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Cover: "Stars." Scanning electron micrograph of star-shaped iron oxide crystals. The iron-oxide stars in this photo are observed in a corrosion pit within calcite. The sample is from the EA survey in Lechuguilla Cave, although similar crystals have been found in many samples of the iron-rich, red corrosion residuum from the cave. Field of view is 11.5 micrometers wide. This secondary electron image was acquired at 20 kV accelerating voltage on a JEOL 5800LV scanning electron microscope at the Department of Earth & Planet Science, University of New Mexico. Photo by M. Spilde and D. Northup, University of New Mexico. For more details, the next issue of the *Journal of Cave and Karst Studies* will feature the Guadalupe Mountains, New Mexico Symposium.

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THE RITUAL USE OF A CAVE ON THE NORTHERN VACA PLATEAU, BELIZE, CENTRAL AMERICA

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Research conducted on the Northern Vaca Plateau in west-central Belize has discovered numerous caves that were utilized by the Maya. In particular, Ch'en P'ix appears to have been used for religious activities, including autosacrificial bloodletting. A constructed platform in the cave was excavated in 1998, and a nearly complete tripod plate (the Ch'en P'ix Tripod) was recovered. This plate depicts a seated single figure that appears to be catching blood dripping from his right hand, in a vessel held in the left hand, and on a loincloth spread in front of the figure. We think that the Ch'en P'ix Tripod was probably used for collecting blood scattered during ritual events conducted on the platform, and we offer the following interpretation. A platform was constructed within Ch'en P'ix (with a speleothem-bordered path leading from the entrance drop to this platform) that was used for ritual activities. One ritual activity involved bloodletting, and a plate depicting autosacrificial bloodletting (the Ch'en P'ix Tripod) was used during this ceremony. The Tripod plate not only depicts the scene, but we also think it was used for collecting blood during the ritual. Upon completion of the ritual, the plate was broken on the platform as an offering. These events might have taken place in Ch'en P'ix sometime during the Late Classic period.

The Northern Vaca Plateau, in west-central Belize, is a well developed karst upland containing an abundance of karst features including sinkholes, dry valleys (valleys without active surface streams), residual limestone hills, and caves. The Vaca Plateau Geoarchaeology Project (VPGP) has conducted archaeological, geologic, and geographic research in this area since 1990. During the course of this research, nearly 200 caves have been discovered, explored, and mapped. One of these caves, Ch'en P'ix, is the focus of this article.

A two week archaeological investigation was completed in Ch'en P'ix during March 1998. Ch'en P'ix (Fig. 1) was selected because of its very high density of artifacts and its location. No surface sites have been recorded within 1.6 km of the cave, yet it contains an abundant, diverse collection of artifacts (Reeder *et al.* 1998: 40). The natural corollaries to this observation are the questions: 1) Why was this cave selected as a depository for the profusion of artifacts it contains? 2) What activities took place within the cave, and how are they related to the artifacts found there? We hope to clarify what activities occurred in Ch'en P'ix, and to seek evidence for relations with other sites, such as the large Mayan city of Caracol, only 15 km south of Ch'en P'ix.

DESCRIPTION OF CH'EN P'IX

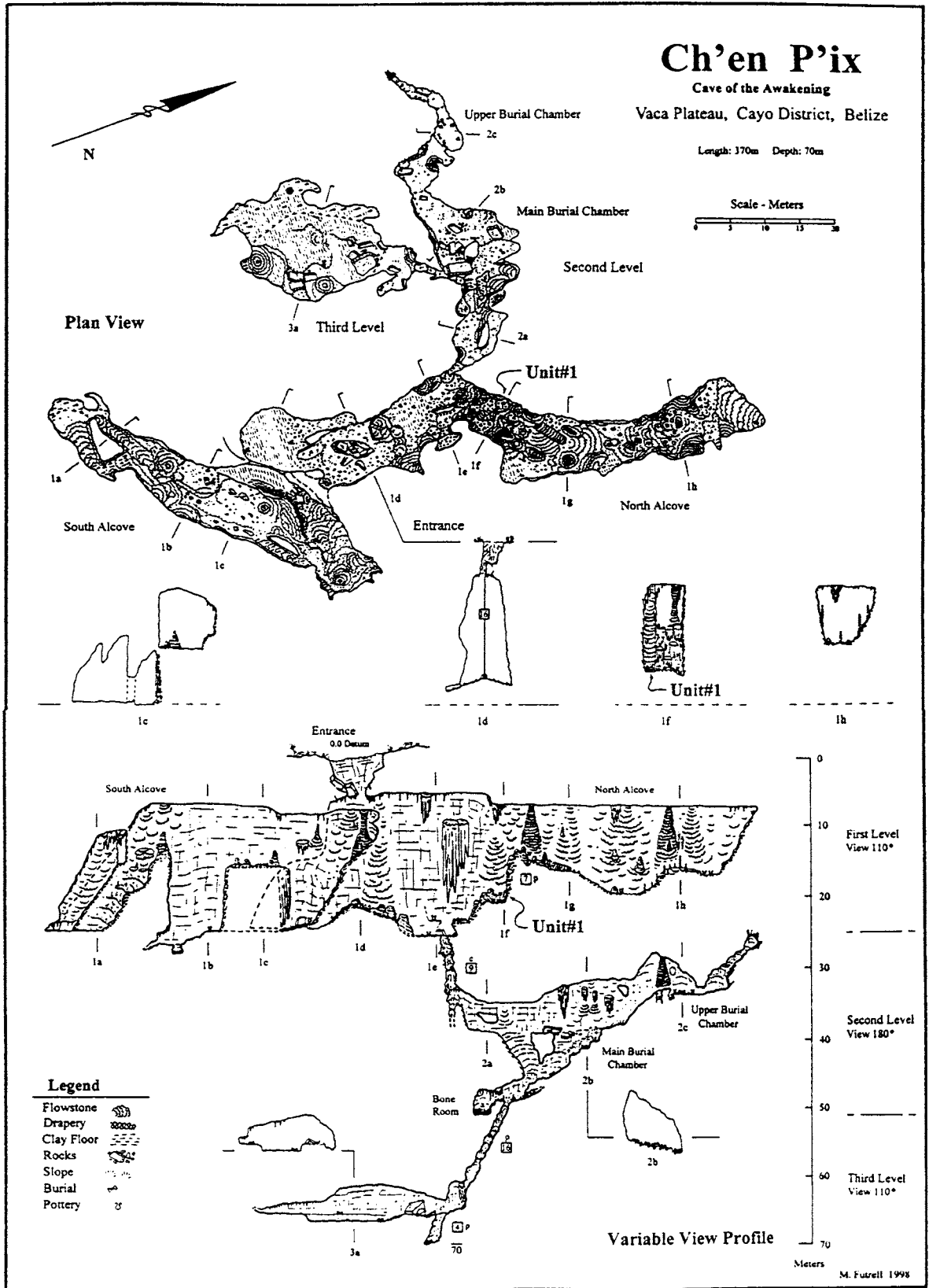
Ch'en P'ix contains three distinct levels, has a total length of 370 m, and a maximum depth of 70 m below the entrance (Fig. 1). The entrance is located in an 8 m deep, 10 m wide surface collapse feature. The entrance is 1.5 m x 1.0 m, and

extends 16 m vertically into a 70 m-long chamber that has an average ceiling height of 15 m. The cave extends both southwest and northeast from the point below the entrance drop. To the southwest, an 8 m wide passage slopes down to a flat floored room that contains numerous pottery shards. This room connects to another 8 m wide, 12 m high, northeast trending room that contains numerous pottery shards and intact pots. An upper level alcove can be reached by a steep traverse up a flowstone formation.

The passage northeast of the entrance shaft is 8 m wide and slopes downward to a flat floored room that contains numerous pottery shards. Perched upon a large flowstone formation on the east side of the passage are eight intact pots exhibiting kill holes. Lithic artifacts also litter the floor in this area, as do shards of broken polychrome pottery. This is the location, 20 m below and 15 m north of the entrance, of the excavation (Unit #1) upon which we based our interpretations. Located higher up on a ledge within the same flowstone are two more intact pots. A steep traverse up the flowstone leads to an upper level passage ~40 m long, trending nearly due north.

Along the west wall of the entrance level passage, just below our excavation site, is a one meter square hole that leads to two lower levels of the cave. After climbing down 6 m, one gains access to a horizontal passage extending to the northwest, or a 15 m deep vertical shaft that leads to a lower level room containing human remains and numerous pottery shards. The northwest trending horizontal passage extends for ~25 m before intersecting a series of small alcoves that contain human remains, intact polychrome pots, ceremonial boot pottery, lithic artifacts, and shell, jade, and turquoise jewelry.

Figure 1. Plan and cross-section map of Ch'en P'ix, with the location of Unit #1 indicated.



UNIT # 1

Because of time limitations, only one feature was excavat-

ed. The location of this unit was chosen for two reasons. First, because there appeared to be a leveled platform bounded on three sides by cave walls, that was thought to be a tomb.

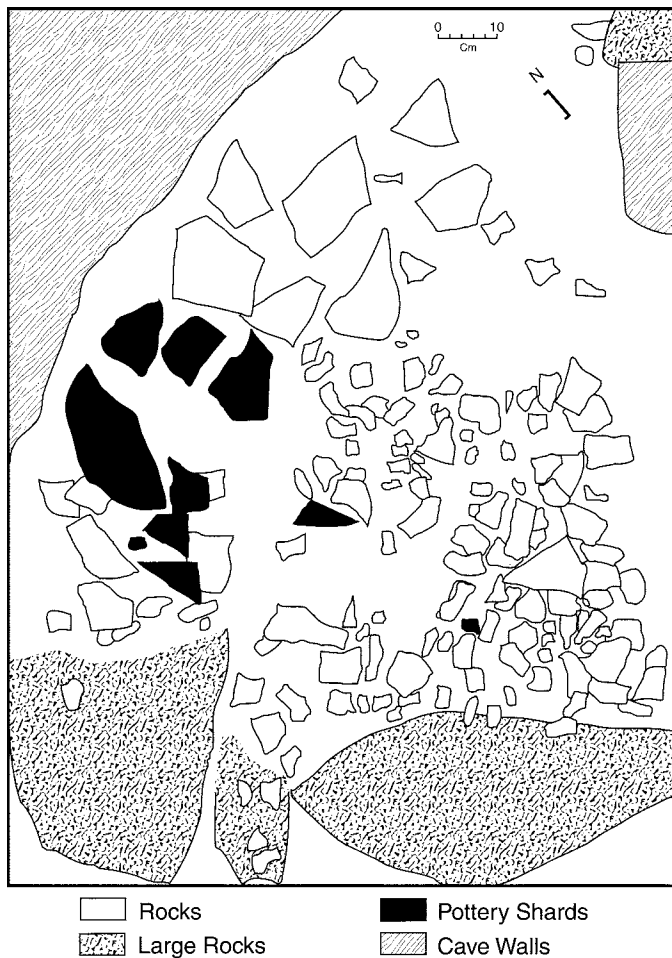


Figure 2. Plan view of the assemblage of artifacts on the surface of the platform where Unit #1 was excavated in Ch'en P'ix.

