they are not exceptionally long, despite propitious lithology. The majority of caves form along the escarpment front where streams flow off the protective caprock onto limestone, to emerge close by at the escarpment foot. Such caves tend to be abandoned and destroyed as the escarpment retreats. In a few cases, caves have developed in inliers of limestone. The associated closed depressions become fragmented as they develop, although a substantial trunk conduit may persist beneath a protective caprock. The longest caves in the region tend to parallel valley sides, and there has been some debate concerning the origin of such “Cumberland” type caves. The landscape in northeastern Alabama has been disrupted by cycles of river incision and aggradation, and by epochs of delivery of excessive sediment loads from the escarpment. River incision leads to stimulation of cave development, abandonment of high level routes and development of links concordant with lowered base level. Subsequent rise in base level has caused burial of sinks and springs and obstructed deeper passages. Clastic sediments have choked sinkholes and redirected surface streams. Large alluvial fans formed in valley heads, probably several million years ago. These fans have redirected surface drainage and appear to have stimulated development of Cumberland type caves along their margins.

Stable Base Levels, Valley Underdrains, Catchment Areas, and Time: The Interplay Responsible for the Master Trunk Caves of the Cumberland Plateau

William B. White, Materials Research Institute and Department of Geosciences, The Pennsylvania State University, University Park, PA 16802

The Cumberland Plateau in central Tennessee and northern Alabama is blessed with a rich population of caves of many lengths, passage sizes and origins. The calculations described here address the large-cross-section trunk passages that form either active or paleo master drains. The coves of the Cumberland Plateau are incised into the sandstone-capped upland. High-gradient streams descend the walls of the coves, often by underground routes with much vertical development. Valley bottoms also provide the gradient for even lower-gradient master trunk development. The volume of trunks represents the tradeoff between rate of conduit development and time of stable base level. Cosmogenic isotope dating of sediment in master trunks by Anthony and Granger has provided a time scale into which cave development must be fitted. With chemical data on active drainage systems as a reference, combined with models for rates of passage development, the calculated time scale for development of master trunk drains is in the range of 10,000–50,000 years. Rapid development of master drains with low hydraulic resistance results in underdraining of valleys. Calculated development times are shorter by an order of magnitude than periods of stable base level indicated by the Anthony and Granger dates. Reconciliation of these data requires a damping effect on cave development probably due to sediment infilling and by the development of protective barrier layers on cave walls. Evidence for the latter is provided by the observed transmission of low-pH acid mine water.

Geologic Controls on the “Deep” Caves of TAG

Pat Kambesis, Hoffman Environmental Research Institute, Western Kentucky University, Bowling Green, KY 42101 pat.kambesis@wku.edu
Alan Cressler, US Geological Survey, Atlanta, GA cressler@usgs.gov

TAG (Tennessee, Alabama and Georgia) is home to a significant number of vertical caves. In this region, caves that have a vertical extent of a hundred meters or more are considered deep. Approximately 1% of all TAG caves fall into this category. Many deep caves are characterized by shafts that are separated by long crawlways and short stretches of borehole before reaching base level. Other deep caves consist of multiple shaft routes to base level. Some deep caves have significant lateral as well as vertical extent that reflect major changes in base level over time. And some deep caves attain their vertical extent from epikarstic domes that have fortuitously intersected paleo-trunk passages. The morphology, lateral extent and vertical extent of deep TAG caves are a function of stratigraphic, structural, hydrologic and geomorphic controls. These controls vary across the physiographic provinces that typify the TAG region and between the two major watersheds that drain it.

Human Sciences

The Kowallis Cave Hazards Rating System

Brandon Kowallis, 85 N 870 E, American Fork, UT 84003 BrandonKowallis@yahoo.com

The Kowallis Cave Hazards Rating System was designed out of an informal request of some of the local cavers and scouts. This rating system is established as a general guide to help people know before hand the degree of difficulty and hazards they may encounter as they enter each cave. It is in reference to the entire cave and not to specific areas. This system is not made to measure the ease or difficulty of a rescue. Numbers are based on how hazards compare to one another. The rating system is based on numerical values assigned to each hazard based on its seriousness and frequency of occurrence, which are based on US cave accident reports published by the NSS. Although several caves have already been rated via various equations based on cave-related data, the system is set up so that anyone can enter the caving hazards data for any cave so that the spreadsheet can produce a value that is then assigned a rating. The development of the data analytic system and spreadsheet will be discussed.

Vertical Skills Checklist

Brandon Kowallis, 85 N 870 E, American Fork, UT 84003 BrandonKowallis@yahoo.com

In light of recent alpine discoveries, and in order to remedy inconsistencies in vertical proficiency and assure that necessary rope skills are not overlooked among its members, the Timpanogos Grotto has developed a Vertical Skills Checklist. The list is based on a mix of European and American techniques. It was carefully designed to create the most efficient vertical training and to avoid liability through its designation as a checklist rather than a qualification guide. Creating the checklist and designing it to apply to a wide variety of vertical techniques and to be helpful to a broad sample of cavers was a challenging task that will be discussed in detail in this presentation.

Caving Projects: Dealing with People You Can’t Stand

Jennifer Neemann, 604 Shirley Manor Road, Reisterstown, MD 21136 Dr_Jen@comcast.net

Every caving project, whether major or minor, includes a variety of personalities, some of which are more easily dealt with than others. Even simply organized caving trips may have members who make the trips less than enjoyable because of their behavior or attitudes. Dealing with difficult people slows down projects and irritates project members. However, learning how to get along with such people, or learning how to deal with others if you are one of these people, will improve the quality of interactions of caving projects. Difficult persons can be identified in several ways. Tank-confrontational, angry, pushy, and aggressive. Sniper-using rude comments, sarcasm, or eye-rolling, this person strives to make you look foolish. Grenade-after a brief period of calm, this person explodes into an unfocused tirade about unrelated material. Know-It-All-this person is seldom in doubt, with a low tolerance for correction and contradiction. Think-They-Know-It-All-can fool enough of the people all of the time, all for the sake of getting some attention. Yes Person-these people agree to nearly anything to avoid confrontation. They overcommit until they have no time for themselves, and they become resentful. Maybe Person-in a moment of decision, this person procrastinates in the hope that a better choice will present itself. Nothing Person-no verbal feedback, no nonverbal feedback, nothing is provided. No Person-this person defeats big ideas with a single syllable. Whiner-this person feels helpless and overwhelmed by an unfair world. Offering solutions makes you bad company, so their whining escalates.

International Exploration

Mexico Tecoman Project 2005

Brandon Kowallis, 85 North 870 East, American Fork, UT 84003 brandonkowallis@yahoo.com
Peter Ruplinger (project coordinator) peter@ruplinger.org

In 1999 Peter Ruplinger led a trip to a small community called San Gabriel near Tecoman, Mexico in the state of Colima. On that trip 15 pits were discovered and mapped.

This year we returned to follow up on Poso Cara del Tigre, a pit that left us hanging at about 100 m. Most of the caves in that area are known for their bad air, so this year we took an oxygen meter to measure levels. We found the bottom of the pit at 168 m in 16.3% oxygen. We also discovered a 30-m-deep pit that we called Poso Hermoso.

After finishing up in the San Gabriel area we moved on to Palos Maria, another small community, where the locals showed us a horizontal stream cave called Cueva Canoa; we mapped about 100 m and then pushed upstream another 200 m through waist-deep water with no end in sight. We were going to return the next day to continue surveying, but due to illness were unable.

http://www.cancaver.ca/int/mexico/zotz/colima/ tecoman98.htm

Proyecto Espeleologico Sierra Oxmolon, Mexico

Jerry Fant, 251 Gold Rush Circle, Wimberley, TX 78676 jerryfant@ev1.net

Located west of Aquismon in the State of San Luis Potosi (Mexico) lies one of the greatest caving areas known. El Sotano de las Golondrinas was discovered by cavers in 1967 and was at that time the deepest single drop in the world. Shortly after, Hoya de las Guaguas and Sotano de Cepilla were discovered, two other world-class vertical pits. Over the years several other large pits were located, marking this area as having the best in large bird pits: green conures, swifts, and military macaws inhabit many of these large-volume pits.

Speculation about a major system existing there brought about a recon in September 2000. On this first visit five new caves were discovered, one being a 100-m drop. The following November saw the first PESO (Proyecto Espeleologico Sierra Oxmolon) trip into La Brecha de Tanzozob and thus the project was born. Many trips have since been undertaken, growing the list of 20 known caves to over 100. One of the latest finds was in Cueva Linda, already known to be over 500 m long. A short bolt climb led to an additional kilometer of new passage and the beginning of the rumored system.

Exploration of caves used by the Maya, El Petén, Guatemala

Philip Rykwalder, 632 Atlanta Dr., Hermitage, TN 37076 livetocave@hotmail.com

Aguateca was a large Maya urban center located near the modern city of Sayaxche in the northern state of El Petén, occupied from 300 BC to 350 AD, and from 710 AD to 810 AD. The site is currently under investigation under the direction of Dr. Takeshi Inomata of the University of Arizona.

In 2005 three US cavers, Bev Shade (TX), Philip Rykwalder (TN) and Nick Johnson (MN), visited Aguateca to help Reiko Ishihara, a speleoarchaeology Ph.D. candidate at University of California, Riverside, map caves at the site. Reiko is currently focused on elucidating the Maya use of the large chasms, or grietas, that dominate the Aguateca site. The grietas are deep, linear cracks in the earth that are open to the surface in places, the largest being 1.5-km long and 80-m deep. The grietas are tectonic in nature, but traditional solutional caves and karst features are located in the area.

We cavers were able to make a number of finds at the site. We found all of the caves and many karst features to be heavily littered with Maya artifacts, including fairly intact monochrome and polychrome pottery, axe heads, religious pieces and other artifacts. On the surface, we also explored a few cliffside karst features, in one of which a large pot 40–50 cm in diameter was found. A few bolt climbs were also done in order to see if the Maya had placed artifacts on elevated ledges within the caves.

Multiyear project to map and photograph caves for the Belize Institute of Archaeology

David Larson and Eleanor Burns Larson, 4346 Via Presada, Santa Barbara, CA 93110 delarson@aol.com
Brian Pease and Bonnie Pease, 567 Fire Street, Oakdale, CT 06370 bpease@myeastern.com
William Hunt, 18300 Mount Baldy Circle, Fountain Valley, CA 92708 willie@surefire.com

In February and March of 2005, NSS cavers from the US and Canada—an informal group named XMET (Xibalba Mapping and Exploration Team)—made their sixth annual trip to survey caves in Belize under the auspices of the Belize Institute of Archaeology. The Maya made extensive use of the caves during the height of their civilization and many of the caves contain cultural material. Over the course of the project, the cavers of XMET have mapped eight km of passageway in Barton Creek Cave, have done dye tracing to find the source of the water in Barton Creek Cave, and have mapped or are in the process of mapping eight other smaller caves. Cave divers have penetrated sumps at the back of several of the caves and have extended the surveyed length more than a 1000 m.

The caves of Belize have beautiful large rooms, which XMET has photographed while surveying them. In 2005, XMET received permission to visit the Chiquibul System to photograph the second largest room in Central America, the Chiquibul Chamber in Actun Kabal.

The XMET team will return to Belize to continue the project in February, 2006.

Caves of Damas, Costa Rica

Robert Abdul cavesofdamas@yahoo.com

The Caves of Damas are located 10 mi north of the town of Quepos and 30 mi south of the town of Jaco. The caves are located on a privately owned 700-ac rainforest, wildlife, and research preserve. The current mapped caverns are 300 m in length. We have explored additional caverns; however, our expertise and equipment have limited our exploration.

The caves contain various species of bats and insects. A particular species of cockroach lives within the caverns, and viewing the full life cycle is amazing. Our group cannot explain how plants are able to grow and produce green leaves in total darkness. Various rock formations lead some to believe the Quepoa Indians were inhabitants of the caves. In addition, within the depths of the River of Damas stone carvings have been photographed. We also have discovered underwater tunnels, which open into caverns.