Because this feature was obviously constructed by humans visiting the cave, we wanted to determine whether it was a tomb, and what significance the platform and associated assemblage of artifacts had for Mayan cave use. Second, the density of monochrome and polychrome pottery shards found within the area that became Unit #1 (an area of 1.6 m x 2.4 m) is the highest in Ch'en P'ix (Fig. 2). Eight polychrome pottery shards, which were eventually determined to be the most elaborate polychrome examples found thus far in Ch'en P'ix, were all located within the bounds of Unit # 1. Also, a number of cached speleothems form a kind of path that extends from the bottom of the entrance drop, steeply upward toward the platform feature. Brady *et al.* (1997) have found that broken speleothems were often deliberately cached in caves, and that they may have had spiritual and/or other meanings. In Actun Tunchil Muknal, a cave recently under investigation by Jaime Awe (Awe *et al.* 1997), numerous speleothems are cached between large pieces of ceiling breakdown. This combination of rocks and speleothems forms a clear path leading to a hidden sepulchre that contains an intact calcified skeleton (Awe

pers.comm. 1997). Awe interpreted this construction as a sort of ritual path that connected various features within the cave (Awe pers.comm. 1997). We suggest that a similar path was constructed within Ch'en P'ix to connect the area below the entrance drop with the platform feature where Unit #1 was excavated, and/or the passage adjacent to the platform, which connects to the lower levels of the cave.

Adjacent to the platform where Unit # 1 was excavated, and 51 cm lower, is a second platform feature (1.3 x 1.3 m) containing a large, intact pottery vessel and a nearly complete Dichrome Tripod plate. All the plate's feet were intact and one foot contained a bead. An 8.6 cm obsidian blade was noted lying on a large pottery shard next to the Tripod plate. This second platform feature was not excavated, although a drawing of the tripod plate was completed. The placement of the obsidian blade adjacent to the platform where Unit # 1 was excavated may prove important in the interpretation of this structure because obsidian blades often functioned as bloodletting instruments (Brady 1989: 324), although they could also be used for "cutting meat or leather" (Brady 1995: 35). A large number of obsidian blades found in Naj Tunich (Brady 1988: 51; Brady 1989; Brady & Stone 1986) and in other caves are thought to imply bloodletting as an auto-sacrificial rite (Awe 1997; Brady 1995: 34).

ARCHAEOLOGY

The platform feature where Unit # 1 was excavated is a northeast/southwest trending, 51 cm high, 112 cm x 112 cm structure nestled between cave walls (Fig. 2). At the southwestern end of the feature, ten large rocks have been placed to span the distance between the cave walls. At the feature's northeastern margin, a number of smaller rocks had been placed on the surface to form a kind of border. Lying in a niche behind these small rocks were several obviously cached, large, ceramic shards. Thus, this feature formed a natural unit; a platform, bordered by intentionally placed stones to the northeast and southwest, and bounded by cave walls on the two remaining sides.

Artifacts recovered from the surface of this platform feature consisted exclusively of pottery shards. Ten of these were polychrome shards clearly belonging to a plate-like object that was smashed at the platform. Ritual smashing of plates is not unusual, especially in front of constructed areas within caves (Graham *et al.* 1980; Stone 1995: 129). This pattern of ceremonial destruction is widely known, but has not as yet been fully explained.

Most of the shards were of an unslipped monochrome type of pottery. A complete ceramic analysis of Unit # 1 has not yet been undertaken, but we plan to complete such an investigation during a future research expedition. In this article, we focus only upon the polychrome shards from Unit #1.

The unit was excavated in 5 cm vertical increments. Below level No. 6, the excavation was terminated when the solid rock floor of the cave was encountered. Except for a 36 cm x 10 cm

speleothem fragment that was encountered in Level 4, all artifacts were recovered from Level 1 (the upper 5 cm of the unit). All of the recovered artifacts were pottery fragments, and with the exception of two shards found below the surface within Level 1, all polychrome shards were found on the surface of the unit. The five levels below Level 1 consisted almost entirely of gravel to clay sized, clastic fill material. Less than 1 g of charcoal was recovered from the entire unit.

The archaeological investigations conducted within Ch'en P'ix reveal that the feature into which Unit #1 was excavated probably functioned as a platform, which appears to have been created by filling in the space between two cave walls. The presence of a speleothem in Level 4 does not contradict this interpretation because it has been shown that speleothems can function as "construction material in caves" (Brady 1989: 132; Brady *et al.* 1997: 731). Hence, no special meaning need necessarily be attached to this speleothem. Based upon the assemblage of artifacts found in Unit # 1, we propose that it functioned as a platform for specific ritual activities. This suggestion is discussed below.

THE CH'EN P'IX TRIPOD

The Ch'en P'ix Tripod is a nearly complete polychrome vessel that was recovered from Unit # 1 (Fig. 3). Ten of the shards used to reconstruct the plate were recovered from the surface of the unit, and two were contained within Level 1 of the excavation. The vessel is best described as a red, black, and gray on cream, polychrome Tripod plate.

The fact that the vessel is a Tripod plate is evident from marks on the underside where attachment points for feet are clearly visible. The Tripod has a diameter of 29 cm (Fig. 4), but its height cannot be estimated because the feet have not yet been recovered, although we have searched for them. It has been observed in other Belizean caves that Tripod plates and their feet may sometimes be cached in different spaces for reasons that are, at present, unknown (Awe pers.comm. 1997).

DATING

The dating of the polychrome Tripod plate is problematic because it was not possible to establish its stratigraphic context. All the shards, with the exception of two, were discovered on the surface of the first level. Charcoal was found mixed within the fill material in underlying levels, but funding was not available for AMS dating to establish a maximum age for the tripod. Thus, the only way of dating the Tripod plate is by comparison to other, already established, ceramic sequences. A detailed ceramic sequence for Caracol has been established by Arlen Chase (Chase 1994), which is appropriate for comparison to Ch'en P'ix artifacts because Caracol is only 15 km to the south. The ceramic sequence for Uaxactun, established by Robert Smith (Smith 1955), is also referred to in discussing the Ch'en P'ix Tripod.

We think that the Tripod plate can be securely placed into the Late Classic Period (AD 650 -AD 900). At Caracol, tripod plates excavated from tombs first appear during the Late

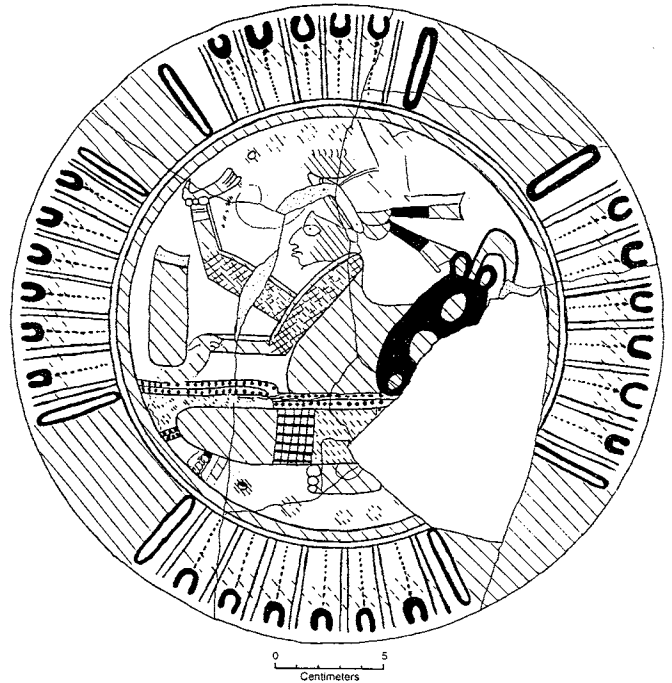


Figure 3. The images painted inside the Ch'en P'ix Tripod.

Classic, specifically in the second Late Classic subcomplex (Chase 1994: 170). Between Caracol's second and third subcomplex there are examples of red-and-orange-on-cream polychrome Tripod plates. In the last phase of the Late Classic Period, the tripod plates appear as Belize-Red Tripod plates with oven shaped feet (Chase 1994: 170). The provenance of Tripod plates at Caracol clearly marks them as belonging to the Late Classic ceramic complex (Chase 1994: 170).

The Ch'en P'ix Tripod exhibits many similarities to the Late Classic Tripod plates found at Caracol. The black-and-gray-and-red on cream polychrome of the Ch'en P'ix Tripod fits into the junction of the second and third ceramic complexes at Caracol. This correlation places it in the Late Classic. Although the Ch'en P'ix Tripod displays an additional grayish color compared to the Caracol Complex, this additional color may just be a variant of black. Because this style first appeared at the end of the second ceramic complex at Caracol, the Ch'en P'ix Tripod should fit into the third ceramic complex, because the red-and-orange-on-cream ware did not appear before the junction of the second and third Late Classic ceramic sub-complexes (Chase 1994: 170). Additionally, the general shape (29 cm diameter) fits into the third complex.

Using the ceramic sequence established for Uaxactun by Smith (1955) provides a very similar date range for the Ch'en P'ix Tripod. At Uaxactun, a vast number of monochrome and polychrome Tripod plates were discovered (Smith 1955: Figs. 9n; 9p; 12m; 51a1, b1; 53a, b; 54e; 55b; 58b, c; 59k; 74h). All the polychrome tripod plates were classified as Tepeu II or Tepeu III, a ceramic phase that has been dated between 9.13.0.0.0 (A.D. 692) and 10.3.0.0.0 (A.D. 889) (Smith 1955:

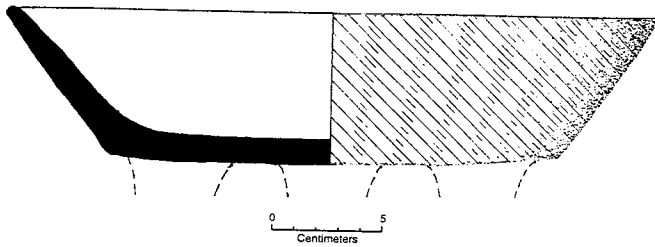


Figure 4. Profile view of the Ch'en P'ix Tripod.

106).

The Ch'en P'ix Tripod displays a pattern of paired lines and dots, similar to a Tripod plate found at Uaxactun (Smith 1955: Fig. 55a) that was placed securely into the Tepeu Late Classic phase. The black-and-red on cream colors of the Ch'en P'ix Tripod are also found on polychrome Tripod plates in the Late Classic ceramic sequence from Uaxactun.

Comparison of the Ch'en P'ix Tripod with established ceramic sequences makes it clear that the vessel belongs to the Late Classic ceramic complex. Furthermore, this comparison indicates that it can be securely placed into the late phase of Late Classic, bordering the Terminal Classic. This means that it probably was produced between 9.13.0.0.0 and 10.3.0.0 (A.D. 692 - A.D. 889).

DESCRIPTION OF THE CH'EN P'IX TRIPOD

The following section contains the description and analysis of the Ch'en P'ix Tripod. By comparison with other ceramics, we hope to clarify the plate's painting, and its significance as part of the platform feature in Unit #1, which in turn may indicate the platform's function within Ch'en P'ix.

The outside rim covers almost one third of the Tripod's surface, and the pattern appears to provide only simple decoration. Painting on the inner portion of the rim is a repetitive set of horseshoe-like half circles and small dots which are separated by two paired lines, that separate the half circles and dots. The half circle set above the figure's head shows only five horseshoe-like half circles with dots, whereas the other three sets display six half circles with dots. The way the dots are painted, the lack of any bars, and the break in the regularity of these sets suggests that no mathematical system is concealed within the painting on the rim. We propose that the painting on the rim is purely geometric with no special meaning.

The interior base of the Tripod is not entirely preserved because lower right part of the scene is weathered away. The main object in the inner base of the Tripod is a human figure. The figure's right foot is shown underneath the left leg, which apparently indicates that the figure is sitting cross-legged, and it has three toes rather than the five that would be expected for the image of a human.

The front leg is painted red, and black vertical and horizontal stripes divide the lower leg. The leg is separated from the main body by what appears to be a string or belt associat-

ed with some type of clothing. The main body is painted red, and the figure has a notably thick abdomen. The figure's shoulder is awkwardly extended to an object that is being carried on, or leaning against, the back.

The left arm is painted gray, except for part of the upper arm that displays a sinuous red line. The lower arm is painted in base color, and is decorated with a bracelet. The right arm is painted gray, except for a sinuous red line almost identical to the one found on the left arm. The upper arm is painted in base color. Similar to the left wrist, a bracelet encircles the right wrist. Both hands are painted red, with the right hand being much more elaborate, possessing four clearly visible fingers and a thumb.

The upper part of the figure's head is not discernible due to fading. The face of the figure is evident, and it possesses an eye, nose, and mouth that are all in the base color. The face from behind the eyes, toward the back of the head and down the neck is painted red. The figure appears to be wearing some type of a headdress. The figure also appears to have a large, oval, black painted, bag-like object with three red shaded circles located along its midline either attached to or just behind his back. The lower part of this object cannot be seen because the shard containing this information is too weathered.

The figure holds a very striking object in his left hand. This object is 1.6 cm wide and 5.5 cm high, hence it is almost four times higher than wide. Approximately 90% of the object is painted red, with the upper 10% left in base color. This upper 10% is divided almost equally by a black dotted line that extends from one side of the object to the other. The figure is holding his right hand above this object and a series of six red dots are directly below the smallest finger of the right hand. These dots are drawn in a arcing pattern, curving inward toward the figure's wrist and forearm.

INTERPRETATION OF THE CH'EN P'IX TRIPOD

The following section contains our interpretation of the scene depicted on the Ch'en P'ix Tripod. We first offer an interpretation based wholly upon the Tripod itself. This is followed by a comparison to other ceramics, which is intended to reinforce our interpretation. We realize that alternative interpretations may be possible. Because we cannot provide a definitive interpretation for the painting on the plate's rim, which in our opinion displays solely decorative dots and lines, we will directly proceed to the interpretation of the interior base.

First and foremost, it should be noted that the scene depicted on the Tripod plate contains a single figure located in the center of the scene. The figure is apparently sitting cross-legged, with his right foot shown below its left leg. Most of the figure's body appears to be painted red, with exceptions being the front of the face and portions of the arms, which remain in the gray base color, and the lower torso which appears to be clothed. A black dotted belt extends from the figure's waist, and seems to split, with part of this feature obscured by the fig-

ure's left leg. A similar pattern, also noted to extend across the figure's thigh, is considered to belong to the figure's dress, as are the red circles and dots located between the split portions of the black dotted belt. We believe that the figure is wearing a belt and loincloth, which appear to be draped in front of the figure.

The small circles around the figure's wrists may represent pearls worn as decoration. Half of the face is painted red, as are the figure's hands and forearms, excluding the wrist area where the pearls are located. Both upper arms are painted with a red sinuous line that appears to be some form of decoration. We suggest that the objects above the figure's head are part of a headdress, which is possibly adorned with feathers.

The object at the back of the figure may be a bag being carried by the figure. This interpretation is equivocal because no attachments joining the bag to the figure are visible. A second possibility is that this object represents a kind of cushion (Nikolai Grube pers.comm. 1998), which is very often shown on ceramics in association with seated rulers (Schele & Miller 1986; Reents-Budet 1994), and, if that is the case here, it may indicate elite status.

The figure holds in its left hand an object that could be a vessel, nearly filled with a red liquid. The lower 90% of this object is painted red, perhaps to indicate that the contents inside the vessel are red. It is, of course, also possible that the object was painted red for decorative purposes. The interpretation of this object as a vessel containing a red liquid becomes more apparent after examining the six red dots below the figure's right hand. It is possible that these red dots represent blood dripping from the figure's hand. Presumably the vessel in the figure's left hand is being used to collect this blood. All of the red circles displayed on the Tripod might in some way relate to the red dots below the figure's right hand, and thus to drops of blood. This is especially true of the red circles on the figure's loincloth. These may represent blood spots that dripped from the figure's bleeding hand, and were collected on the cloth draped in front of the figure. The Ch'en P'ix Tripod may, therefore, represent a ritual autosacrificial bloodletting event. If the Ch'en P'ix Tripod does display a bloodletting event, then it is possible that the platform was a place where bloodletting ceremonies were conducted. This idea is further strengthened by the presence of obsidian blades adjacent to the platform.

BLOODLETTING DEPICTED ON CERAMICS AND IN CAVES

Bloodletting events are widely distributed throughout Mesoamerica (Schele & Miller 1986). The Lintels from Yaxchilan show many bloodletting scenes, as do the walls in Bonampak (Miller 1986), which also present hieroglyphic inscriptions that feature many verbs referring to bloodletting (Schele & Miller 1986). Bloodletting scenes are also shown on murals from the Naj Tunich caves (Brady 1988; Stone 1989; 1995). It should be noted however, that bloodletting events are rarely displayed in public areas (Schele & Miller 1986), rather they are mostly presented on hidden lintels or in

caves.

Bloodletting was mainly conducted by the elite "to bring the gods into man's presence" (Schele & Miller 1986: 182). Through bloodletting the Maya sought visions such as the serpent at Yaxchilan. These manifestations may result from massive blood loss affecting the brain and inducing hallucinogenic experiences (Schele & Miller 1986: 177). These experiences allowed the elite to communicate with ancestors and supernaturals (Schele & Miller 1986; Stross & Kerr 1990), thus establishing their divine status within society. Bloodletting events were undertaken on special occasions, either celestial occurrences or on period endings in the Calendar Round such as baktun, katun, and tun endings. Bloodletting events were also undertaken by the elite in connection with childbirth, marriage, death of parents, inauguration of buildings, and most important, accession to thrones (Schele & Miller 1986: 180).

It must be emphasized that the Ch'en P'ix Tripod presumably depicts an autosacrificial bloodletting event. Of all the rituals recorded from caves, bloodletting seems to be one of the most important. It has been documented in Honduras (Brady 1995: 36), in Belize (MacLeod & Puleston 1978), and most importantly in Naj Tunich, where overwhelming evidence for autosacrificial bloodletting rituals is recorded on cave walls (Stone 1985: 26; 1989: 328; Brady 1989: 432).

Presuming that a bloodletting ritual is displayed on the Ch'en P'ix Tripod, it should be emphasized that "flat-bottomed plates with slanting sides and three rattle feet (like the Ch'en P'ix Tripod) are the type of bloodletting bowl used in Late Classic times to hold torn paper and receive the bloody rope" (Schele & Miller 1986: 194). Such a Tripod plate, decorated with a Quadripartite Monster from the Late Classic, which was used for collecting blood, is shown in Schele and Miller (1986: 207). The polychrome Ch'en P'ix Tripod stylistically corresponds to this Tripod plate as both were made during the Late Classic period. It could be that the Ch'en P'ix Tripod functioned as a bowl for collecting blood during rituals performed within Ch'en P'ix. The plate may also depict the ritual itself.

Comparing the Ch'en P'ix Tripod to other ceramics displaying bloodletting events reveals no equivalent to the Tripod plate's image. The Maya Vase Books (Kerr 1989; 1990; 1992; 1994; 1997) provide no single example that is even roughly equivalent to the Ch'en P'ix Tripod. One example of bloodletting from the genitals can be found on a cylindrical vase that depicts the so-called "Fat Cacique" (Reents-Budet 1994: 97). He is sitting inside a palace watching dancers perform a ritual dance while they let blood from their genitals, which drips onto panels tied under their loincloths. All persons, presumably lords (Schele & Miller 1986: 193), to the left of the "Fat Cacique", are performing the same ritual. All their faces are painted in a "two tone pattern" (Schele & Miller 1986: 193), that resembles the colors of the figure's face on the Ch'en P'ix Tripod.

Another cylindrical vase (Schele & Miller 1986: 202) depicts two bloodletting scenes. The first depiction is the

accession of a Lord, and the second scene displays two people occupied in a ritual bloodletting event that was probably associated with the accession (Schele & Miller 1986). The Lord, who has acceded to the throne, is about to perforate his penis with a lancet, while the person to his left, presumably a noble (Schele & Miller 1986: 180) is pulling a rope through his already perforated tongue and is collecting the blood in a bowl.

The above mentioned scenes depict bloodletting from the tongue or the genitals, which are the parts of the body that were mainly used for ritual bloodletting. The Ch'en P'ix Tripod, however, displays a ritual bloodletting event from the hand. An example of ritual bloodletting from the veins of the hands and feet is given by MS 0075 (Reents-Budet 1994: 353). This vase depicts a vision-quest rite (Reents-Budet 1994: 270) with one human being, the central figure, flanked by two supernaturals. All wear blood-splattered clothing and scarves of autosacrifice. The blood seems to primarily come from the figures' hands and feet. The tips of all the figures' hands are also painted red. This vase might therefore provide an indication that hands and fingers also functioned as prominent body parts for the letting of blood.

Another example of a ceramic vessel depicting a human figure with blood dripping from its hands is a cylindrical polychrome vase found at Naj Tunich, which shows a seated figure with liquid falling from his hand. "This posture is generally thought to depict the ceremonial scattering of blood following autosacrifice" (Brady & Stone 1986: 24). The figure in this example is sitting cross-legged like the figure on the Ch'en P'ix Tripod. The figure holds his left hand up and liquid is dropping from his hand and fingers in a stream, in contrast to the Ch'en P'ix Tripod where the liquid appears to be dripping from the hand in drops. The figure from Naj Tunich does not hold an object in his right hand, as does the figure on the Ch'en P'ix Tripod, and both hands are decorated at the wrists, like the figure on the Ch'en P'ix Tripod. The Naj Tunich figure seems to sit on an object that is not clearly identifiable, and the figure's face is not discernable. We think that the scene from the cylindrical vessel from Naj Tunich displays a very similar ritual bloodletting event to the one displayed on the Ch'en P'ix Tripod.

Bloodletting from the fingers is also depicted in the still unpublished colonial book *Chilam Balam of Kaua*. On pages 11, 12, 14 and 21, the phrase "k'ik'el yich'ak" appears (Miram & Miram 1988: 667). K'ik'el yich'ak can be translated from Yucatec into Spanish as "sangre de las uñas del hombre" (Martínez Hernández, 1929), which translated into English means "blood from the fingers of a human being". This phrase appearing five times in the book, in the context of bloodletting, indicates that bloodletting from the fingers is also possibly attested to in this ethnohistorical source.

Victoria Bricker and Helga-Maria Miram point out that the walls at Bonampak provide an example comparable to the phrases in the book of Kaua (Miram, pers. comm. 1998). We think that the phrases in the book of Kaua are further evidence that blood dripping and blood letting from fingers and hands

are a more widely distributed phenomenon in the Maya area than previously considered. A complete, detailed analysis of the phrase from the book of Kaua must await its publication, however.