A National Geographic representative visited the location years ago and felt that up to 13 km of caves may exist. Nearly 20 years ago, when the government of Costa Rica threatened to nationalize the property, the previous landowners dynamited entrances to several tunnels.

A portion of the Caves of Damas tour proceeds is donated to Costa Rica Latin America Schools Supplies, Inc. (CLASS). CLASS is a Florida non- profit, 501(c)(3) corporation with programs to help students of all ages learn to read, write, and speak English in Costa Rica.

http://www.costaricaclass.org

Caves of Long Island, Bahamas

Marc Ohms, 1212 Sherman St., Custer, SD 57730 marcohms@yahoo.com

In December of 2004 nine cavers traveled to Long Island, Bahamas to take part in a 10-day expedition led by Dr. John Mylroie of Mississippi State University. The goal of the expedition was to survey as many caves as possible to support the science mission of understanding how these caves formed. Sixteen caves were surveyed, varying in length from 10 m to just over a kilometer in length (second longest in the Bahamas). Many other caves were discovered but not surveyed due to a lack of time. The caves are flank margin caves, similar to those found on other tropical carbonate islands such as Isla de Mona in the Caribbean or Tinian in the Pacific. Typical characteristics include large rooms, plentiful formations, numerous skylights, and bell holes. While most caves are dry, one consists of a single large lake room with water over three m deep. Some pit caves, with depths up to 13 m, were examined. Cave location utilized traditional ridge-walking, but also a boat to reach offshore cays and remote peninsulas. One cave was used to house a goat herd, and one participant ended up with a "jigger," a type of bot fly larva, in his foot; the first case reported by a caver in the Bahamas.

Boquerones and Beyond: Continued explorations in Sancti Spiritus Province, Cuba

Kevin Downey, 21 Massasoit St., Northampton, MA 01060 kevin@kdowneyphoto.com

Cyndie Walck, 10485 Courtenay Ln., Truckee, CA 96161 cmwalck@unr.edu

The joint projects of the NSS Cuba Caves group and the Cuban Speleological society's Grupo Sama over the past four years have finally resulted in a completed map of the Boquerones system at over 9 km in length, and the project is now considered finished (until someone finds a bit more…). Last year's expedition seemed to be wrapping up and all the leads were crossed off until the last day when, as so often happens, new caves and some promising pits were found, all headed into new sectors of this complex multi-level system. This year's work yielded three independent but related caves, several dead-bottom pits and one connection from a new pit series to already mapped sectors of the main cave.

Looking to the future, we have begun exploration and survey of areas along the North coast including some very unusual and extensive flank margin caves in the Lomas of Punta Judas and at Caguanes. Camping in the caves of Punta Judas has proven to be a comfortable base for mapping, and the Loma has yielded almost a kilometer per day in often huge passages. The future in this area is very exciting as the cave density is very high, and the caves seem to be very different types of systems than those seen elsewhere. Other regions in Cuba have been scouted for additional new projects in conjunction with local cavers and clubs. There seems to be endless potential, but considerable effort is still needed to obtain needed permissions from both the US and Cuban governments.

The lava tubes of Harrat Kishb, Saudi Arabia

John and Susy Pint, 362 Sandefur, Shreveport, LA 71105 thepints@saudi-caves.com

The first speleogical study of lava tubes in Saudi Arabia began in November of 2001 in Harrat Kishb, a lava field located 300 km northeast of Jeddah. The expedition had two goals. One was to investigate a series of collapse holes, visible in airphotos, extending from an extinct volcano named Jebel Hil and suggesting the presence of a lava tube at least three kilometers long. The second goal was to try locating several shorter lava tubes seen in this area by a hunter. A hair-raising climb up Jebel Hil revealed an opening in the side of the crater, presumed to be the upper end of the long lava tube. A ground reconnaissance then gave the coordinates of most of the collapses and indicated the floor of the tube was from 26 to 42 m below the surface.

The shorter lava tubes were found with the help of Bedouins living at the edge of the lava field. One of the tubes, Kahf Al Mut'eb, was surveyed to a length of 165.8 m and was found to contain lava levees, stalactites, animal bones and a plant-fiber rope that may be 8,000 years old. In Ghostly Cave, tall stalagmites of rock-dove guano were found, as well as two L-shaped throwing sticks, thought to be Neolithic.

Saudi Arabia has 89,000 km² of lava fields, suggesting that many more caves will be found in the future.

Caving in the Peruvian Andes: 2004 Expedition

Matt Covington, 74 Barnes Ct., 408, Stanford, CA 94305 mdcovin@physics.ucsc.edu

Steve Knutson, P.O. Box 111, Corbett, OR 97019 sssknutson@aol.com

In 1996, a new high elevation pit area in Peru was discovered. Since then, nearly annual expeditions into the area have occurred. This karst, averaging about 14,000 ft in elevation, proved to have an incredible concentration of deep pits. Of the 23 known limestone open-air pits over 100 m in depth in South America, 18 are in this area. Three of these pits are over 150 m in depth. In July of 2004, Steve led another expedition into this area to reconnoiter further out into the wilderness and examine the potential for caves. A new base camp was established and the group made a number of new cave discoveries, including a multi-drop cave that was pushed to a constriction at -300 m. The caves in this new area were unlike most of the pits previously discovered in that a number of them contained both airflow and water. The group theorizes that the caves feed into a larger main-drain system, and future expeditions are being planned.

2005 Sino-American Expedition to Hunan Province, Peoples Republic of China

Patricia Kambesis, Western Kentucky University, Bowling Green, KY 42101 pnkambesis@juno.com

Chris Groves, Western Kentucky University, Bowling Green, KY 42101 chris.groves@wku.edu

In Spring of 2005, U.S. cavers sponsored by the Hoffman Institute of Western Kentucky University, and cavers and researchers from the Karst Geology Institute of Guilin, worked together in continuing the exploration and survey of Wanhuayan Cave (Cave of 10,000 Flowers), in Hunan Province. The main objective of the expedition was to pursue a waterfall lead, which was originally discovered and documented during a Cave Research Foundation trip in 1988. This lead, which is at the end of a 4 km long side passage, contributes 70% of the water flow in the cave. Dye tracing from other cave entrances in the area showed that the Wanhuayan Cave System is much more extensive than previously expected. Besides exploring and mapping cave leads and doing quite a bit of resurvey and fieldwork, the American team had to deal with the perils of Chinese banqueting and relentless gambe.

Caving in Middle Earth: A photographic safari to the caves of New Zealand

Dave Bunnell, P.O. Box 879, Angels Camp, CA 95222 dbunnell@caltel.com

A group of 12 cavers from the USA were hosted by four New Zealand cavers for three weeks of caving on the South Island of New Zealand. Rather than exploration, our primary goals were to provide our hosts with professionally made photos of their caves and learn about their caves and caving approaches.

Most of the caves on the South Island are in the northwest corner, and roughly divided into three karst regions. The west coast has numerous long, dendritic stream caves, including the 20-km-long Honeycomb Hill, noted for bone deposits of the extinct Moa bird, and Metro. Alhough on Department of Conservation land, both are used extensively by cave-for-pay concessions, with some significant impact to the caves. The Mount Owen and Mt. Arthur regions have alpine karst housing the longest (Bulmer, 50+ km) and deepest (Nettlebed) systems, as well as the major Czech discovery, Bohemia. The latter contains an immense chamber and an unusually diverse collection of helictites. Takaka Hill, the third region, is intermediate in elevation and contains two large vertical systems, Greenlink-Middle Earth and Harwood's Hole. The latter affords a remarkable vertical through-trip starting with a 186-m rappel.

Caves of Panama

Keith Christenson, 2012 Peach Orchard Dr., Apt. 24, Falls Church, VA 22043 tropicalbats@hotmail.com

Panama, not known as a cave-rich country, does have limestone and caves. A broad-scale approach was taken to try to find caves in many different regions of Panama, instead of focusing on any particular area. About 60 caves were located and surveyed, totaling six km of passage. The longest cave was Ol' Bank Underground at 1.1 km, until the recent British expedition pushed Nibida past 1.4 km. Panama has many karst areas, and at least one zone includes roughly 2,000 km² of karst that has not been explored by any speleologist.

Paleontology

Hamilton Cave, West Virginia Paleontology Update

Frederick Grady, 201 South Scott Street, Apt. 123, Arlington, VA 22204

Continued excavations in Hamilton cave have produced additional fossil vertebrates. Several more parts of the *Miracinonyx inexpectatus* skeleton recovered in the 1980s have been found including parts of the left mandible and a nearly complete right ulna. The ulna is especially important as only the distal end of the left side had been recovered previously. An incisor and several phalanges of *Smilodon* cf *S. fatalis* have been found, presumably belonging to a cluster of bones and teeth recovered mostly in the 1980s. In addition, fine screening has produced additional microvertebrates, including the rodents *Mimomys virginianus* and *Phenacomys brachyodus* and the bat *Tadarida* sp.

Pleistocene Beaver Tooth Is New Record For West Virginia

Frederick Grady, 1201 South Scott Street, Apt. 123, Arlington, VA 22204

E. Ray Garton, Curator, WV Geological Survey, 1 Mont Chateau Road Morgantown, WV 26508

An upper cheek tooth of a small beaver has been recovered from Pleistocene age deposits from Hamilton Cave, Pendleton County, West Virginia. The tooth appears to represent the extinct genus *Dipoides* which is best known from the Pliocene. The Hamilton Cave deposit from which the tooth was recovered dates to the Middle Irvingtonian Land Mammal Age, about 850,000 years before present. An apparently similar tooth has been noted from Cumberland Cave, Allegheny County, MD, which is believed to be slightly younger than the Irvingtonian deposits in Hamilton Cave. The living beaver, *Castor canadensis,* is also present in the Hamilton Cave Fauna.

New Records of Mammut americanum (Mastodon) from Monroe County, West Virginia

Frederick Grady, 1201 South Scott Street, Apt. 123, Arlington, VA 22204
E. Ray Garton, Curator, WV Geological Survey, 1 Mont Chateau Road Morgantown, WV 26508
Terry Byland, 863 Massillon Road Lot 11, Millersburg, OH 44654
Robert L. Pyle, 1964 Negley Avenue, Morgantown, WV 26505.

During several expeditions to Scott Hollow in Monroe County, WV, cavers have recovered seven teeth of the extinct, Pleistocene age, mastodon *Mammut americanum* as well as other postcranial bones. At least three individuals are represented. This is the largest number of teeth ever recovered from a single locality in the state and brings the total number of known mastodon occurrences to 19. All of the teeth except one are well preserved. Molds and casts have been made of the teeth and deposited in the U.S. Museum of Natural History (Smithsonian) and Carnegie Museum of Natural History. The original teeth are on loan from the owner and on exhibit at the West Virginia Geological Survey Museum. One complete tooth minus roots and one fragment of a humerus were submitted for radiocarbon dating. Both samples were from different parts and levels of a large cave system and are thus not from the same individual. The ^{14}C dates are 11,350 ± 360 years BP for the tooth and 21,830 ± 660 years BP for the humerus fragment. These are the first ^{14}C dates for mastodon in West Virginia and were made possible through a grant provided by The Robertson Association (TRA).