CH'EN P'IX AS A PLACE FOR RITUAL BLOODLETTING

A large obsidian blade was found close to where Unit #1 was excavated. This implement could have functioned as a bloodletting instrument. Unit # 1 yielded no evidence that it was a burial site, but it does appear to have been a small platform constructed of fill material. Thus, this feature may have been a ritual bloodletting platform. The obsidian blade and the depiction on the Ch'en P'ix Tripod both suggest that this activity may have taken place within Ch'en P'ix.

We offer the following interpretation. A platform was constructed within Ch'en P'ix (with a speleothem bordered path leading from the entrance drop to this platform) that was used for ritual activities. One ritual activity involved bloodletting, and a plate depicting autosacrificial bloodletting (the Ch'en P'ix Tripod) was modeled for use during this ceremony. The Tripod plate not only depicted the scene, but was also used for collecting the blood during the ritual. Upon completion of the ritual, the plate was smashed on the platform as an offering. These events might have taken place in Ch'en P'ix sometime during the Late Classic period.

CONCLUSIONS

If the Ch'en P'ix Tripod does depict a bloodletting ritual, then another piece has been added to the puzzle of Maya cave ritual. Indeed, bloodletting seems to have been a major ritual conducted in caves. Such events must have been important to the Maya because they recorded themselves carrying out these rituals in caves, the best examples being the drawings on the walls of Naj Tunich. In Ch'en P'ix, we suggest that an entire structure, with a path outlined by placed speleothems, was built specifically for ritual activities, which included bloodletting. Just such an event seems to be depicted on a polychrome Tripod plate that was found broken on the surface of the platform. The discovery and analysis of this plate provides a rare insight into Maya ritual cave use.

Several other platforms are present near the one where the Ch'en P'ix Tripod was found. It is possible that these structures also served specific ritual purposes. We hope that further research will clarify not only the uses of these platforms, but also the functions of other cave passages as well. The discovery of Ch'en P'ix, and analysis of the plethora of artifacts it contains, will add more information to existing knowledge regarding ritual Maya cave utilization, especially on the Northern Vaca Plateau of Belize.

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HOTSPOTS OF SUBTERRANEAN BIODIVERSITY IN CAVES AND WELLS

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We documented 18 caves and two karst wells that have 20 or more stygobites and troglobites. Crustacea dominated the aquatic fauna. Taxonomic composition of the terrestrial fauna varied, but Arachnida and Insecta together usually dominated. Geographically, the sites were concentrated in the Dinaric Karst (6 caves). Sites tended to have high primary productivity or rich organic input from the surface, be large caves, or have permanent groundwater (phreatic water).

Dokumentirala sva 18 jam in dva kraška vodnjaka, iz katerih je znanih 20 ali več vrst troglobiontov in stigobiontov. V vodni favni preladujejo raki. Taksonomski sestav kopenske favne je raznolik, vendar pajkovci in zuzelke skupaj navadno prevladujejo. Največ takšnih jam (šest) je v Dinarskem krasu. Nadpovprečno so zastopane jame z lastno primarno produkcijo ali bogatim vnosom hrane s površja, obsezne jame in jame, ki vključujejo tudi freatsko plast.

Over the past few years, there has been a growing awareness and concern with biodiversity worldwide. Books and monographs with a focus on biodiversity have appeared (e.g., Wilson 1992; Master *et al.* 1998) and a rapidly increasing amount of information is available about patterns of biodiversity for many groups of organisms. The same can be said for the fauna of caves and other subterranean habitats. Tabulations and often lists of cave and subsurface-limited species are available for many countries in *Stygo fauna Mundi* (Botosaneanu 1986) and in the multi-volume *Encyclopaedia Biospeologica* published by the Societe de Biospeologie in Moulis, France. Extensive lists of the caves and wells in which a particular subterranean species is found have been published. Prominent examples include Virginia (Holsinger & Culver 1988), the Iberian Peninsula (Belles 1987), and Slovenia (Bole *et al.* 1993). While not as well studied as temperate areas, similar information exists for many tropical regions (Peck & Finston 1993; Deharveng & Bedos 2000).

Understanding patterns of subterranean biodiversity requires an understanding of regional patterns. In general, the number of species found in any one cave or subsurface site is small relative to the number of species in the region. Cave habitats (as opposed to small cavity, interstitial habitats such as the underflow of rivers) are especially fragmented, with different species occurring in caves only a few kilometers apart. For example, of the more than 500 caves biologically investigated in West Virginia, the maximum number of obligate species in any cave is 14, but the state, with a karst area of 2500 km², has 76 obligate species. It is the documentation of these regional patterns and their explanation that is one of the major tasks of speleobiologists over the next several decades (Peck & Finston 1993; Sket 1999a).

Nevertheless, it is important not to neglect diversity pat-

terns at individual sites. Even though most subterranean biodiversity results from the accumulation of different species from nearby sites, there are some outstanding examples of high biodiversity from individual caves and wells that are worth documenting. Protection and concern for the subterranean fauna of a region often begin with protection and concern for a particular cave. It is, after all, individual caves and wells that provide the building blocks for regional biodiversity.

The purpose of this short communication is to enumerate those caves and wells that are particularly rich in subterranean species and to offer some preliminary explanations for these biodiversity hotspots, both in terms of their geographic distribution and in terms of the types of sites. We use the terms troglobite for terrestrial, cave-limited species and stygobite for aquatic, cave-limited species. Stygobites also include interstitial species but they are not considered here.

METHODS AND MATERIALS

We used an arbitrary cutoff of 20 or more obligate subterranean species for a site to be included. This resulted in a manageable number of sites to enumerate, representing less than one-tenth of one per cent of the sites sampled. We limited our attention to large cavities—caves and wells that intersect large cavities. According to Curl (1964), **proper caves** are large enough for humans to enter (and proper entrances are entrances large enough for humans to enter). We restricted our attention to proper caves, whether they do or do not have proper entrances, since many wells in carbonate rock intersect proper caves that lack proper entrances. What constitutes a single cave is a matter of considerable debate and confusion. We restricted our attention to connected voids, either water- or air-filled, regardless of how many separate entrances or names

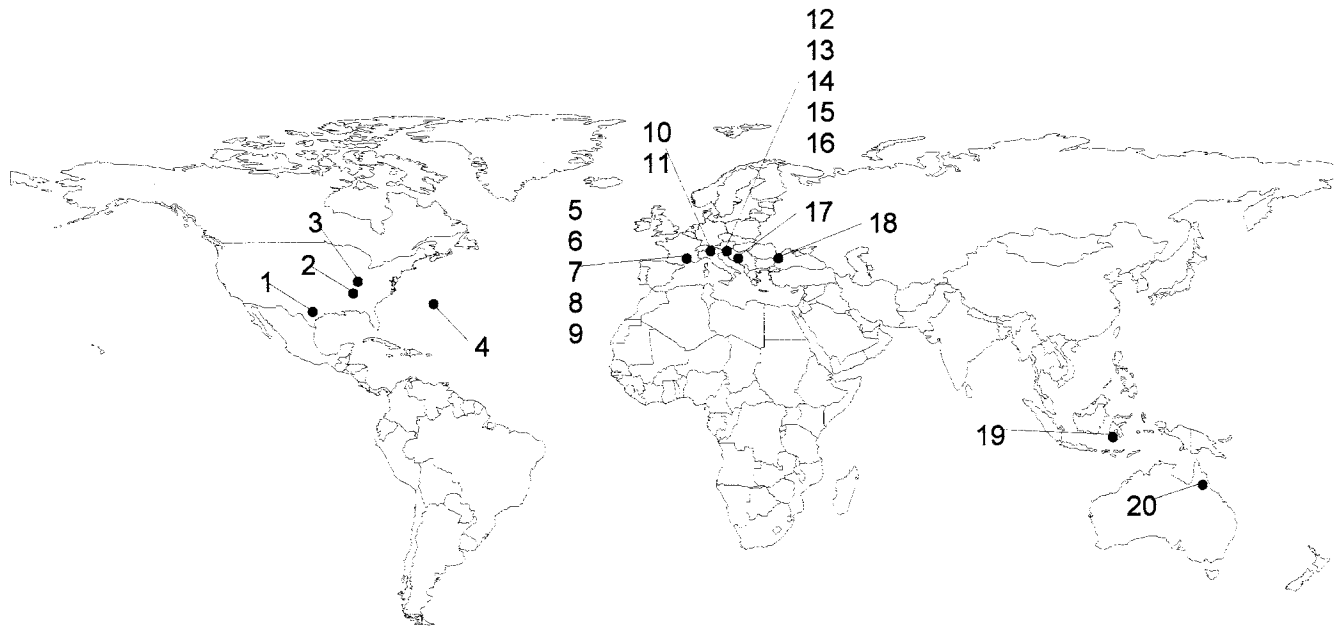


Figure 1. Location of hotspots of subterranean biodiversity: 1—San Marcos Spring, Texas; 2—Shelta Cave, Alabama; 3—Mammoth Cave, Kentucky; 4—Walsingham Caves, Bermuda; 5—Triadou Wells, France; 6—Baget/Grotte de Sainte Catherine, France; 7—Goueil di Her/Reseau Trombe, France; 8—R surgence de Sauve/Vidouurle souterrain, France; 9—Cent-fons, France; 10—Grotta dell’Arena, Italy; 11—Buso della Rana, Italy; 12—Sistem Postojna-Planina; 13—Šica-Krka Sistem, Slovenia; 14—Jama Logarcek, Slovenia; 15—Grad (Osapka Jama), Slovenia; 16—Krizna Jama, Slovenia; 17—Vjetrenica Jama, Bosnia & Hercegovina; 18: Pestera de la Movile, Romania; 19—Salukgang-Kallang/Towakkalak, Indonesia; 20—Bayliss Cave, Australia.

the cave had. We specifically excluded porous aquifers—they have been less thoroughly studied and are likely to have a pattern very different than that of proper caves. We also excluded the few known fungal parasites.

In order to generate the list, we consulted with many colleagues throughout the world with the request for information about any particular cave or well fauna. We consulted available species lists from throughout the world. An Excel file of the species list is available from the authors. We are aware of the fact that a number of caves may be missing from our list because we lack a faunal list. We also expect some species to be shown eventually not to be limited to caves. However, none of the sites enumerated here is likely to be excluded from the list owing to such changes.

RESULTS

Eighteen caves and two wells have 20 or more obligate species. Of the 20 sites, fourteen are from Europe (five of them from Slovenia and five from France), three from North America, one from Australia, one from southeast Asia, and one from an island in the Atlantic (Fig. 1). The major taxonomic composition of these faunas is listed in Table 1. Each site is briefly described below.

San Marcos Spring, Texas, USA—This artesian spring serves as an exit point for water from the Edwards Aquifer.

Two-thirds of its aquatic species are crustaceans, of which 11 are amphipods (Holsinger & Longley 1980, Table 1). Endemism is high, with 11 endemics representing 40% of the fauna. The aquifer itself is about 280 km long and 8-64 km wide. Oil and peat deposits above the aquifer may be the primary energy input into the system (Longley 1981). The aquifer is threatened by excessive drawdown, both by agricultural interests and the City of San Antonio.

Shelta Cave, Alabama, USA—Slightly over 700 m long, Shelta Cave consists of three large rooms of considerable volume that intersect permanent groundwater. Pioneering biological studies by Cooper (1975) led to the purchase of the entrance sink by the National Speleological Society. Half of the species are aquatic (Table 1). No group dominates the terrestrial fauna, but crustaceans dominate the aquatic fauna. Installation of a bat-unfriendly gate apparently led not only to a loss of bats, but to a major decline in the population sizes of the aquatic species (Hobbs & Bagley 1989; Culver 1999).

Mammoth Cave, Kentucky, USA—Mammoth Cave is the longest known cave in the world, with over 500 km of surveyed passages. Most of the cave is within the boundaries of Mammoth Cave National Park. It rivals the Postojna-Planina Cave system of Slovenia in the amount of study devoted to the biota. Major discussions of the fauna of Mammoth Cave include Packard (1888), Barr (1967), and Poulson (1992). One-third of the fauna is aquatic, two-thirds terrestrial.

Taxonomically, arachnids dominate the terrestrial fauna and crustacea dominate the aquatic fauna (Table 1). Noteworthy is the co-occurrence of five species of trechine beetles in the closely related genera *Neaphaenops* and *Pseudanophthalmus*.

Walsingham Caves, Bermuda—This complex of anchihaline caves (ones with a direct connection to the sea), including Walsingham Sink Cave, Walsingham Cave, and Tuckers Town Cave, is ~1 km long, with most of the passages submerged. With a freshwater lens and a redox boundary between fresh and saltwater, Walsingham Cave likely has considerable secondary and possibly primary productivity. The fauna is entirely aquatic and dominated by Crustacea from many orders (Sket & Iliffe 1980, Table 1). Some of the micro-crustacean species may occur outside the hypogean realm.

Triadou Wells, France—Two wells (F1 and P1) only a few meters apart in the Lez Basin in southern France at a depth of 50 m yielded a variety of stygobites, especially crustaceans (Malard *et al.* 1994, Table 1). Located in a major karst area, the wells tap a network of fissures and solution tubes beginning at a depth of ~35 m.

Baget—Sainte Catherine System, France—This subterranean system is situated in the Pyrenees, near Moulis, in the small valley of Lachein. The basin occupies an area of 13.25 km². The object of intense study by R. Rouch and his colleagues for more than 20 years (*e.g.*, Rouch & Danielopol 1997), three components have been extensively sampled—the outlet of the subterranean stream, a mostly flooded conduit (Aven de la Peyrere), and Grotte de Sainte-Catherine. The aquatic fauna is especially diverse, with 21 species of Crustacea (Table 1).

Goueil di Her/Reseau Trombe, France—The Trombe system is located in the Pyrenees in the Arbas Massif. The subterranean system consists of over 100 km of air- and water-filled passages, with numerous pits providing access to the submerged part of the system. The most extensively studied part of the system is Goueil di Her and its resurgence. The terrestrial and aquatic fauna are about equally diverse (Table 1), with Crustacea and Coleoptera predominating.

Resurgence de Sauve and subterranean Vidourle, France—The fountain of Sauve, near Montpellier, is the resurgence of the subterranean Vidourle River, which drains about 75 km² of area. The fountain is well known on account of the violence of its floods. Twenty stygobites have been collected from the watercourse, and most of these are crustaceans (Juberthie & Juberthie-Jupeau 1975, Table 1).

Cent-fons, France—The cave, which is flooded, and its resurgence are located at the southern border of the Massif Central. There are ten resurgences. The populations are diverse (Table 1) and abundant—about 16,500 crustaceans have been ejected out of the resurgence in ten weeks (C. Juberthie, pers. comm., October, 1999).

Grotta dell'Arena, Italy—This fossil cave is located in an alpine pasture (1512 m msl) and consists of a single large gallery less than 100 m long with the floor covered by large blocks of limestone. Percolating water forms some small, per-

manent pools at the end of the gallery. The stygobitic fauna consists of six, mostly tiny crustaceans (Table 1). Beetles and arachnids dominate the richer terrestrial fauna.

Cave Buso della Rana, Italy—This large and complex cave system, with more than 20 km of passage, shows a high habitat diversity, with an alternation of inactive and active branches. A small permanent brook flows along the main passage and emerges at the entrance. During the rainy season, most of the cave may be flooded. Crustaceans dominate the aquatic fauna (Table 1). None of the terrestrial groups is particularly diverse.

Grad (Osapska Jama), Slovenia—The entrance is a boiling spring with 1070 m of passage accessible during the dry season. After rains, the water can rise 50 m and flood most of the cave. There is no connection with a surface stream except at the periodically emerging spring. Terrestrial fauna is largely un-investigated, and the stygobitic fauna includes 17 crustaceans (including two amphibious Oniscoidea) and among them the large cirrolanid isopod *Sphaeromides virei* (Brancelj 1992, Table 1).

Krizna Jama, Slovenia—This is a hydrologically active but nevertheless beautifully decorated cave of more than 8000 m length. It is isolated from permanent surface rivers and, therefore, has very few non-stygobitic animals. The fauna is very scarce but species rich. Crustaceans (Table 1) dominate the rich aquatic fauna. Remarkable is the high number of gastropods: 2 terrestrial and 6 aquatic species have been found.

Jama Logarcek, Slovenia—A multi-level cave with a river in its deepest corridors; it measures 2300 m. It is situated close to Postojna-Planina Cave System, but with less apparent habitat diversity. Two-thirds of the fauna is aquatic, with gastropod and crustacean species predominating (Table 1). There also is an exceedingly rich epizoic ciliate protozoan fauna, described from one specimen of the bizarre isopod *Monolistra spinosissima* (Hadzi 1940).

Sistem Postojna-Planina, Slovenia—There are 17 km and 6 km of passages connected by 2 km of flooded corridors. The sinking river in the main passages is inhabited by a rich assortment of stygobites, stygophiles, and accidental surface species (Sket 1979). Hydrologically inactive parts of the system contain other aquatic and terrestrial habitats. This is the type locality of a number of “first cave” animals, including the first described troglobite, the beetle *Leptodirus hochenwarti* and the European cave salamander, *Proteus anguinus*. It also is a site of long-term ecological studies (Sket & Velkovich 1981). Slightly over half of the species are aquatic, with a rich crustacean, snail and oligochaete fauna. Beetles dominate the terrestrial troglobitic fauna (Table 1). Some of the cave has been heavily visited by tourists since 1818.

Šica-Krka Sistem, Slovenia—Šica-Krka Sistem consists of two caves 1700 m and 250 m long, hydrologically connected by 5 km of underground flow. This sinking river is inhabited mostly by surface animals at the sink and mostly by stygobites at the resurgence. Most parts of the cave are hydrologically active and more than 70 percent of the cave fauna is aquatic, primarily crustacean (Table 1).

Table 1. Taxonomic summary of stygobites and troglobites found in the 20 caves and karst wells. See Figure 1 for their location.

Higher Groups		San Marcos Spring TX, USA	Shelta Cave AL, USA	Mammoth Cave KY, USA	Walsingham Caves Bermuda	Triadou Wells F1 & P1 France
AQUATIC						
Protista:	Ciliata (epizoic)					
Cnidaria						
Aschelminthes:	Nematoda					
	Rotatoria					
Nemertini						
Turbellaria:	Tricladida	1	1	2		
	Temnocephala					
Annelida:	Hirudinea					
	Oligochaeta		1			3
	Polychaeta				4	
Mollusca:		5		1	3	3
Crustacea:		18	8	11	29	28
Arachnida:	Acarina				1	
Insecta:		1				
Vertebrata:	Amphibia	2	1			
	Pisces		1			
Aquatic Subtotal		27	12	15	37	34
TERRESTRIAL						
Annelida:	Oligochaeta					
Mollusca:	Gastropoda		1	1		
Crustacea:	Isopoda		1			
Arachnida:			2	12		
Symphyla:						
Diplopoda:			1	2		
Chilopoda:						
Insecta:	Collembola		2	4		
	Coleoptera		3	5		
	Other		2	2		
Terrestrial Subtotal			12	26		
TOTAL		27	24	41	37	34
Higher Groups		Baget—Ste. Catherine System France	Goueil di Her Reseau Trombe, France	Resurgence de Sauve Vidourle souterrain France	Cent-fons France	Grotta dell’Arena Italy
AQUATIC						
Protista:	Ciliata (epizoic)					
Cnidaria						
Aschelminthes:	Nematoda					
	Rotatoria					
Nemertini						
Turbellaria:	Tricladida		1			
	Temnocephala					
Annelida:	Hirudinea					
	Oligochaeta	1	1			
	Polychaeta					
Mollusca:		2	1	3	1	
Crustacea:		21	11	14	20	6
Arachnida:	Acarina			3	1	
Insecta:						
Vertebrata:	Amphibia					
	Pisces					
Aquatic Subtotal		24	14	20	22	6
TERRESTRIAL						
Annelida:	Oligochaeta					
Mollusca:	Gastropoda					1
Crustacea:	Isopoda		1			1
Arachnida:		1	2			5
Symphyla:						
Diplopoda:		1	2			1
Chilopoda:						
Insecta	Collembola	3	1			
	Coleoptera	4	6			6
	Other					
Terrestrial Subtotal		9	12			14
TOTAL		33	26	20	22	20

Higher Groups	Buso della Rana Italy	Grad (Osapka Jama) Slovenia	Krizna Jama Slovenia	Jama Logarcek Slovenia	Sistem Postojna-Planina Slovenia
AQUATIC					
Protista:Ciliata (epizoic)			1	9	1
Cnidaria					1
Aschelminthes:					
Nemertini					
Turbellaria:			1		1
				3	2
Annelida:					1
			6		7
		1			
Mollusca:	1	1	6	7	8
Crustacea:	14	15	15	8	26
Arachnida:					
Insecta:					
Vertebrata:				1	1
Aquatic Subtotal	15	17	29	28	48
TERRESTRIAL					
Annelida:					
Mollusca:	1		2	4	3
Crustacea:		2	1	1	2
Arachnida:	1		4	3	9
Symphyla:					
Diplopoda:			1	1	2
Chilopoda:					
Insecta:			1		9
	3	1	6	6	8
					1
Terrestrial Subtotal	5	3	16	15	36
TOTAL	20	20	45	43	84

Higher Groups	Sica-Krka Sistem Slovenia	Vjetrenica Jama Bosnia- Herzegovina	Pestera de la Movile Romania	Salukkang Kallang Towakkalak Indoesia	Bayliss Cave N. Queensland Australia
AQUATIC					
Protista:					
Cnidaria		1			
Aschelminthes:					
	3		3		
			2		
Nemertini		1			
Turbellaria:			1	1	
Annelida:					
	3	3			
		1	1		
	1		2		
		1			
Mollusca:	6	8	1		
Crustacea:	12	23	7	4	
Arachnida:					
Insecta:			1		
Vertebrata:					
	1	1			
				2	
Aquatic Subtotal	27	39	18	7	
TERRESTRIAL					
Annelida:			1		
Mollusca:	3	2			
Crustacea:	1	3	4	3	2
Arachnida:	2	4	10	8	5
Symphyla:			1		
Diplopoda:		3	1	3	4
Chilopoda:		1	3		1
Insecta:		1	3	4	1
	1	6	4	1	3
		1	2	2	8
Terrestrial Subtotal	7	21	29	21	24
TOTAL	34	60	47	28	24

Vjetrenica Jama in Popovo polje, Bosnia and Hercegovina—This complex cave system has 7.6 km of passages, which include a number of small streams, pools, and trickles of water. There are no sinking streams but there are extensive opportunities for the import of organic debris through crevices and shafts. About two-thirds of the fauna is aquatic, and dominated by Crustacea (Pretner 1963, Sket 1999a, Table 1). Noteworthy are the amphibious catopid beetle and amphipod species that occupy rock walls covered by a film of water trickling from above (hydropetric habitat).