An Update on Vertebrate Fossil Research in Caves of Southeast Alaska

Timothy H. Heaton, Department of Earth Sciences, University of South Dakota, Vermillion, SD 57069
Frederick Grady, 1201 South Scott Street, Apt. 123, Arlington, VA 22204

Fossil research in Southeast Alaska has expanded geographically from Prince of Wales Island to other islands and the mainland. In 2002 Enigma Cave and Kit-n-Kaboodle Cave on Dall Island were excavated, with many bear, seal, and bird remains recovered. In 2003 human remains and many artifacts, along with fish, birds, and mammals, were found in Lawyers Cave on the Alaska mainland near Wrangell. Colander, Deer Bone, and Otter Den caves were excavated on Coronation Island. No bones were found exceeding 12,000 years old in any of these caves, but the post-glacial record was well-represented. In 2004 we returned to On Your Knees Cave, Prince of Wales Island, where an excellent record of the Last Glacial Maximum and Middle Wisconsin Interstadial was previously excavated from 1996 to 2000. Deep excavation in the Seal Passage of that cave revealed a large collection of bird, bear, rodent, and other fossils. Dense layers of broken speleothems were also found, and these can be dated to add information to the cave's chronology. The search will continue on other islands to find sites with a fossil record like On Your Knees Cave, especially the islands of the outer coast (Coronation and Dall islands) because they were further from the center of major glaciers.

Some Remarkable New Paleontological Finds from Tennessee Caves

Blaine W. Schubert and Steven C. Wallace, Department of Physics, Astronomy and Geology Box 70636, East Tennessee State University, Johnson City, TN 37614 schubert@etsu.edu

Tennessee is extremely rich in caves, and where these subterranean shelters occur there is usually evidence of past life, otherwise known as fossils. Two recent discoveries from the state are discussed here. The first is a collection of bones and teeth, (recently donated to the East Tennessee Museum of Natural History) that originated from Guy Wilson Cave, a well known late Pleistocene site in Sullivan County. This material was collected in the early 1970s and had remained in private hands ever since. While this new sample contains many of the extinct species already reported from the cave, like Jefferson's ground sloth (*Megalonyx jeffersonii*), dire wolf (*Canis dirus*), tapir (*Tapirus* sp.), and a large collection of flat-headed peccary (*Platygonus compressus*), it also includes unreported extinct mammals, such as the long-nosed peccary (*Mylohyus nasutus*) and horse (*Equus* sp.). Although this donation spawned interest in doing systematic excavations, the cave is not currently accessible. The second discovery was recorded by cavers a number of years ago, but was not assessed by paleontologists until recently. The cave is in north-central Tennessee and houses some of the most extensive peccary and bear trackways known. In addition, bear claw marks are found throughout the cave, and one location, which also has some black bear (*Ursus americanus*) skeletal remains, appears to have been a denning area. Because of these sensitive and irreplaceable paleontological resources, this cave is in serious need of protection and management.

An Enigmatic Tooth from a Pleistocene Deposit in Georgia—Is it Human?

Joel M. Sneed, NSS 10137LF

A Pleistocene deposit in a Bartow County cave has yielded over 150 taxa, including fauna both extinct and extirpated, an intermingled fauna with more western affinities, more northern affinities and more southern affinities than those found in the area today. Radiocarbon dates on elements from this deposit include one of 12,470 ± 50 years BP from the antler of a deer, *Odocoileus virginianus*, and another of 12,790 ± 50 years BP from bone collagen of an extinct peccary, *Mylohyus nasutus*. One tooth recovered from the deposit has eluded identification, despite being examined by several specialists. This tooth, a well-worn molar, was initially identified as being human, commanding the attention of many due to the age of the deposit and its association with extinct fauna. The tooth has been subjected to several tests of its macrostructure and microstructure, including scanning electron microscopy, x-ray, and photomicrography. None of the tests to date has yielded a definitive answer as to whether the tooth is from an animal or human. Interestingly, physical anthropologists that have seen the tooth feel that it must be animal, and zooarchaeologists insist that the tooth matches no animal, living or extinct.

The Gray Fossil Site: A Late Miocene Sinkhole Deposit in the Southern Appalachians

Steven C. Wallace and Blaine W. Schubert, Department of Physics, Astronomy and Geology Box 70636, East Tennessee State University, Johnson City, TN 37614 wallaces@etsu.edu

Because limestones and dolomites are highly soluble and erode away over relatively short periods of geologic time, most fossil-bearing karst deposits in North America are Pleistocene in age. However, the Gray Fossil Site, a recently discovered fossiliferous sinkhole deposit in Washington County, Tennessee, dates to the late Miocene (between 4.5–7 million years old). This age is based on the known temporal and stratigraphic occurrence of the rhino *Teleoceras* and the short-faced bear *Plionarctos* at other localities. Geologic interpretation of the site indicates that a sinkhole acted as a natural trap and/or watering hole that attracted, then possibly trapped, terrestrial vertebrates. The limestone walls of the sinkhole have long since weathered to a loose residuum, leaving behind the more resistant fossil-rich sediments as a topographic high. Core samples show that these sediments cover roughly 4–5 acres and are up to 35–45 meters thick. The highly-laminated, organic-laden, silty sediments are rich in both plant and animal remains. Excavation and surface collection have yielded vertebrate remains such as shovel-tusked "elephant," rhinoceros, tapir, peccary, camel, saber-toothed cat, a new species of badger, a small fox-sized canid, short-faced bear, a new species of red panda, rodent, shrew, alligator, snake, turtle, frog, salamander, and fish. In addition, the site is rich in plant macrofossils and invertebrates such as gastropods, bivalves and ostracodes. Due to a lack of similar-aged deposits in this region, this site offers a unique opportunity to study the the paleoecology of southern Appalachia at that time.

Spelean History

Charles A. Muehlbronner & John Nelson: Heroes of Mammoth Cave's "Echo River Club"

Dean H. Snyder, 3213 Fairland Dr., Schnecksville, PA 18078 dsnyder3@ptd.net
Dale R. Ibberson, 445 Hale Ave., Harrisburg, PA 17104 ibberson@paonline.com

In January, 1904, the annual convention of the League of Commission Merchants was held in Louisville, Kentucky. As part of their activities, a trip was organized to visit Mammoth Cave. During the Echo River tour inside the cave, seventeen passengers on guide John Nelson's boat were dumped into the icy water due to the horseplay of one of the men. Only the quick thinking and heroic action of Nelson and Charles A. Muehlbronner, former Pennsylvania state senator from Pittsburgh, saved the group from drowning. Back at the Mammoth Cave Hotel, the grateful passengers formed the Echo River Club with membership limited to those people on the trip. Muehlbronner was elected as President for life. The group held annual reunions in different cities for several years.

On White Fish And Black Men: Did Stephen Bishop Really Discover The Blind Cave Fish Of Mammoth Cave?

Aldemaro Romero, Department of Biological Sciences, Arkansas State University, P.O. Box 599, State University, AR 72467 aromero@astate.edu
Jonathan S. Woodward, 3738 Middlebury College, Middlebury, VT 05753 jwoodwar@middlebury.edu

Some of the chronology of discoveries at Mammoth Cave, KY., is marred by contradictory reports and legends. The first published reference to a blind cave fish ("white fish") in Mammoth Cave appears to be by Robert Davidson in 1840; however, the chronology given in his book is contradictory. We did archival and field research aimed at identifying the first person to have seen (and probably collected) this blind cave fishes at Mammoth Cave. We also researched all the known specimens of the two species of blind cave fish ever found at Mammoth Cave to see if that information could provide evidence of which of the two species was seen first. We conclude that: (1) Davidson's chronology in his book is probably wrong and that he did not visit the cave until 1838 or 1839; (2) it is possible that Bishop was the first person sighting the fish, but others cannot be definitely excluded from having been involved in this discovery; and, (3) that although there are two species of blind cave fish that inhabit the waters of Mammoth Cave, the first one sighted was likely *Amblyopsis spelaea*, also the first one to be recognized in the scientific literature. We finally conclude that the facts surrounding Stephen Bishop's fame need to be further investigated under the perspective of the romantic movement of the mid-nineteenth century that gave rise to the noble savage mythology as well as on the perspective of race in the United States prior to the Civil War.

Diamond Caverns: Jewel of Kentucky's Underground

Stanley D. Sides, Cave Research Foundation, 2014 Beth Dr., Cape Girardeau, MO 63701 ssidesmd@aol.com

Saltpeter was being mined in Short Cave and Long Cave on the west side of a karst valley near Three Forks, Kentucky during the War of 1812. Beneath this valley was a beautiful cave discovered when landowner Jessie Coats' slave was lowered down a 35 foot pit on July 14, 1859. He saw sparkling calcite that resembled diamonds.

The Kennedy Bridal Party was the first to enter the new show cave a month later. Joseph Rogers Underwood, a renowned Bowling Green lawyer, senator, and managing trustee of the Mammoth Cave Estate, bought Diamond Cave and 156 acres from Jesse Coats. A close relationship existed between Mammoth Cave and Diamond Cave with cave literature describing both caves. Mammoth Cave Railroad opened in 1886 with Diamond a stop.

Amos Fudge of Toledo, Ohio, and his son-in-law, Presbyterian minister Elwood A. Rowsey, purchased Diamond in 1924. The fledgling National Speleological Society organized an expedition to Diamond in October, 1942. Dr. Rowsey and his son, Elwood, and Rowsey's niece, Jan Alexander McDaniel and her husband, Vernon, ran the cave and campground adjacent to Mammoth Cave National Park until 1982. NSS cavers Gary and Susan Berdeaux, Larry and Mayo McCarty, Roger and Carol McClure, Stanley and Kay Sides, and Gordon and Judy Smith purchased the cave on July 7, 1999 to promote the cave as a historic attraction and develop a national show cave museum. Virgin passages have since been discovered and a new cave found on the property.

The Rediscovery of Le Sueur's Saltpeter Caves in Minnesota

Greg A. Brick, Department of Geology, Normandale College, 9700 France Avenue South, Bloomington, MN 55431 greg.brick@normandale.edu
E. Calvin Alexander, Jr., Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455 alexa001@tc.umn.edu

A 300-year-old mystery in spelean history may recently have been solved. In September 1700, the French fur-trader Pierre-Charles Le Sueur reported saltpeter caves along the shores of Lake Pepin, a widening of the Mississippi River, in what is now Minnesota. This is the earliest record of cave saltpeter in the United States. Although these caves have been a topic of discussion at major saltpeter symposia, no one has actually searched for them, to the best of our knowledge. In 2004, small, narrow, crevice caves were identified in Ordovician-age Oneota dolomite outcrops along the river bluffs in Goodhue County, Minnesota. The caves match Le Sueur's description as well as could be expected given several centuries of slope-wasting processes. While Le Sueur's journal suggests that he found actual saltpeter, rather than petre dirt, no efflorescent salts were seen in the caves. But analyses of floor sediments from these caves and others along the bluffs on both sides of the Mississippi River reveal nitrate concentrations up to over one weight percent-comparable to those of Mammoth Cave.

History of Early Ownership and Passage Naming in Grand Caverns, Virginia

Craig Hindman, 7600 Pindell School Rd., Fulton, MD 20759 ctider@us.ibm.com

Grand Caverns, in Virginia's Shenandoah Valley, was known as Amonds Cave when it was discovered by Bernet Weyer on Mathias Amond's property in 1804. The cave was commercialized in 1806 and has been operating ever since under a variety of names, including Weyers Cave and Grottoes of the Shenandoah. The cave was modified for trail improvements over the years, but most of the current commercial trail was in place by 1808. The cave's formations and rooms have had a variety of names over the years. Early names were based on parts of a house (the Ballroom and Balcony) and some features were named for political figures (Washington and Jefferson Halls) or religious figures (Solomon's Hall). The names of the features have varied over time, based on the cave owner's whim and, perhaps, political correctness.