Movile Cave, Romania—Movile Cave is a small, mostly water filled cave near the coast of the Black Sea. Slightly more than a third of its fauna is aquatic. No one taxonomic group dominates either the aquatic or terrestrial fauna (Table 1), and the fauna, as a whole, has the remarkably high level of over 65% endemism (Sarbu 2000). Extensive chemoautotrophic production occurs in the cave system (Sarbu, Kane *et al.* 1996). The cave is threatened by extensive trash dumping in the sink-hole in which the entrance is located.

Gua Salukkan Kallang—Towakkalak, Indonesia—This immense river cave system has over 20 km of passage, a large bat population, and 25% of the obligate cave fauna is aquatic. Comprising mostly undescribed species, crustaceans predominate in the aquatic fauna and arachnids in the terrestrial cave fauna (Deharveng & Bedos 2000, Table 1).

Bayliss Cave, Australia—Bayliss Cave is a small (900 m) cave formed in lava. It is a “bad-air” cave, with up to 200 times the ambient atmospheric level of carbon dioxide (Howarth & Stone 1990), likely the result of *in situ* production of CO₂ from the oxidation of organic matter (James 1977). The cave-limited fauna is entirely terrestrial with no one group dominating (Table 1).

DISCUSSION

It is worthy reiterating that, compared to surface habitats, diversity in caves is low (Sket 1999a) and that most diversity in caves and wells is expressed regionally rather than locally. Sket (1999a) gives a variety of reasons for the low diversity compared to surface habitats, including reduced area of ecological regions between surface and subsurface, reduced subterranean habitat diversity, and reduced food resources. The fragmented nature of the cave habitat and restricted opportunities for dispersal keep local diversity much lower than regional diversity.

One obvious difference, even among the caves and wells listed in Table 1, is the breadth of taxonomic scrutiny. In only a scattering of caves have epizoic ciliates been collected, let alone described (Walsingham Cave and Logarèek Cave in Table 1). Likewise, microcrustaceans have not been collected from all sites; even those listed in Table 1. It seems that Copepoda in North American subterranean waters have been nearly completely ignored. Nonetheless, most of the species in all sites listed in Table 1 are easily observed and collected.

What in the way of generalities can be gleaned from the list

of caves and wells with high species diversity? First, there is a remarkable concentration of sites in the Dinaric karst of Slovenia, Croatia, and Bosnia-Herzegovina, which is also the richest region of subterranean biodiversity (Sket 1999b). This is particularly evident in the stygobitic fauna. Of the ten sites with 25 or more stygobites (Table 1), six are in the Dinaric karst. France also has a concentration of sites, although, in general, diversity at these sites is slightly less than that at Dinaric karst sites. Sket (1996) points out that the Dinaric Karst in general, and the Slovenia karst in particular, is extensive in areal extent and with a rich geologic history. Poulson (1992) makes a similar argument for Mammoth Cave. Second, sites with high productivity, especially chemoautotrophy, compared to other subsurface sites are well represented. These include Walsingham Cave, Movile Cave, Bayliss Cave, and San Marcos Springs. Such high productivity caves are rare. This reinforces the widely held view that caves are resource poor (*e.g.* Sket 1999a). Gua Salukkan Kallang Towakkalak and Sistem Postojna-Planina also can be counted as caves with high (secondary) productivity, but the scarcity of high diversity caves in the tropics is still a puzzle. Another example of a high diversity cave with high productivity is Cabaret Cave in Western Australia. This small cave has extensive root mats penetrating the aquatic habitat, with over 40 species in a 20 m reach of stream (Jasinska *et al.* 1996; Jasinska & Knott 2000). We did not include it in the list of hotspots because the majority of species are probably not strictly stygobitic. Nevertheless, it is a striking example of high diversity in a very small cave. Third, caves and wells that intersect the permanently saturated (phreatic) zone also are well represented. These include Movile Cave, Shelta Cave, San Marcos Spring, all six caves in the Dinaric karst, and all six caves in France. This is an especially intriguing result, and suggests that there are a great many undiscovered species at such sites. Finally, many of the caves are long caves. Seven of the caves listed in Table 1 (Mammoth Cave, Buso della Rana, Krizna Jama, Sistem Postojna-Planina, Vjetrenica Jama, Reseau Trombe, and Gua Salukkan Kallang—Towakkalak) are over 5 km long, yet less than 1% of caves are this long, at least based on U.S. cave data (Culver, unpublished). A longer cave usually means a higher number of different habitats.

More complete explanations of the patterns of subterranean biodiversity must await a more detailed regional analysis, but we hope that this report sparks an increased interest in hotspots of subterranean biodiversity.

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CAECIDOTEA CAROLINENSIS (ISOPODA: ASELLIDAE): FIRST RECORD OF A STYGOBITE FROM SOUTH CAROLINA

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This report of Caecidotea carolinensis, the first stygobitic organism reported from Parlar Cave, South Carolina, USA, extends its known range by 370 km from its only previous collection site in North Carolina. Aquatic fauna from Parlar Cave also included an amphipod, aquatic annelids, aquatic oribatid mites, crayfish, copepods, and ostracods.

A recent summary of cave-inhabiting fauna by Peck (1998) did not list any obligate subterranean organisms for South Carolina because biologists have not studied the state's caves and subterranean streams. South Carolina's limestone caves were well known and reported in the literature by the 1840s, but Lyell (1845), who explored some of the caves of the Santee region, reported no biological data. Other speleologists have not documented biological collections in the Santee region caves, yet similar Coastal Plain caves in Florida and Georgia have been well studied, with numerous endemic stygobitic Crustacea reported (Holsinger & Peck 1971; Franz *et al.* 1994; Peck 1998). Thus, it seemed likely that surveys would reveal the presence of stygobites in South Carolina's Coastal Plain caves.

On 30 March 1999, 4 males and 9 females of *Caecidotea carolinensis* Lewis and Bowman were collected from the subterranean stream of Parlar Cave, Orangeburg County, South Carolina using two techniques. Three specimens were collected in a commercial minnow trap baited with tuna and placed in the cave stream, 2 m from the Big Sink Entrance on 16 March 1999. The remainder of the specimens were collected by lifting rocks and debris upstream of a plankton net. Isopods washed into the plankton net were collected and stored in 90% ethanol for later identification. Other aquatic invertebrates associated with *C. carolinensis* included a potentially stygobitic amphipod *Stygobromus* sp., the annelids *Aeolosoma* sp., *Chaetogaster diaphanous* (Gruithuisen), and *Pristina leidy* Smith and an aquatic oribatid mite *Trhypochthoniellus crassus* Warburton & Pearce. Collections made the same day in Chapel Branch Cave, which is the downstream entrance to the Parlar Cave system, did not produce *C. carolinensis*. The subterranean stream in Chapel Branch Cave receives runoff from a neighboring golf course, which could have had detrimental effects on the population of *C. carolinensis*. Other non-stygobitic Crustacea, including the copepods *Eucyclops agilis* (Koch), *Eucyclops elegans* (Herrick), and *Elaphoidella bidens* (Schmeil) a crayfish, *Cambarus (Puncticambarus) acuminatus* Faxon, and an ostracod tentatively identified as *Cyclocypris* sp. were collected in Chapel Branch Cave on 16 and 30 March and 3 April 1999. According to the distribution records of Reid

and Ishida (1993), this collection of *El. bidens* is a South Carolina record.

Caecidotea carolinensis was known previously only from a small tectonic fissure cave, Bennetts Mill Cave, McDowell Co., North Carolina (Lewis & Bowman 1977). This study's collection in South Carolina was a 370-km range extension and represents the first stygobitic organism identified in the state. Bennetts Mill Cave, in the Piedmont of North Carolina, is geologically separated from Parlar Cave, in the Coastal Plain of South Carolina. Many stygobitic asellids, including several species of *Caecidotea*, live in phreatic waters and move between caves (Steeves 1966; Lewis & Holsinger 1985). Thus, it is likely that *C. carolinensis* is a well-distributed species in the poorly sampled subterranean waters of South Carolina.

Voucher specimens of *C. carolinensis* have been deposited in the United States National Museum and the Clemson University Arthropod Collection.

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RESULTS OF A SPELEOTHEM U/TH DATING RECONNAISSANCE FROM THE HELDERBERG PLATEAU, NEW YORK

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The Helderberg Plateau consists of Silurian-Devonian carbonates that crop out across central New York State, supporting a well-developed, multiply glaciated karst. Stalagmites and flowstone were collected from five caves spread across a 60 km long traverse of the Plateau from Albany west-northwest to Schoharie County. Subsamples from these speleothems yielded 36 U/Th alpha count dates ranging from 3 ka to >350 ka. While the data reported here are only a reconnaissance study, they represent the most comprehensive geochronologic data base for any karst area in the northeastern United States.

Hollyhock Hollow, southern Albany County: two cave-fill samples yielded three dates of 70-56 ka and four dates of 41-35 ka; the mid-Wisconsin dates may reflect the cave's southerly position. Onesquethaw Cave, central Albany County: two stalagmites yielded 5 dates, all Holocene (<9 ka); the dates suggest that Onesquethaw Cave may be post-glacial in origin. Caboose Cave, eastern Schoharie County: five stalagmite and flowstone samples provided 13 dates, ranging from 207-56 ka, with distinct clusters at 100-56 ka and 207-172 ka; the dates support the cave being older than the last glaciation. Schoharie Caverns, 2 km west of Caboose Cave: six samples from one flowstone all dated to >350 ka; the dates indicate that the cave has survived more than one glaciation. Barrack Zourie Cave, western Schoharie County: two stalagmites yielded four dates, which cluster at 161-158 ka, with a younger overgrowth at 61 ka (two previously reported dates were 165 ka and 277 ka); the dates support the cave being older than the last glaciation.

The U/Th dates indicate that both pre- and post-glacial caves exist in New York. The dates cluster in the 100-56 ka and 207-158 ka range, and there are a surprising lack of dates from the last interglacial (130-120 ka), possibly an artifact of the sampling regime.

The Helderberg Plateau contains a sequence of Upper Silurian to Middle Devonian carbonates that crop out across central New York State (Fig. 1). The Plateau supports a well-developed karst and has undergone multiple glaciations during the Pleistocene. The Helderberg Plateau contains the longest caves in the northeastern United States (Palmer *et al.* 1991) and, as a result of being located near the New York City population center, the caves receive a significant amount of recreational visitation. The caves also form part of the regional hydrologic system, with implications for land use and water quality.

The geologic and karst setting of this region has been studied by Egemeier (1969), A. Palmer (1972), Kastning (1975), Baker (1976), M. Palmer (1976), Mylroie (1977), Palmer *et al.* (1991), and Dumont (1995), and references therein, but little geochronologic work has been done on the caves located there (Lauritzen & Mylroie 1996). The purpose of this study was to collect speleothem samples from cave locations across the Helderberg Plateau in Albany and Schoharie Counties, in order to make a reconnaissance evaluation using U/Th analyses to determine the age of the speleothems. Such a reconnaissance would provide guidance to a more in-depth geochronologic

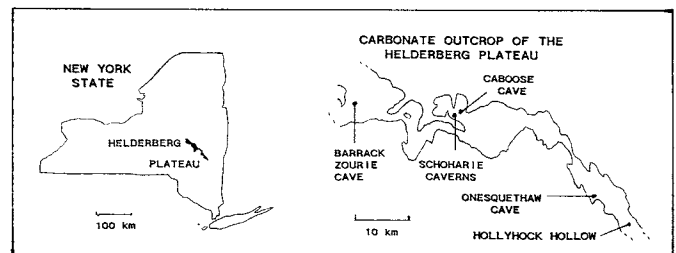


Figure 1: Location of the carbonate outcrop of the Helderberg Plateau, New York. Sampled caves locations shown. Albany County is right (east) half of the displayed outcrop, Schoharie County is left (west) half.

study in the future. For example, if all the speleothems turned out to be Holocene, then the likelihood of the caves carrying useful paleoclimatic information about the Pleistocene would be small, and further work would not be warranted. The reconnaissance work reported here, therefore, provides a pathway for future experimental design to determine the geochronology of karst processes in this region, and the paleoclimatology that helped drive cave genesis and development.

The Helderberg Plateau region offers useful potential information regarding the nature of ice cover during the late Pleistocene in this region of the United States. The karst area is located within a few hundred kilometers of the southern margin of the maximum ice sheet extent during the Pleistocene. Such a location is more sensitive to subtle variations in ice margin location than would be karst areas farther to the north and, therefore, farther from the ultimate ice margin, such as those in Canada (Ford 1977). The relatively low elevation of the Plateau (<500 m) removes alpine effects from consideration. Many studies of glaciation and karst (e.g. Ford 1977) in North America have focussed on alpine examples, where tectonism, high hydraulic gradients, and small glacier size create conditions unlike those found in lowland continental glaciation situations. Geochronological analyses have been done in glaciated midwestern caves in the United States (e.g. Milske *et al.* 1983), but not in the northeast.

The first approximation of continental ice-cover effects on speleothem deposition is that speleothem growth terminates when ice advances over a cave and vadose groundwater flow commonly stops. This cessation of vadose flow can be the result of permafrost development (White 1988 and references therein), or as a result of entombment of the regional hydrology creating stagnant phreatic conditions in the caves (Ford & Williams 1989, and references therein). A hiatus in speleothem growth is assumed to represent ice cover conditions, and continuous growth is thought to represent the absence of ice and free circulation of vadose groundwater (Ford & Williams 1989, and references therein). However, a growth hiatus can represent other factors, such as change in vadose water input location, or other climatic effects, such as aridity.

The initial goal of a reconnaissance speleothem geochronological survey is to identify the episodes of growth and non-growth. With sufficient speleothem samples, patterns may develop that correlate with ice-cover and ice-free conditions. More detailed analyses of speleothem growth bands, carbon and oxygen isotopes, and intercalated sediments may lead to a more sophisticated interpretation of paleoclimatology of a given region (e.g. Lauritzen 1996). The study reported here lays the foundation for more detailed work.

GEOLOGIC SETTING

As noted earlier, the geologic and karst setting of this region has been studied by A. Palmer (1972), Kastning (1975), Baker (1976), M. Palmer (1976), Mylroie (1977), Palmer *et al.* 1991, and Dumont (1995), and references therein, and that body of description is condensed and presented here. The outcrop pattern of the Helderberg Plateau carbonates in central New York (Fig. 1) begins as a narrow band of folded rocks parallel to the Hudson River in southern Albany County. This outcrop swings west and broadens as it leaves Albany County and enters Schoharie County. The degree of deformation declines significantly, with major faults and folds absent in western

Albany County and Schoharie County (Gregg 1974; Mylroie 1977). Cave development occurred in two major parts of the carbonate stratigraphy. The majority of cave development occurred in the Helderberg Group limestones and dolomites, which cross from late Silurian to early Devonian. A major clastic section, the Ulster Group, overlies the Helderberg Group carbonates, and in turn is overlain by the Onondaga Group limestones of Middle Devonian age. Cave development in the Onondaga Group is significant in central and eastern Albany County, but declines in importance westward into Schoharie County.

The glacial history of the area has been studied by LaFleuer (1969), Dineen and Hanson (1985) and Dineen (1987) and references therein. Ice advanced into the area from the north, but was diverted by the Helderberg Escarpment into a more westerly direction in Schoharie and western Albany Counties, and in a southerly direction in eastern Albany County. During the Wisconsin glaciation, Schoharie Creek was ponded by stagnant ice on a number of occasions, creating glacial lakes that extended from Schoharie County into western Albany County. Glaciolacustrine clays are found at a variety of elevations in this area. Analogues to these clays occur in many caves in the area (Mylroie 1977, 1984; Dumont 1995). The entire area contains abundant evidence of glaciation, including drumlins, polished rock surfaces, and till sequences of variable thickness. Cave systems commonly have small, active passages that are in concordance with the glacially-deranged landscape, while larger upper level passages are concordant with the original landscape as determined by gravity and seismic data (M. Palmer, 1976; Mylroie, 1977; Dumont, 1995; Milunich & Palmer, 1996). These latter passages are, therefore, interpreted to have existed at least prior to the last glaciation.

METHODOLOGY

SAMPLE COLLECTION

Stalagmites and flowstone were collected from five caves across a 60 km traverse, WNW to ESE, along the limestone outcrop of the Helderberg Plateau in Albany and Schoharie Counties (Fig. 1). Collection was done from both *in situ* deposits, and from loose clasts on the cave floor. The *in situ* samples were carefully collected from areas in the caves where sample removal would not detract from the esthetics of the cave. Loose samples were taken from stream deposits and cave floors to further avoid damage to the caves' natural beauty. Pristine samples were avoided, but a casual effort was made to collect speleothems that had an appearance of significant age. The samples were logged and transported to Norway for analyses. A total of 12 samples was collected over a time frame from 1982 to 1996. All but the Hollyhock Hollow samples were analyzed in 1995; those latter samples were analyzed in 1996.

URANIUM-SERIES DATING

Uranium-series disequilibrium dating can be performed on

speleothems provided sufficient uranium is present (>0.02 ppm) and that the system was initially free from non-authigenic ^{230}Th , as monitored with the $^{230}\text{Th}/^{232}\text{Th}$ index (Latham & Schwarcz 1992). The 12 samples collected were then cut to produce 36 subsamples (10 - 15 mm thick, 10 - 60 g) at regular stratigraphic levels for U-series dating. All contained sufficient uranium for dating. Given that alpha counts were being performed, and that this was a reconnaissance study, smaller sample analyses, which would give greater resolution, were not performed.

The samples were digested in excess nitric acid, spiked ($^{228}\text{Th}/^{232}\text{U}$) and equilibrated by H_2O_2 oxidation and boiling for several hours. Uranium and thorium were pre-concentrated by scavenger precipitation on ferric hydroxide. Iron was then removed by ether extraction in 9M hydrochloric acid, and uranium and thorium separated by ion exchange chromatography on Dowex 1 resin. The purified, carrier-free fractions of uranium and thorium were then electroplated onto stainless steel disks and counted for alpha particle activity in vacuo on an Ortec Octéte unit with silicon surface barrier detectors for 2-4 days. Each spectrum was corrected for background and delay since chemical separation and processed by tailored software (Lauritzen 1993). Samples with Th index ($^{230}\text{Th}/^{232}\text{Th}$) less than or equal to 20 were corrected for initial ^{230}Th by using equation 8 in Schwarcz (1980), assuming an initial $^{230}\text{Th}/^{232}\text{Th}$ ratio of 1.5. All samples can be corrected, but for $^{230}\text{Th}/^{232}\text{Th}$ greater than 20 the correction does not move the corrected age outside of the 1σ error of the original date. In other words, the effect of the correction is not significant and it is therefore not done. It will, however, give a significant ($>1\sigma$) shift if the index is less than about 20. All dates were performed at the Uranium-Series Geochronology Laboratory at the Department of Geology, University of Bergen, Bergen, Norway.

RESULTS

Summaries of the results obtained are presented in Table 1. Analytical results and ages are reported with 1σ error. Some samples yielded "finite" ages between 300 and 400 ka, but the associated errors (up to +300 ka) render these numbers useless. It is safer to assume them as greater than or equal to 350 ka at the 1σ level. A description of each of the sample locations follows (also see Fig. 1).

Two stalagmite pieces were collected from rubble in a surface cave dig at Hollyhock Hollow at the southernmost portion of the study area in southern Albany County in 1996. Sample HH1 yielded U/Th dates of 70-56 ka and sample HH2 dates of 41-35 ka. The site is developed in the Helderberg Group limestones.

Two stalagmites were collected *in situ* from Onesquethaw Cave in central Albany County in 1982. Sample O-1 was collected near the terminal sump at the downstream end of the cave; sample O-2 was collected from a breakdown block upstream from the Barnyard, a point in the middle of the cave. These stalagmites yielded five dates, all Holocene, less than 9

ka. See Palmer (1972) for a map and detailed description of the cave. The cave is developed in the Onondaga Group limestones.

Five stalagmite and flowstone samples collected in 1982 from Caboose Cave in eastern Schoharie County provided 13 dates ranging from 207-56 ka, with a distinct clustering from 100-56 ka and 207-172 ka. Some of the samples (C-1, C-3, C-5) were flowstone clasts in coarse sediment, so their growth position cannot be determined. Sample C-1 came from the north rift in the Maximum Formation Room. Sample C-3 was a clast in an eroding bank of sediment in The Streamway. Sample C-5 was found loose outside the cave entrance. Sample C-2 was a flowstone crust located *in situ* in the Drownstream Siphon area. Sample C-4 was collected *in situ* in the upstream end of the Loxodrome area. For a full description of Caboose Cave, see Mylroie (1977). Caboose Cave is developed in the Helderberg Group limestones.

Schoharie Caverns is located a few kilometers west of Caboose Cave in Schoharie County. One flowstone sample, S-1, was collected *in situ* from this cave in 1982, part of a large mass directly against the cave wall ~120 m upstream of the cave entrance. Six sub-samples from this flowstone all dated to in excess of 350 ka. See Kastning (1975) and Mylroie (1977) for a cave description. Sub-sample S-1F was re-run after the initial results gave an age out of stratigraphic order (226 ka); the second run produced an age of >350 ka, in agreement with the rest of the sample, and an error in sub-sample processing is assumed for the first run of S-1F. Schoharie Caverns is developed in the Helderberg Group limestones.

Barrack Zourie Cave is located at the northwestern end of the traverse, in western Schoharie County. Two stalagmites (BZ95-04 and BZ95-05) were collected *in situ* from large passages in 1995, and they yielded four dates. The dates cluster at about 161-158 ka, except for one, an obvious younger overgrowth that had a 61 ka date. BZ95-04 was collected from the Virginia passage midway through the cave, and BZ95-05 was collected from Rocky Road in the last third of the cave. A complete description of the cave can be found in Dumont (1995). Barrack Zourie Cave is developed in the Helderberg Group limestones.

DISCUSSION

It is important to emphasize that the dates reported from this reconnaissance study reflect a limited number of samples collected in a manner designed to be unobtrusive as opposed to thorough. As a result, interpretation of these data needs to be considered somewhat speculative. Nonetheless, possible interpretations are presented here to help guide the design of future work of a more detailed nature.

CAVE INTERPRETATIONS

Hollyhock Hollow: Some dates here are the youngest collected from Pleistocene-aged samples, and may reflect the southern position of the cave. In other words, ice could have

Table 1. Uranium- series disequilibrium dates of speleothems from New York State.