State Cave Surveys of the US

Alabama Cave Survey

Jim Hall

The Alabama Cave Survey was started in the 1930s by State Geologist Dr. Walter B Jones. Cavers took charge in the 1970s and our first publication was in 1979. We currently have over 4100 caves on our survey, with maps for about half. In 2003 we started putting maps only on CD-ROM in Adobe Acrobat (PDF) format to reduce use of paper, because our survey book had become over 1000 pages long. The original cave data are still only available on paper copies. The CD-ROM contains only cave maps, cave ID numbers and cave names. The survey has about 50 to 100 members on an average year. Membership is currently $10, which covers publication costs. The only membership requirement is to be a NSS member for at least two years. To be included in the survey database, a cave must be over 50 ft deep or 50 ft long; have documented biological species; or extends into total darkness. All submitted data are sent to the cave files director. Our web page has report forms and a data key that can be downloaded (www.alacaves.org). Landowner relations are handled by local grottos. Cave locations are specified by either Township and Range or Latitude/Longitude. We accept all cave surveys sent in that have good locations and a description (for instance length, depth, and number of drops).

Overview of the Georgia Speleological Survey

Nancy Aulenbach, GSS Secretary, 195 Windy Court SW, Lilburn, GA 30047 flittermice@att.net (NSS# 18052)

The Georgia Speleological Survey (GSS) is a National Speleological Society (NSS)-affiliated state cave survey with the goal of exploration, documentation, and conservation of Georgia caves. The GSS was founded in 1966 and was active until the mid-1970s, then reformed in the early 1980s. The GSS has documented around 570 caves so far, including 16 caves over a mile long and four deep caves (> 300 feet of vertical extent). About 70% of Georgia caves have at least one map on file. The GSS averages about 80 members and has a very open membership policy, with the requirement that you must be an NSS member to receive the GSS Cave Data Listing. The GSS is very active, hosting ridgewalks and running a project to resurvey Frick's Cave in Walker County, Georgia—in which inexperienced surveyors are encouraged to participate and learn how to survey. The *GSS Bulletin*, which is published annually, contains articles and maps from recent exploration and survey, along with his-

torical accounts of Georgia caves. The GSS Mapbook is now being distributed in an electronic medium that includes a nice Web-browser-based interface for accessing maps and metadata. The GSS also maintains extensive paper and electronic archives containing articles, references, maps, and photos.

The Caves of Mississippi

Adam Walker, Chris Moore, John Mylroie, Lindsay Walker, Mississippi State University, Department of Geosciences

The survey of Mississippi caves is part of the National Karst Map, funded by the National Cave and Karst Research Institute and the National Park Service. The goal of the project is to create a database of fully surveyed caves as well as a GIS-based digital map of the state. There are a total of 47 known caves in Mississippi, 40 of which are limestone caves. To date, 21 caves in Mississippi have been mapped to modern standards. Most of the state's caves are located in three limestone formations: the Mariana Limestone of the Vicksburg group, running east to west across mid-state; the Ripley Limestone of the Wilcox Group, cutting diagonally across the state from north to southeast; and the Mississippian-Devonian limestone of the Fort Payne Group, occupying the northeast corner of the state. Pseudokarst caves are found in sandstone and quartzitic beds, as well as in loess deposits. Mississippi is not well known for its caves, even to its residents. The most recent publication regarding Mississippi caves, *Caves of Mississippi* (Knight *et al*., 1974), is 31 years old. In this time, the knowledge of many of Mississippi's caves has become lost or forgotten. No caving organizations currently exist in Mississippi to preserve cave location data or the caves themselves. Deforestation, mining and other land use practices have altered the landscape, resulting in the concealment of some caves, and complete or partial destruction of others. The cave inventory of Mississippi is being accomplished from scratch without an established caver infrastructure.

Florida Cave Survey

Jason Richards

In the last year the Florida Cave Survey has made a paradigm shift from secretive political infighting to an organized, frequently used print and electronic database with more than nine hundred and fifty caves and more than two thousand lines of related data. Almost all of the large data holding organizations have been included in the database from as far back as the mid 1960s. Borrowing from database examples such as the TCS and GSS, the FCS electronic database is indexable by almost every entry field, while retaining a simple and common spreadsheet format, similar in use and appearance to those produced by other southern state cave surveys. The FCS now is in the process of updating our print map book, with more than five hundred maps, to a digital format which can be easily updated and disseminated to cavers across the state. As the organization matures, we hope to continue our mapping efforts across the state, providing a permanent and long-lasting cave record for Florida's caver communities.

Operational Overview of the Tennessee Cave Survey

Jack Thomison, TCS East Tennessee Co-Chairman

The Tennessee Cave Survey (TCS) is governed by a nine-member Executive Committee including West and East Tennessee Co-Chairmen. Applicants must be cavers recommended by two regular members and approved by two of the Executive Committee. Dues are currently $6.00/year.

Information about caves is collected using a report form with specified data fields, a narrative description of the cave and its location, and a marked copy of the applicable topographic map. All data is kept both as a hard copy and an electronic file. Cave maps are currently only maintained as hard copy.

The cave database and a county narrative file are published for all Tennessee caves. A map book is produced in an 8 ½" x 11" format. These publications are available to TCS members at printed cost. A newsletter is published at irregular intervals and is free to TCS members.

The data are not to be distributed to anyone else without permission from the Co-Chairmen or the Executive Committee. No electronic copies are released. For special purposes, limited information may be provided to outsiders for research or to limit damage to caves.

The West Tennessee Co-chairman maintains the data, checks and corrects the report forms, and updates the information in the database and narrative files. The Map Book Director keeps the map files and maintains the map books. The East Tennessee Co-chairman keeps an off-site copy of all electronic files.

An Introduction to the Texas Speleological Survey

Jerry Fant, Texas Speleological Survey Director, 251 Gold Rush Circle, Wimberley, Texas 78676

George Veni, Texas Speleological Survey President, 11304 Candle Park, San Antonio, Texas 78249-4421

The Texas Speleological Survey (TSS) is a nonprofit corporation dedicated to the management of Texas cave data in support of research, exploration, education, and conservation. It was founded in 1961, and formalized itself with a now 12-member Board of Directors in 1994 and nonprofit status in 1995. The TSS office is housed at The University of Texas at Austin, through the support of the university's Texas Memorial Museum. TSS has produced or co-produced 40 publications on Texas caving regions, plus Kentucky and New Mexico. Currently (April 2005), 8,884 records are in the digital database, of which 3,806 are caves, 2,687 are karst springs, 233 are rockshelters, and 1,282 are sinkholes and other karst features. Hundreds of additional paper files of caves and karst features are being recorded digitally. Access to the data is available through casual requests, where non-sensitive or small amounts of sensitive data are requested (a simple procedure most commonly used by cavers) and formal requests, where large amounts of sensitive data are requested or greater assurance for responsible use is needed (a written request used mostly by consultants). Each method includes procedures to assure, as much as possible, the proper use of the data, protection of cave and karst resources, and the return of new data to TSS.

TSS strives to support Texas cavers and caving projects, while generating more information for its database, through its publications, a regular column in the Texas Speleological Association's newsletter, data-cataloguing sessions, technical workshops, and an active Internet web site: www.txspeleologicalsurvey.org.

Virginia Speleological Survey

Phil Lucas, HCR 3 Box 104, Burnsville, VA 24487 Lucas@VirginiaCaves.org

The Virginia Cave Survey became the Virginia Speleological Survey (VSS) in 1974 after the publication *Descriptions of Virginia Caves* (probably the last state-wide publication of cave locations and descriptions). Since then the survey has continued to prosper. Its primary mission has been to gather and archive Virginia cave information, disseminating data when appropriate. Conservation has always been an intrinsic part of the survey.

The VSS's organization has no regular members, but its Board is comprised of both Regional Directors who represent a county or drainage basin and At Large Directors. The in-flow of information comes through directors, county surveys, individuals, publications, and the VSS website. The VSS has contracts/agreements to share information with several governmental and private entities as well as working relationships with others.

VSS data is maintained both in a relational computer database and in hard files. The database has components that contain information about cave owners, maps, reporters, significant caves, closed caves, histories of exploration, karst springs, karst features, cave entrances as well as the main data file. As of April 2005, there are 4260 caves recorded, of which 366 are designated significant. Records of 1624 springs have been established and search of tax records provided 1884 addresses of cave owners.

A quarterly newsletter, The Virginia Cellars, provides cave descriptions, scientific/historical articles, maps and other cave information to subscribers. Cave locations are not published. A new endeavor called the Cave Observation Program is being developed to further document cave features and the various phenomena seen in caves.

Survey and Cartography Session

Using GIS to create The Mammoth Cave Atlas

Aaron Addison, 3 Sheffield Ct., Saint Charles, MO 63304 addison@caveresource.com

In the spring of 2005, over 50 years of Cave Research Foundation (CRF) exploration efforts in the Mammoth Cave area were assembled in a Geographic Information System (GIS). Among other tasks, one result of this goal was the initial prototyping and production of The Mammoth Cave Atlas. Maps from different data sources including, pencil on mylar, ink on mylar, Adobe Illustrator, and CAD formats have been combined into one dataset to visualize the world's longest known cave system.

Work continues on this CRF project, but preliminary results indicate that GIS provides an excellent software platform for producing color sheets of various maps, scales, and themes. A base of maps depicting known cave passage is being assembled as 11x17 sheets in to the +200 page The Mammoth Cave Atlas.

U.S. Exploration

History of the Exploration and Mapping of Hellhole, Pendleton County, West Virginia

Gordon S. Brace, 028 Cherri Drive, Falls Church, VA 22043 gbrace@cav-tel.net

Hellhole is located in Germany Valley, Pendleton County, West Virginia. Hellhole and the NSS have had a long and storied association, dating back to the inception of the NSS. Many of the techniques we now know as Single Rope Technique (SRT) were developed in Hellhole's 154-ft entrance drop and nearby Schoolhouse Cave. As well as being historically significant to the caving community, Hellhole is a hibernaculum site for two endangered species of bats: the Indiana Myotis and over 25% of the world's population of the Virginia Big-Eared.

With the exception of the United States Fish and Wildlife Service (USFWS) sponsored bi-annual bat counts, Hellhole has essentially been closed to the caving community since 1988. In 2002, after prolonged negotiations with Greer Industries (owner and operator of an adjacent limestone quarry), the USFWS, the West Virginia Department of Natural Resources (DNR), the West Virginia Department of Environmental Protection (DEP) and local landowners, the Germany Valley Karst Survey (GVKS) was contracted to survey the extent of the cave. In accordance with USFWS requirements regarding endangered bats, all survey activities must be completed in a 16-week window during the summer months. In three years (44 short weekends) of epic caving, the GVKS has surveyed over 12 mi of virgin passage, increased the length of the cave from 8.5 mi (13,679 m) to 20.3 mi (32,669 m), and revealed the deepest drop in West Virginia of 265 ft (81 m).

Exploration and Survey in Grand Caverns—Augusta County, Virginia

Scott Wahlquist, 2845 Shiffletts Mill Rd., Crozet, VA 22932

At management's request, the Virginia Region of the NSS is re-surveying Grand Caverns, a commercial cave located in the central Shenandoah Valley of Virginia. The cave is developed in Cambrian limestone/dolomite, and is known for its abundance of shield formations. With completion of the re-survey in the commercial cave (2650.7 m), a 20-cm high passage was pushed, leading to 3023.0 m (current) of unexplored cave. This newly discovered portion of cave is highly decorated with many forms of speleothems, including shields. As in the commercial portion, the northeast two thirds of the new passage is formed along NE-SW-oriented nearly vertical bedding. In the southwest third of the new passage, the bedding moves towards horizontal. The northern portion of the new passage is terminated by the hillside, while the southern portion is terminated by an inferred fault first described by Kass Kastning. The bedding-plane-oriented passages of the north are fairly dry with abundant brilliant white formations, earning it the name New Mexico. The more horizontal bedding in the southern portion of the new cave has led to the creation of a series of large rooms with massive breakdown. The largest of these rooms, Kentucky, is over a hundred meters long by forty meters wide. The highest and lowest points in the cave are found in the new passage. The total relief is 35.5 m. Exploration continues along the fault.

Gap Cave Exploration by Cave Research Foundation Cumberland Gap

Mike Crockett, 108 Ann Street, Pineville, Kentucky 40977 cumberlandgap@gmail.com

The Cave Research Foundation Cumberland Gap Project continues a multidisciplinary study at Cumberland Gap National Historical Park (CUGA) in Kentucky, Virginia, and Tennessee. Since 2003 CRF has been mapping Gap Cave. Thirty-five percent of the known cave has been surveyed. Mapped length exceeds 6 miles with 478 ft depth. 1.6 mi of virgin passage has been mapped. Project partner Lincoln Memorial University has improved the Cumberland Mountain Research Center (CMRC). Cave inventory forms, procedures, and training have been developed. All project participants now complete low-impact training and enter a contract to implement it in-cave. The CMRC Powell River Aquatic Research Station has been completed 14 mi south of Cumberland Mountain on the Powell River. Cumberland Mountain presents the 53-m-long edge of an uplifted fault sheet with an exposed limestone member 560 ft thick. The Powell River Valley, encompassing 950 mi^2 in Virginia and Tennessee, is primarily a karst plain of diverse carbonate structure. The potential for productive cave exploration and research remains high.

Recent Exploration at Jewel Cave

Mike Wiles, Jewel Cave National Monument, RR1, Box 60AA Custer, SD 57730

In an extensive cave system like Jewel Cave, exploration has evolved into dual purposes: to map as much of the far extents of the cave as possible (pushing the edge), and to map the rest of the passages to a practical level of completeness (mop- up). Both are necessary for increasing knowledge of the entire cave and for protection of cave resources; both known and unknown.

The park's exploration program continues to make use of technology, including a ruggedized laptop at camp, laser distance meters, digital cameras for cave feature inventory, and a joined multi-table database for recording trip reports and relevant statistics. We are also beginning to use inexpensive PDAs for data collection.

Attempts to push past a linear geologic obstruction have not yet been successful. However, geologic mapping has shown that there is no visible offset on the surface, so the lineament may be a fold axis. This is a less severe obstruction than a fault; as it was previously believed to be; and barometric airflow indicates that there is much cave beyond.

New Discoveries in Lilburn Cave, California

Peter Bosted, 630 Valley Forge Dr, Newport News VA 23602 peter@cavepics.com

Lilburn Cave is formed in a banded marble unit of the Sierra Nevada Mountains in central California. Several new discoveries in the past few years have pushed the length of the cave length to over 20.6 mi. The new areas carry such prosaic names as Southern Comfort, Canyonlands, the Area of Low Hanging Fruit, and the Paris Opera House. Typical passages are narrow, muddy canyons with many intersections, forming complex three-dimensional mazes. The new areas also include some rooms that are relatively large for a California cave. Of particular interest is the discovery of a missing section of Redwood Creek, the stream that is responsible for much of the passage formation in Lilburn Cave. The largest area was reached by an aid climb, while others involved pushing tights crawls through breakdown. Other new discoveries include large deposits of malachite.

Recent Discoveries in the Chestnut Ridge Cave System, Bath Co., VA

Nevin W. Davis, HCR 03 Box 99, Burnsville,VA 24487 nwdavis@va.tds.net

On August 9, 2003 a digging effort by Butler Cave Conservation Society members spanning 12 years on a lead called the Air Blower was rewarded by a significant extension of the cave. To date 3.48 mi.(5.6 km.) of passage has been surveyed with a vertical extent of 437 ft. (133 m.) The Boondocks Section of the cave spans lower levels which flood to depths of 90 ft. (27 m.) to large upper paleo levels adorned with exotic world class anthodites. The lower level also contains a stream carrying nearly all of the flow of Cathedral Spring which drains this portion of the system. This is the first time the main flow has been encountered in the cave although many tributaries have been seen. The surveyed length of the system now stands at 17.49 mi. (28.2 km.). Presently explorers are within a few feet of connecting to Burns' Chestnut Ridge Cave which will add another 2.39 miles (3.8 km.) to the Chestnut Ridge Cave System; however, the connection may be challenging.

Lechuguilla Cave: Recent Exploration Highlights

John T. M. Lyles, P.O. Box 95, Los Alamos, NM 87544 jtml@losalamos.com

Exploration and survey continued in Lechuguilla Cave in the past year. Through methodical examination of obscure leads in fissures, climbs, boneyards, pancake layers, and breakdown, cavers have extended the known length beyond 114 mi. Resurvey in the Western Branch is improving the complex Chandelier Graveyard Quads above the Western Borehole. Survey in the Promised Land was completed; the western edge of the cave is now defined where the 260-m-long Congo trunk abruptly ends. At the southwest edge of the spacious Zanzibar chamber, a tight chimney was pushed to find Zombie Zoo, trending out below the Rainbow Room, the original end of the Western Branch. Paris-Texas continued to meander in horrendous boneyard under the Haupache Highway portion of the Western Borehole. It came close to making a connection to the deeper Frostworks complex. The spectacular Mother Lode chamber yielded a half dozen new leads, some dropping deep into fissures. Over a 100 m lower, the Widowmaker continued to be explored and mapped. In the southwest, an impact map was made for the Chandelier Ballroom, the most photographed chamber in the cave. In the Eastern Branch, La Morada room was resketched and survey continued in the Outback. In the central Rift of the cave, teams explored both the north and south ends in numerous day trips. There are 2200 surveys recorded, with approximately 27,000 stations in the cave. After 18 years since its discovery, Lechuguilla Cave is far from finished.

Manu Nui Cave, Hawai'i

Peter and Ann Bosted

Manu Nui is a recently explored cave on the Big Island of Hawaii. It is unusual among lava caves in being profusely decorated with long, curved stalactites. Some areas of the cave also contain a rich variety of colors and splash features. The cave follows a very steep gradient, probably resulting in unusually strong chimney effect air currents in at the time of active lava flows. The cave is named for bones of the extinct Manu Nui bird. There are many entrances (pukas) to the system, most of which are named after native species growing near the entrances in this lush rain forest environment. With over 1.5 mi surveyed to date in the system (which also includes Laulu Cave), many leads remain before the exploration can be considered finished.

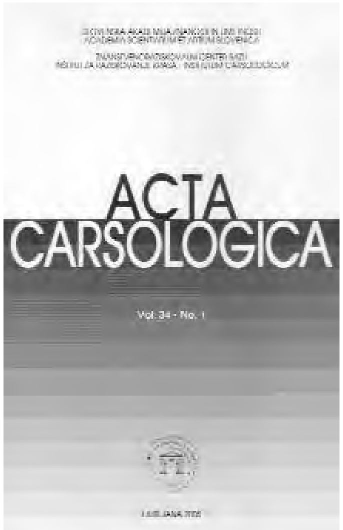
Experimental research using Thermography To locate heat signatures from caves

Jim Thompson[1] *and Murray Marvin*[2]
[1]*1 Jim Thompson Way, Blackwell, MO 63626 disasterjim@aol.com*
[2]*621 W. Alder Street Suite 200, Portland, OR 97205 murray@murraymarvin.com*

Thermal differences between cave entrances and the surrounding landscape have long been known. Cavers traditionally ridgewalked in cave-likely temperate regions in cold mid-winter with a falling barometer in order to visually detect 'fog-plumes' of escaping subterranean air from crevices in order to locate caves. We are experimenting with a high-technology solution to this cave detection method by applying infrared thermography, a useful tool in fire detection, human body location and other building examination remote sensing to the surface of the earth. Early trials during the spring of 2005 with a Therma CAMTM B20 HSV infrared (IR) camera, even under foliage-filled and warm atmospheric conditions, produced promising results in initial trials in New Mexico, Missouri and West Virginia. Further research is underway at Fisher Cave, Franklin County, Missouri.

This research began by documenting temperatures of cave openings and surrounding substrates. Atmospheric, ambient conditions (temperature, relative humidity, specific humidity and dew point) were recorded inside the cave, at the entrance and at intervals up to 183 meters. Normal images were contrasted with thermograms that showed full temperature gradients of the openings. At 118 meters, the opening could no longer be seen with the naked eye. The thermograms showed distinct images of cave openings. Trials continued to 388 meters. In excess of 300 meters, thermograms showed the distinct cave opening of Fisher Cave. At 388 meters, the thermograms showed signatures that could be that of a cave entrance. The initial results indicate that individual cave entrances have separate and unique temperature gradients. Thus, individual cave thermograms are a "fingerprint" or signature of that cave. Thermograms can be used to isolate and identify caves entrances from surrounding terrain. Once standardized procedures are established, thermograms may become an important tool for cave location and exploration.

WORLD KARST SCIENCE REVIEWS



Acta Carsologica 2005
Issue 34(1)

Theoretical investigation of the duration of karstic denudation on bare, sloping limestone surface. Gábor Zzunyogh, pp. 9–24.
Tectonics impact on poljes and minor basins (Case studies of Dinaric Karst). Ivan Gams, 25–42.
Dating of caves by cosmogenic nuclides: Method, possibilities, and the Siebenhengste example (Switzerland). Philipp Häuselmann and Darryl E. Granger, 43–50.
Dating ancient caves and related paleokarsts. R. Osborne and L. Armstrong, 51–72.
Mapping of hazards to karst groundwater on the Velika planina plateau. Gregor Kovačič and Nataša Ravbar, 73–86.
Karst and cave systems in Bosnek region (Vitosha Mountain, Bulgaria) and Wintimdouine (High Atlas Mountain, Morocco). Dora Angelova, M'hamed Alaeddine Beloul, Sophia Bouzid, and Farid Faik, 87–112.
Structural position of the shaft Habečkovo Brezno (Idrijsko, Slovenia). Jože Čar and Bojana Zagoda, 113–134.
The show cave at "Gran Caverna de Santo Tomás" (Pinar del Rio province, Cuba). Mario Parise and Manuel Valdes Suarez, 135–150.
Towards establishing effective protective boundaries for the Lunan Stone Forest using an online spatial decision support system. Chuanrong Zhang, Weidong Li, and Michael Day, 151–168.
Terrestrial fauna from cavities in northern and central Slovenia, and a review of systematically ecologically investigated cavities. Tone Novak, 169–210.
Babbage's calculating machines, the Proteus from Postojna Cave, and the Carniolan Museum Society. Stanislav Južnič, 211–220.
The inscriptions of the Tartarus Panel and the 1833 Fercher-survey, Postojnska jama. S. Kempe, 221–236.
Škocjanske jame, Slovenia, in 1891—An alpine club excursion. Trevor R. Shaw, 237–260.

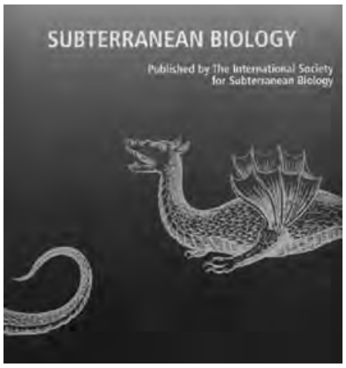
Cave and Karst Science 2005
Issue 31(3)

Eogenetic karst development on a small tectonically active, carbonate island: Auijan, Mariana Islands. Kevin Stafford, John Mylroie, Danko Taboroši, and John Jenson, 101–108.
Koru Polje and karst landform evolution in the middle part of the Kure Mountains, Northern Anatolia, Turkey. Ali Uzun, 109–112.
A brief history of stalagmite growth measurements at Ingleborough Cave, Yorkshire, United Kingdom. Donald A. McFarlane, Joyce Lundberg, and John Cordingley, 113–118.
A note on the distribution of plants in Scoska Cave, North Yorkshire, United Kingdom, and their relationship to light intensity. Allan Pentecost and Zhaohui Zhang, 119–122.
Hydraulic and geological factors influencing conduit flow depth. Stephen R. H. Worthington, 123–134.
Vested interests at Cango Cave, South Africa, in the Nineteenth Century. Stephen A.Craven, 135–138.

International Journal of Speleology 2005
Issue 34(1-2)

Radon in caves. Arrigo A.Cigna, 1–18.
Agraphorura calvoi n. sp. from Venezuelan caves (Collembola: Onychiuridae). Javier I.Arbea, 19–24.
Cavity-based secondary mineralization in volcanic tuffs of Yucca Mountain, Nevada: A new type of the polymineral vadose speleothem, or a hydrothermal deposit? Yuri V.Dublyansky and Sergey Z.Smirnov, 25–44.
Conceptualisation of speleogenesis in multi-storey artesian systems: a model of transverse speleogenesis. Alexander Klimchouk, 45–64.
Re-published from: Speleogenesis and Evolution of Karst Aquifers 1(2), www.speleogenesis.info
Cross-formational flow, diffluence and transfluence observed in St. Beatus Cave and SiebenHengste (Switzerland). Philipp Häuselmann, 65–70.
Re-published from: Speleogenesis and Evolution of Karst Aquifers 1(2), www.speleogenesis.info
Partitions, compartments and portals: Cave development in internally impounded karst masses. R. Osborne and L. Armstrong, 71–81.

Re-published from: Speleogenesis and Evolution of Karst Aquifers 1(4), www.speleogenesis.info



Subterranean Biology 2004
Volume 2

On some interesting freshwater Annelida, mainly Oligochaeta, of the underground waters of southwestern France with the description of a new species. Route N., Martinez-Ansemil E., Sambugar B. & Giani N., 1–6.

Trophic sources partition and population genetic structure of the isopod *Androniscus dentiger* from a chemoautotrophy based underground ecosystem. Gentile G. & Sarbu S.M., 7–14.

Pattern of gene flow and genetic divergence in the three Italian species of the cave cricket genus *Troglophilus* (Orthoptera, Rhaphidophoridae): Allozyme data. Ketmaier V., De Matthaeis E. & Cobolli M., 15–26.

The location of terrestrial species-rich caves in a cave-rich area. Culver D.C., Christman M.C., Ereg I., Trontelj P. & Sket B., 27–32.

Niphargus and *Gammarus* from karst waters: first data on heavy metal (Cd, Cu, Zn) exposure in a biospeleology laboratory. Coppellotti Krupa O., Toniello V. & Guidolin L., 33–52.

Interactions of plant roots and speleothems. Taborosi D., Hirakawa K. & Stafford K., 43–52.

Does sexual experience influence mate choice decisions in Cave Molly females (*Poecilia mexicana*, Poeciliidae, Teleostei)? Arndt M., Parzefall J. & Plath M., 53–58.

Size-dependent male mating behaviour in the Cave Molly, *Poecilia mexicana* (Poeciliidae, Teleostei). Plath M., Arndt M., Parzefall J. & Schlupp J., 59–64.

Four new species of the subterranean amphipod genus *Hadzia* (Hadziidae) from caves in the western Pacific, with a re-evaluation of the taxonomic status of the genus. Sawicki T.R., Holsinger J.R. & Iliffe T.M., 65–90.

Towards a revision of Candoninae (Crustacea, Ostracoda): On the genus *Candonopsis vavra*, with descriptions of new taxa. Karanovic I., 91–108.

Bragasellus comasioides, sp. nov., crustacé isopode, asellote stygobie des Picos de Europa (Espagne). Magniez G. J. & Brehier F., 109–112.

Une nouvelle espèce du genre Plusiocampa Silvestri, 1912 (Diplura, Campodeidae) et données pour sa reconstruction paléobiogéographique dans les Bétiques. Sendra A., Lara M.D., Ruiz Aviles F. & Tinaut A., 113–122.

Speleogenesis and Evolution of Karst Aquifers 2005
Volume 3 (1)

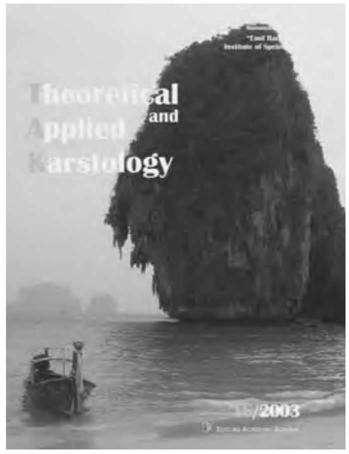
Dating ancient caves and related palaeokarsts. R.A.L. Osborne, 15 pages (re-published from Acta Carsologica 34(1), 51–72).

Thermal variations in the hyporheic zone of a karst stream. T.Dogwiler and C.Wicks, 11 pages.

Hydraulic and geological factors influencing conduit flow depth. S .R. H.Worthington, 19 pages (re-published from Cave and Karst Science 2005, 31(3), 123–134).

Engineering classification of karst ground conditions. A. C. Waltham and P. G. Fookes, 20 pages (re-published from Quarterly Journal of Engineering Geology and Hydrogeology, 2003, vol. 36, pp. 101–118).

Trace elements in speleothems: a short review of the state of the art. S. Verheyden, 5 pages (re-published from International Journal of Speleology 2004, 33(1/4), 97–104).



Theoretical and Applied Karstology 2003
Issue 16

Chemical transmission of information through air in the cave environment: a theoretical approach. Raymond Tercafs, 5–23.

Microclimate controls of vadose carbonate precipitation: evidence from stalactite morphology. Danko Taboroši and Kazuomi Hirakawa, 25–40.

Mineralogy of Cave No. 4 from Runcului Hill (Metaliferi Mts., Romania). Luminița Zaharia, Tudor Tamas and Erika Suciu-Krausz, 41–46.

Study of hydraulics and hydrocarbon-pollution behavior of a karst aquifer in a tropical area: Yucatan Peninsula, Mexico. Jesús Garcia-Sánchez, and Inés Navarro-Gonzáles, 47–55.

The musk ox in the bison's shadow of West European Upper Palaeolithic rock art. Todor Stoytchev and Nikolai Spassov, 57–66.

Bird remains from the Late Pleistocene deposits of Mališina stijena (Montenegro). Erika Gál, Vesna Dimitrievic, and Eugen Kessler, 67–75.

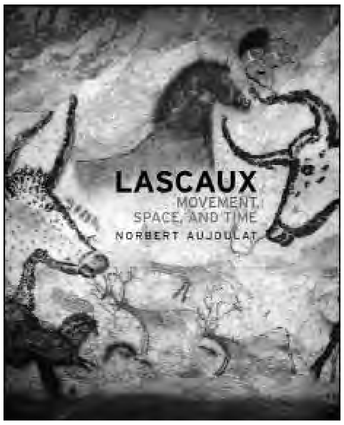
The oldest modern humans in Europe. Oana Moldovan, Þtefan Milotă, Laurențiu Sarcina, Erik Trinkaus, Ion Băltean, Andrei Soficaru and Rajka Géza, 77–81.

Checklist of the Romanian cave minerals. Bogdan P. Onac, 83–89.

Mineralogical analyses in the cave "Pestera de la Podul Natural" (Mehedinti Plateau, Romania). Gabriel Diaconu, Delia Dumitraþ, and Þtefan Marincea, 91–97.

New data on the evolution of the Arvicola (Mammalia, Rodentia) from the karst of Romania. Alexandru Petculescu, 99–103.

BOOK REVIEWS



Lascaux: Movement, Space, and Time

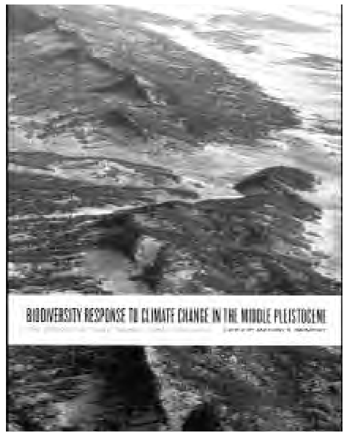
Norbert Aujoulat and Henry Abrams, 2005, New York, 274 p. ISBN 0-8109-5900-3, hardbound, 10.5 x 13.5 inches, $65.

Yet another coffee-table book on European Paleolithic cave art. In fact, at six pounds and too tall for any bookshelf in my house, it might well serve *as* a coffee table. The text was translated from the French original, *Lascaux: le geste, l'espace et le temps*, by Martin Street. There is also a British edition of the same book, titled *The Splendour of Lascaux*.

The cave at Lascaux is the most famous of the cave-art sites in southern Europe, with art made around seventeen thousand years ago. This book consists primarily of 226 color illustrations printed on paper as thick as the covers of some paperbacks. Some of the photos cover two full pages, and the largest, a double foldout, is forty inches wide. As is frustratingly customary, almost all the photos lack anything for scale, and it is hard for the viewer to appreciate how large the paintings are. Fortunately, there are a couple of exceptions near the beginning of the book.

The text is relatively brief, with widely spaced type never covering more than two-thirds of the parts of pages not occupied by photographs. Even so, few buyers of the book will do more than dip into it here and there, because it consists almost entirely of very dry descriptions of the cave, the artists' techniques, and the art. But of course the text is not the point, and anyone interested in a picture book of Paleolithic art should consider it. It is probably one of the few such books available, because these books go out of print quickly. I've seen previous similar books by the same publisher on remainder tables within a year or two.

Reviewed by: Bill Mixon, 14045 N Green Hills Loop, Austin TX 78737-8627. (billmixon@worldnet.att.net), October 2005.



Biodiversity Response to Climate Change in the Middle Pleistocene: The Porcupine Cave Fauna from Colorado

Anthony D. Barnosky, ed., 2004, University of California Press, Berkeley, 385 p. ISBN 0-520-24082-0, hardcover, 8½ x 11¼ inches, $135.00.

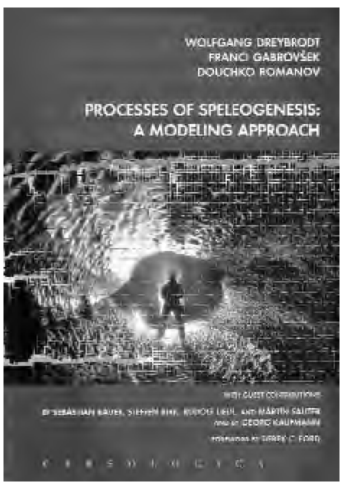
In the absence of appropriate changes in worldwide government attitudes and policies, the growing consensus among scientists is that Earth's temperature will continue to rise. As this alarming trend in global warming continues, scientists predict an average increase in global mean temperature of 1.4–5.8º C by the year 2100. Regional warming may be even more extreme. These changes may have planet-wide impact on dwindling ecosystems, especially on the diversity of existing species. Biodiversity is of concern because it is believed to be a direct measure of the health of an ecosystem, and, by extension, a proxy for how safe the environment is for human habitation.

Porcupine Cave is located in the Colorado Rockies, at an elevation of 2900 meters in the South Park intermountain basin. It is developed on three levels, with approximately 600 meters of mapped passages. Since the mid 1940s, the cave has been a popular site for beginner caving trips. The cave's wealth of middle Pleistocene fossils (dating from approximately 600,000 to one million years ago–a span characterized by repeated advance and retreat of glaciers) was first recognized in 1981. Since 1985, its fossils have been excavated by teams from three major institutions: the Carnegie Museum of Natural History, the Denver Museum of Nature and Science, and the University of California Museum of Paleontology. Hundreds of thousands of fossils have been excavated from the cave's interior, tens of thousands of which have been subjected to rigorous analysis. They provide the best evidence about the animals that once lived at high elevations in North America and form the basis for hypotheses about the local habitat of South Park during the middle Pleistocene. They also provide unique insight into how global climate change might affect living ecosystems today.

This is a scholarly work focused principally on description and analysis of the vast array of fossil remains excavated from Porcupine Cave. Preliminary chapters introduce the cave and its environs. Throughout the text, emphasis is placed on taphonomic relationships–the various forces and circumstances that govern the movement and physical condition of bones following an animal's death. Despite the book's title, it is only in the last few chapters that the discussion moves away from the fossils themselves to a short, theoretical consideration of the potential impact of climate on ecosystem diversity, past and future. Mitigation of global warming and prevention of habitat fragmentation are presented as major elements in forestalling widespread ecological disaster.

This book will be of interest primarily to paleontologists concerned with vertebrate evolution, as well as ecologists and conservationists focusing on the long-term preservation of ecological diversity. Although the editor intends the caving community to be among the book's intended readership, it is appropriate mainly to cavers with a strong interest in paleontology. The level of descriptive detail is likely to be overwhelming for the general reader. On the other hand, many in the caving community, most of whom have undoubtedly seen fossilized remains underground and who may be interested in knowing how scientists go about studying them, may be impressed by both the amount of work involved in excavating underground fossil sites and the wealth of information that can be derived from such finds.

Reviewed by: Danny A. Brass, 70 Livingston St. Apt. 3K, New Haven, CT 06511-2467 (brassda@yahoo.com), October 2005.



Processes of Speleogenesis: A Modeling Approach

Wolfgang Dreybrodt, Franci Gabrovšek, and Douchko Romanov, with contributions by Sebastian Bauer, Steffen Birk, Rudolf Liedl, Martin Sauter, and Georg Kaufmann, 2005. Postojna-Ljubljana, Slovenia, Carsologica, ZRC Publishing, 376 p. + CD. ISBN 961-6500-91-0, softbound, 6.6 x 9.3 inches, 33.2 euros. Order on-line at www.zrc-sazu.si/zalozba.

This book draws together the results of digital modeling of cave origin over the past 15 years. It represents the combined work of Dreybrodt at the University of Bremen, Germany, and his recent PhD graduates Gabrovšek (Slovenia) and Romanov (Bulgaria), plus complementary work by researchers at other German universities. The authors do not attempt to cover all aspects of karst, nor do they deal specifically with aquifer modeling, but the methods and conclusions in this book give valuable insight into these fields. Most of this material has already been published elsewhere, but in scattered locations. This book synthesizes all the authors' prior work and ties it together with a narrative thread. The fact that all or most of the authors are familiar with real karst and caves enhances the book's credibility.

The usual approach to digital modeling of karst is to design a grid of primitive fissures, which is then subdivided into many small segments. Boundary conditions such as head and chemical values are assigned, and the dissolutional growth of each segment is calculated over small time increments. As the results of each time step are accumulated, the evolution of cave passages can be tracked. Finite-difference analysis involves the use of a fixed grid (normally rectangular). Nearly all karst models are of this type. Finite-element analysis uses irregular grids that may change shape with time. Digital karst modeling originated in America and England around 1980, but it is in Europe that the technique has blossomed over the past 15 years. Most of these advances have been the work of Prof. Dreybrodt and his colleagues.

This book is an extraordinary achievement that warrants close attention by anyone interested in speleogenesis. The English is good, with only minor irregularities that do not interfere with the reader's understanding. Still, the book may be intimidating for those unfamiliar with hydraulics and chemical kinetics. There are 250 figures, most with multiple panels, which consist almost entirely of computer-generated grids that track conduit growth under various boundary conditions. There are no photos, except on the cover, nor are there any maps or diagrams of real karst or caves. Happily, the book also contains an interactive CD with animated clips that show the results of the most significant models. The software is clear, user-friendly, and seems to be bug-free. It is possible to retrace steps to facilitate close examination of model progress. Use of color in the book and CD is effective and essential to the clarity of the presentation.

Some readers may criticize digital models as too idealized, and unable to predict exact field conditions. This attitude misses the point. Models are not designed to reconstruct the evolution of real caves, but to examine the interaction between the many variables involved. The results show what happens under the exact boundary conditions chosen. A great deal can be learned about real systems by examining how they differ from idealized models whose boundary conditions are precisely known.

Chapters in the book are as follows: (1) Introduction to concepts; (2) Equilibrium chemistry and dissolution kinetics of limestone in H_2O-CO_2 solutions; (3) Evolution of single fractures; (4) Evolution of two-dimensional networks under constant head; (5) Unconfined aquifers; (6) Karstification below dam sites; (7) Conclusion and future perspectives. Two final chapters are by guest authors: Simulation of karst aquifer genesis with a double permeability approach, by Bauer, Birk, Liedl, and Sauter (University of Tübingen); and Structure and evolution of karst aquifers – a finite-element approach, by Georg Kaufmann (University of Göttingen). There is some overlap among the three major sections, but readers can benefit from multiple views of these complex subjects.

For the sake of clarity and repeatability, models in the book are given fairly simple boundary conditions. Even so, the internal complexity of the models makes it necessary to look at general trends rather than specific details. It will take many readings to absorb the book's full message. Conclusions are necessarily veiled in technical terms, and they do not stand out as bold concepts that can be applied to one's favorite cave. This is probably a good thing – if presented with a bulleted list of guidelines to cave interpretation, readers would be tempted to apply them without understanding the inner workings of the models. The book has no index, but the topics are complex enough that it would be difficult to find individual words to describe them.

I have cautiously selected a few representative conclusions from the book, to show the nature of the topics discussed. They must not be taken at face value without close scrutiny of the book, because their validity depends on the exact model design. [In the following statements, breakthrough time (***T***) is the time required for initial openings to undergo slow gestation prior to the rapid growth that produces caves; cave development is favored when ***T*** is small.]

T decreases if CO_2 is introduced at points along the flow path, rather than just at the upstream end. The effect is greatest if the sources are located in the downstream half. Mixing corrosion, at junctions of flow paths having different CO_2 values, is greatest where mixing takes place about half-way through the conduit length. But mixing corrosion is not essential to cave development, because water is not fully saturated with calcite when it enters the ground.

T is reduced where there is a single major sequence of fissures that extends through an initial network of narrow fractures. Inflow of saturated water from the surrounding network increases ***T***. Where water is introduced at only a few points, proto-solution conduits tend at first to finger outward in the downstream direction, but this pattern is later overwhelmed by convergent flow when rapid cave development takes over. In contrast, if calcite-saturated water enters the main flow routes from the network of surrounding fissures, mixing between the two water types increases ***T***, and the conduits tend *not* to branch downstream.

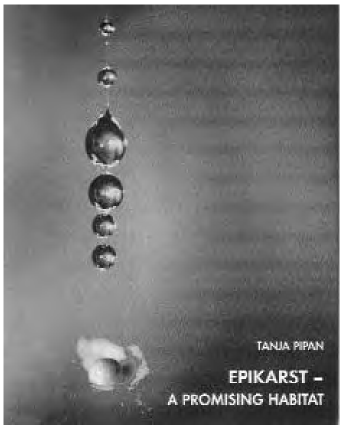
In unconfined settings, cave development concentrates at the water table, whether or not prominent fractures are present. But adding prominent fractures can lead to a few deep phreatic loops, if they develop before the preferred water-table route is established. Depth of penetration of solution conduits below the water table is hardly affected by aquifer thickness, because water at depth is mainly saturated. Erosional downcutting of the outlet valley, followed by aggradation, tends to establish nearly horizontal water-table caves. Leakage through limestone beneath dams can cause a great deal of water loss within about 50 years by the solutional enlargement of fissures, especially if the reservoir water is at less than 50% calcite saturation.

How do the results compare with earlier conceptual models of the past 30–40 years? There is a satisfyingly close fit to the earlier work, and anyone who has contributed to this field will find supporting evidence somewhere in the book. But the modeled time scales for cave development seem too short compared to those verified in the field. That is because the models consider ideal dissolution processes unhindered by such factors as sediment accumulation and degassing of CO_2 through openings to the surface, which extend the time frame.

This book is ideal for researchers in speleogenesis who have a solid grasp of the technical aspects. Most of the necessary background information is outlined in the first chapter, but the subtle aspects will be clear only to those who already have a good background in geochemistry and computer modeling, especially when interpreting the figures. This book is not aimed at groundwater hydrologists, although the results would be eye-opening to anyone in that field who denies the importance of solution conduits in carbonate aquifers.

This book poses a challenge: If you can understand intuitively why the different models produce the results they do, you are well on the way toward being able to interpret the origin of typical caves and the behavior of karst groundwater.

Reviewed by Arthur N. Palmer, Dept. of Earth Sciences, State University of New York, Oneonta, NY 13820-4015 (palmeran@oneonta.edu).



Epikarst, a promising habitat. Copepod fauna, its diversity and ecology: a case study from Slovenia (Europe).

Tanja Pipan. 2005. ZRC Publishing, Karst Research Institute at ZRC SAZU, 101 p. ISBN 961-6500-90-2. Softbound, 6.5 x 9 inches, 16 EUR. Order online at www.zrc-sazu.si/zalozba.

This monograph summarizes part of the dissertation research of Dr. Tanja Pipan. Her work focused on the diversity and distribution of organisms from the epikarst habitat from six cave systems in southwestern Slovenia. This volume deals with copepods, a group of microscopic crustaceans commonly found in most marine and freshwater habitats, and, as revealed by Pipan, also ubiquitous in ceiling drips and drip pools in caves.

Although there is healthy debate among karst scientists on various aspects of the epikarst, including the definition of the term epikarst itself (Jones et al., 2004), there is no doubt that the soil-rock interface above the vadose zone in caves has tremendous capacity to store water. It is the common experience of cavers world-wide that, no matter how dry the surface seems, one does not need to penetrate far into a cave before encountering ceiling drips. Biologists have long suspected that water in the epikarst may harbor many species. Pipan's work is significant in that it is the first quantitative and systematic survey of epikarst organisms over time.

This volume is divided into four sections. The first section provides an introduction to the epikarst, clearly lays out the goals of Pipan's research, and includes an excellent introduction to copepods in general and a detailed summary of copepod diversity and distribution in the Dinaric region and Slovenia. In the second section, Pipan describes her field sites, sampling method, and statistical tools for data analysis. A most interesting part of this section is her simple, inexpensive, yet ingenious method of sampling organisms from drips and drip pools.

The third and fourth sections detail the results of Pipan's work. Here she shows an impressive number of specimens belonging to a wide variety of taxa collected from drips and pools in each of the six cave systems. Her data definitively shows that the epikarst is indeed a habitat harboring a distinctive set of organisms. For example, among 37 species of copepods collected, she identified 27 as stygobionts and 11 of them are new to science. She also shows statistically that her results were based on a fully representative sampling of the fauna. Besides high diversity, the large number of specimens dripping into the vadose zone implies that this is also an important pathway of energy into the cave ecosystem.

Beyond demonstration of the richness of this fauna, Pipan's analysis gives additional insights into this interesting habitat. She uses canonical correspondence analyses to reveal physical and chemical factors that potentially control the distribution of each species. One result is that some species are highly specialized for certain ecological conditions. Pipan also compares the community of copepods at different geographic scales, and conclusively reveals a high degree of heterogeneity in the species distributions. Her analysis shows that the epikarst is a much more complex environment than previously anticipated.

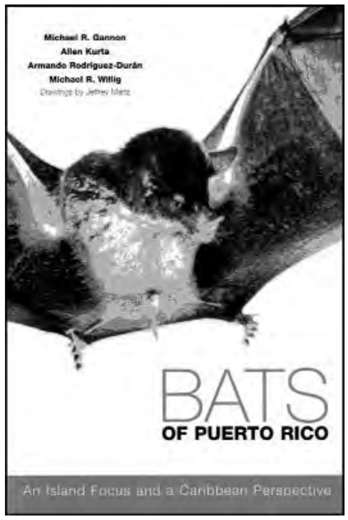
Although this is a small volume, one should be prepared to take some time to go over it slowly. Many of the figures are extremely dense and pack in a lot of information, such as the ordination diagrams from the canonical correspondence analyses. I found the summary figures for the abundance of species over time slightly difficult to follow. Overall, this monograph is well written, well organized and contain much information presented in a logical order.

I think with time this will prove to be a seminal work. I anticipate that the results will stimulate activity to examine the up-to-now much neglected epikarst fauna in many parts of the world. This work should be of interest not only to biologists concerned with cave organisms, but to any karst scientist wanting some insight into this "promising habitat."

Reference

Jones, W.K., Culver, D.C., and Herman, J.S. (eds.), 2004, Epikarst: Charles Town, WV, Karst Waters Institute Special Publication 9, Proceedings of symposium held in Shepherdstown, West Virginia, 2003, 160p.

Reviewed by Daniel W. Fong, Associate Professor, Department of Biology, American University, Washington, D.C. 20016 (dfong@american.edu).



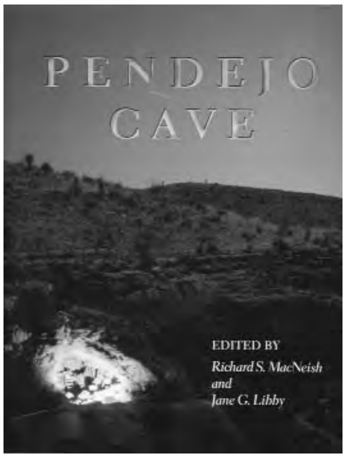
Bats of Puerto Rico: An Island Focus and a Caribbean Perspective

Michael R. Gannon, Allen Kurta, Armando Rodríguez-Durán, and Michael R. Willig, 2005, Texas Tech University Press, Lubbock, TX, 239 p., ISBN 0-89672-551-0, softbound, 6 x 9¾ inches, $19.95.

The Caribbean islands are fragile ecosystems, highly vulnerable to natural and human impact. Because of various factors, species richness is considerably less than that of mainland sites at comparable latitudes. Hence, even minor environmental damage can have major ecological consequences for island fauna. *Bats of Puerto Rico* is divided into three sections: (1) a well-balanced description of Puerto Rico as an island ecosystem, (2) a general section on basic bat biology, and (3) an in-depth discussion of Puerto Rico's 13 species of bats – the only mammalian fauna native to the island. Section 3 includes a discussion of bat taxonomy, distribution and status, external anatomy, and various aspects of their natural history. A nice feature is the inclusion of the etymologic derivation of both genus and species names for all bats discussed. Distribution maps show the range of each species across the island. The text concludes with a chapter on conservation of Caribbean bats and two keys for the identification of Puerto Rican species (one based on external morphology and the other on cranial and dental characteristics).

This is the first comprehensive treatise on the biology of Puerto Rican bats to be published. It should appeal to persons interested in the ecology, natural history, and biology of bats. It is quite readable and well written, with minimal use of technical jargon. Several detailed appendices, an extensive list of references, and a glossary of selected terms are provided. It should be easily grasped by anyone having a basic grounding in biology.

Reviewed by: Danny A. Brass, 70 Livingston St. Apt. 3K, New Haven, CT 06511-2467, (brassda@yahoo.com).



Pendejo Cave

Richard S. MacNeish and Jane G. Libby (eds.), 2003, University of New Mexico Press, Albuquerque, NM, 526 p. ISBN 0-8263-2405-3, hardcover, 8½ x 11¼ inches, $85.00.

Modern humans are generally believed to have first arisen in Africa some 150,000 to 200,000 years ago. From there, they slowly spread into the Old World and then across the globe. They appeared in the New World relatively late compared to elsewhere. The major obstacle to peopling of the New World was the Bering Strait, which now separates Siberia and Alaska. However, during the time of the last major glaciation (between 75,000 and 12,000 years ago), when much water was tied up as ice, a land bridge connected the two continents. Many scholars believe that 40,000 years ago was the earliest practical time for the movement of modern humans across the Bering Strait because of the cold conditions. However, some scholars see no obstacles to an earlier crossing, and that it likely for humans to have occupied the Americas as early as 50,000–70,000 years ago.

According to the scenario most widely accepted by modern anthropologists and archaeologists, the first unimpeachable evidence of human occupation of the Americas is that of the Clovis people, whose artifacts have been dated to between 10,900 and 11,600 years ago. These sites have been found throughout the contiguous United States, as well as in Mexico and Central America. However, no unassailable evidence for an earlier culture yet exists in the Americas.

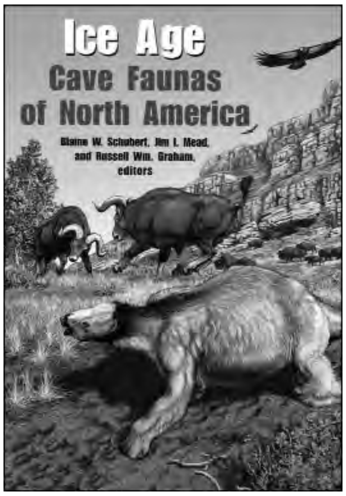
Since the initial discovery of Clovis artifacts, there have been numerous challenges to the widely accepted doctrine that the Clovis people were the first humans to inhabit the Americas. Several well-studied sites, such as Pendejo Cave in southern New Mexico, suggest a chronology of human habitation that pre-dates the Clovis culture by tens of thousands of years. But, like all presumed pre-Clovis sites (many of which are discussed in the text), their validity is questionable and a high degree of skepticism remains widespread within the scientific community.

The discovery of Pendejo cave in modern times was reputedly made in 1975 as part of a geological survey of the region by the U.S. Army. The Army maintains the area as a weaponry and training site. This "off-limits" status has been instrumental in protecting the site from vandals. Pendejo Cave was excavated between 1990 and 1992, under the watchful eye of MacNeish, an experienced archaeologist and ardent proponent of pre-Clovis civilization in the Americas. For the most part it is the accuracy of the interpretations that have raised criticism and which remain in dispute. Artifacts unearthed at Pendejo Cave, such as the various "stone tools" found within the deeper layers in the floor, were sent to various outside experts for detailed analysis. Typically, the results were inconclusive, some experts supporting the view that these "tools" were fashioned by humans and others considering them to be artifacts of natural, non-human processes. Even Mark Stoneking – one of the original architects of the mitochondrial Eve theory (as dubbed by the popular press) and the geneticist who performed MtDNA analysis of human hair from the cave deposits, which dated as early as 19,180 years ago – could not rule out the possibility of sample contamination.

In any event, this book presents an interesting and detailed account of the excavation of this potential pre-Clovis site. Its multi-authored text contains 19 chapters divided into three main sections: (1) *Paleoecology*, in which the environment of the cave and its surroundings (including geological, zoological, and botanical aspects) are discussed, (2) *Evidence of Human Occupation*, in which the in-cave excavation and the recovery and analysis of ancient artifacts (including stone tools, imported stone, modified bone, burned bone, friction skin imprints in fired clay, cordage samples, hearths, and hair) are discussed in detail, and (3) *Conclusions*, in which the findings are put into theoretical perspective as to past climates, vegetation, and animal habitats during the time of potential pre-Clovis human occupation, as well as aspects of life, and culture of the people. On the basis of their findings at Pendejo Cave, the authors present speculative timetables for the early migration of human populations out of Asia and into the New World.

Whether or not you agree with the basic thesis of a pre-Clovis civilization in the Americas, the authors of *Pendejo Cave* present an excellent study of cave archaeology. It is written in a matter-of-fact and readable style, but clearly not intended as a popular account. Their finds make us pause to think and, perhaps, to re-consider current doctrine concerning the peopling of the New World. In this way, the book offers a valuable contribution to the ongoing debate over how long humans have lived in the Americas.

Reviewed by: Danny A. Brass, 70 Livingston St. Apt. 3K, New Haven CT 06511-2467 (brassda@yahoo.com).



Ice Age Cave Faunas of North America

Blaine W. Schubert, Jim I. Mead, and Russell W. Graham (eds.). Indiana University Press, Bloomington, and the Denver Museum of Nature & Science (2003). Hardcover, 299 pages, 7¼ x 10¼ inch format, ISBN 0-253-34268-6, $65.00.

This is an interesting collection of papers that discusses the fossil finds of largely extinct animals from various North American caves. Study locations include fossil-bearing caves of Mexico, Arizona, Kentucky, Iowa, Missouri, Texas, and Alaska. The number of fossil sites for each location varies from one to several dozen. Discussions of vertebrate paleontology are also included. This book will be of most interest to paleontologists, geologists, comparative anatomists, and zoologists. Speleologists and cavers with an interest in these disciplines may also find the book of interest. Indeed, many of the original fossil finds were made by observant cavers, which points out how important their contributions can be to paleontology. In fact, portions of the book have previously been presented at the 1997 NSS Convention, at a cave paleontology symposium co-chaired by Blaine Schubert and Jim Mead.

With notable exceptions, descriptions of the studied caves are included to help provide context to the various finds. When the fossil evidence permits a suitable interpretation, limited reconstructions of life histories and paleoenvironments are made, and an animal's natural history is discussed. Individual chapters include a detailed discussion of osteology (bone structure), especially in relation to identification of fossils, aspects of the animal's natural history, and taphonomy of the finds. Biostratigraphy analysis and fossil-dating studies are also included for most of the study sites.

The value of excavated fossils is only as good as the descriptions of their context. Such descriptions help to provide important taphonomic information about fossils. Taphonomy considers the context of death assemblages, as well as the later disposition of fossils. For example, did an animal die a natural death within the cave, one that was consistent with a cave-related life history? Or did it live in the outside world but became trapped in the cave by circumstances beyond its control? On the other hand, perhaps it died in the light of day, but its bones were somehow carried inside the cave after death. In the latter case, were the bones (or carcass) washed into the cave by floodwaters, transported by local geologic forces (*e.g.*, slope wash), carried in by carnivores, deposited as fecal remains, dragged in by pack rats, or did they fall through a vertical entrance that formed either a natural trap or a convenient disposal chute beneath a predator's favored tree or ledge? Were the bones weathered by exposure, preserved by rapid burial, or chewed by carnivores and corroded by digestion, or even separated into assemblages of large and small bones? A careful analysis of fossil remains can tell the experienced "bone detective" much about their transit, from the original site of an animal's death to the final resting place of its bones within a cave or elsewhere. To the extent that site analysis permits, this information is presented for most finds. In addition to the final disposition of an individual animal's remains, such studies help paleontologists to characterize the environment and natural history of local inhabitants.

Reviewed by: Danny A. Brass, 70 Livingston St. Apt. 3K, New Haven CT 06511-2467 (brassda@yahoo.com) October 2005.

FROM THE EDITOR

THESIS AVAILABILITY

The last issue of the *Journal of Cave and Karst Studies* (vol. 67, no. 2) published the abstract for Stefan Eberhard's Ph.D. thesis. Since then, Dr. Eberhard's thesis has been made available for download via the web ex of the Australian Digital Thesis program at:

http://wwwlib.murdoch.edu.au/adt/browse/view/adt-MU20051010.141551

ERRATUM

While typesetting the paper by Ira Sasowsky and Cory Dalton "Measurement of pH for field studies in karst areas" (vol. 67 no. 2, pp. 127–132) two errors were inadvertently incorporated into the text.

Error 1
The final sentence of the paragraph directly beneath the equation discusses two parameters that were incorrectly swapped in the text. The sentence should correctly read: "In that expression the values in brackets are molar concentrations of the species, γ is the calculated activity coefficient for the species, and K_2 is the 2nd dissociation constant for carbonic acid."

Error 2
The caption for Table 1 should read "Geochemical parameters for three water samples from Scott Hollow Cave, West Virginia (Davis, 1999)"

INDEX TO VOLUME 67 OF THE *JOURNAL OF CAVE AND KARST STUDIES*

IRA D. SASOWSKY & ELAINE SINKOVICH
Department of Geology, University of Akron, Akron, OH 44325–4101, USA

This index covers all articles and abstracts published in volume 67 parts 1, 2, and 3. Selected abstracts from the 2005 Society convention in Huntsville, Alabama are included.

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

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

KEYWORD INDEX

BIOLOGIC NAMES INDEX

AUTHOR INDEX