J.No	Sample	Cave	U(ppm)	$^{234}\text{U}/^{238}\text{U}$	$^{230}\text{Th}/^{234}\text{U}$	$^{230}\text{Th}/^{232}\text{Th}$	Age (ka)	Corrected Age
0931	BZ95-05 Rocky Road	Barrack Zourie	0.17±0.003	1.974±0.039	0.8077±0.0195	34	146.7±6.7	
0935	S-1 A	Schoharie	0.51±0.01	1.639±0.047	1.0688±0.0413	61	>350	
0936	S-1B	Schoharie	0.75±0.01	1.432±0.028	1.0624±0.0256	599	>350	
0937	S-1 C	Schoharie	0.86±0.02	1.351±0.027	1.0309±0.0259	182	>350	
0938	S-1 D	Schoharie	0.93±0.02	1.321±0.020	1.0209±0.0352	89	>350	
0939	S-1 E	Schoharie	0.74±0.01	1.373±0.022	1.0546±0.0242	>1000	>350	
0940	S-1 F base	Schoharie	0.48±0.01	1.444±0.033	0.9443±0.0272	133	226.1±20.0	
0941	C-5 A 170-180 mm from base	Caboose	2.75±0.04	2.434±0.025	0.4318±0.0104	>1000	57.8±1.8	
0942	C-5 B 135-140 mm from base	Caboose	2.5±0.03	2.313±0.015	0.4231±0.0049	>1000	56.4±0.82	
0943	C-5 C 120-130 mm from base	Caboose	0.88±0.01	2.163±0.026	0.5461±0.0088	172	79.0±1.75	
0944	C-5 D 95-87 mm above base	Caboose	0.71±0.01	2.138±0.031	0.5802±0.0110	55	86.0±2.3	
0945	C-5 E 85-80 mm above base	Caboose	0.68±0.01	2.095±0.026	0.6006±0.0097	67	90.5±2.1	
0954	C-1A NY	Caboose	0.20±0.004	1.608±0.037	0.8852±0.0233	28	184.6±11.0	
0955	C-1B	Caboose	0.20±0.004	1.614±0.032	0.8835±0.0197	379	183.6±9.0	
0956	C-1C	Caboose	0.75±0.015	2.411±0.048	0.6573±0.0202	24	102.2±4.7	
0957	S-1 Base repeat S-1 F	Schoharie	0.48±0.006	1.370±0.014	1.0197±0.0149	>1000	>350	
0962	BZ 95-O4A	Barrack Zourie	1.96±0.03	2.015±0.023	0.4457±0.0088	>1000	60.7±1.53	
0963	BZ 95-O4B	Barrack Zourie	0.17±0.004	1.643±0.037	0.8503±0.0215	17.4	168±8.8	161.49±9.5
0964	BZ 95-O4C	Barrack Zourie	0.20±0.004	1.565±0.033	0.8537±0.0204	9.25	171.7±8.7	158.49±9.6
0965	BZ 95-O4D	Barrack Zourie	0.16±0.005	1.652±0.060	0.8347±0.0298	28	161.7±12.0	
0966	O-1A	Onesquethaw	0.11±0.003	1.502±0.050	0.1097±0.0108	3.59	12.5±1.31	7.49±1.8
0967	C-2A	Caboose	0.41±0.015	2.002±0.083	0.6398±0.0309	32.9	99.7±7.45	
0979	O-1B	Onesquethaw	0.10±0.003	1.390±0.060	0.1105±0.0136	4.94	12.6±1.65	8.96±2.1
0980	O-2A	Onesquethaw	0.81±0.012	1.013±0.013	0.0279±0.0034	2.5	3.1±0.38	1.24±0.6
0981	O-2B	Onesquethaw	0.74±0.013	0.956±0.017	0.0281±0.003	19.2	3.1±0.34	2.86±0.4
0982	O-2D	Onesquethaw	0.71±0.014	1.159±0.026	0.0614±0.0063	3.21	6.9±0.73	3.71±1.0
0983	C-4A	Caboose	0.16±0.003	1.577±0.031	0.9244±0.0219	53.1	206.0±12.0	
0984	C-4B	Caboose	0.13±0.003	1.559±0.032	0.9126±0.0240	4.80	200.3±13.0	172.11±15.1

J.No	Sample	Cave	U(ppm)	$^{234}\text{U}/^{238}\text{U}$	$^{230}\text{Th}/^{234}\text{U}$	$^{230}\text{Th}/^{232}\text{Th}$	Age (ka)	Corrected Age
0985	C-3A	Caboose	0.23±0.006	1.820±0.049	0.8889±0.0247	20.4	180.4±11.0	
0986	C-3B	Caboose	0.36±0.006	1.997±0.034	0.9531±0.0188	62.1	206.9±9.8	
1655	NY-96- HH1-1	Hollyhock Hollow	0.09±0.003	1.497±0.071	0.5195±0.0400	4.44	75.8±8.3	56.32±10.2
1656	HH1-2	Hollyhock Hollow	0.13±0.003	1.466±0.040	0.5117±0.0191	11.3	74.4±3.8	67.28±4.2
1657	HH1-3	Hollyhock Hollow	0.14±0.003	1.534±0.045	0.4909±0.0216	19.7	70.0±4.20	66.16±4.4
1658	HH2-1	Hollyhock Hollow	0.15±0.005	1.607±0.057	0.3259±0.0197	>1000	41.7±3.0	
1659	HH2-2	Hollyhock Hollow	0.14±0.004	1.510±0.050	0.3191±0.0182	30	40.8±2.8	
1660	HH2-3	Hollyhock Hollow	0.14±0.004	1.467±0.044	0.3159±0.0175	28	40.3±2.6	
1661	HH2-4	Hollyhock Hollow	0.12±0.004	1.451±0.054	0.2986±0.0200	15.8	37.8±3.0	34.74±3.2

retreated earliest from this locality during the mid-Wisconsin interstadial (oxygen isotope stage 3) without having had ice yet retreat from caves farther north and west (and therefore no speleothem growth occurred in those caves at these times). Ice re-advance would have reached this southern locality later than caves to the north. The samples were part of fill material removed from a rock-walled sinkhole, so the actual provenance of the samples is suspect, but the field setting indicates a collapsed cave passage. This collapse might be related to the late Wisconsin ice advance (oxygen isotope stage 2) in the area.

Onesquethaw Cave: The U/Th dates reported here are Holocene, and may support the argument that Onesquethaw Cave might be post-glacial in origin (A. Palmer 1972), as its passages are small, active, and in accordance with the glacially re-arranged topography. Secondary calcite is notably sparse in this cave, which may reflect the cave's youth, or may indicate that stalagmite formation is not prolific enough to provide an adequate record. The cave floods many times a year, and older speleothems may have been removed by flood water dissolution (even though modern speleothems are growing today). The cave may well be older than the last glaciation.

Caboose Cave: The samples came from large high level passages underdrained by small, youthful passages. These youthful passages are in agreement with current surface geomorphology. The older nature of the upper level passages is supported by the U/Th dates determined from samples collected in those passages. As only two samples were *in situ* (and one other sample was actually found outside the cave), the data here are not rigidly controlled. This cave has been reported to contain sediments considered to be glacial rock flour (Mylroie 1984), and the U/Th dates support the cave's existence prior to the last glaciation (oxygen isotope stage 6).

Schoharie Caverns: The entrance to this cave was created by excavating a large amount of glacial till from a buried cliff line in the limestone. The cave contains an abundance of flow-stone material, including very large chunks in the streambed. The relationship of the glacial till to the cave indicates the cave was in existence at least prior to the last ice advance of the Wisconsin glaciation. The U/Th dates support the field evidence of the cave being at least older than one glaciation, and suggests that the cave has been in existence at least prior to the glaciation associated with oxygen isotope stage 10 (350 ka).

Barrack Zourie Cave: In addition to the sample dates reported here, Dumont (1995) reported two previous dates, from a stalagmite in the upstream end of the system, as 165 ka and 277 ka. The data reported here extend from that 165 ka date (161-158 ka) to more recent time (61 ka). The cave drains a glacially blocked valley, indicating it existed at least prior to the last glaciation. Barrack Zourie Cave also contains glacial rock flour (Dumont 1995), as was reported for Caboose Cave, another indication of origin prior to at least one glaciation. The U/Th data from the study reported here support this interpretation and the earlier work of Dumont (1995) suggests that the cave was in existence prior to the glaciation associated with oxygen isotope stage 8; i.e. the cave has survived multiple glaciations.

REGIONAL INTERPRETATIONS

Regional interpretations are limited by the same conditions of low sample number and non-systematic sample collection that limited interpretations of individual caves. While detailed, solid interpretations cannot be made, it is clear caves in the northeastern United States survived continental glaciation. Further interpretations are more speculative, but are presented again to help guide future work.

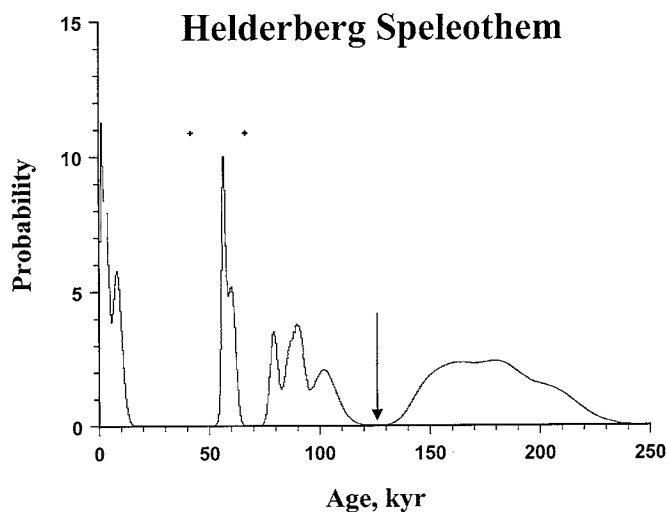


Figure 2: Graph displaying the date distribution of 29 U/Th samples. Crosses mark the approximate center of the two Hollyhock Hollow date clusters. Arrow emphasizes the lack of dates from the last interglacial (oxygen isotope substage 5e).

A total of 36 valid U/Th alpha count dates was obtained. While the number of samples is low, some preliminary observations are possible. The first and most obvious conclusion is that four of the five of the caves sampled must be older than at least the last glaciation, and Schoharie Caverns has evidence that it has persisted through perhaps three full glaciations. Caboose Cave and Schoharie Caverns, as well as other caves in the county, such as Howe Caverns and McFails Cave, were interpreted by Mylroie (1977) to have been in existence at least prior to the Wisconsin glaciation. That conclusion was based on field evidence such as glacial rock flour deposits in caves, entombment of caves in glacial drift, upper level passages not in concordance with current topography, and extrusion of glacial drift into cave passages. The geochronological observations support this interpretation for Schoharie Caverns and Caboose Cave (Barrack Zourie Cave was not discovered until 1992 and was therefore not part of the 1977 study).

Figure 2 is a standard probability distribution plot (PDF) of the data (Gordon *et al.* 1989) from Table 1. The broadening of the peaks with increasing age is an indication of the increase in error and, therefore, uncertainty. The data clearly show that speleothem growth was active in the Holocene, about 60 ka, in a band from 105-75 ka, and a broader band from 235-135 ka. The Holocene data is entirely from one cave, Onesquethaw, in central Albany County. This is perhaps an artifact of the sampling procedure, in that we sought to avoid active, pristine stalagmites, and also were preferentially searching for older looking speleothems to get a Pleistocene record. As noted earlier, Onesquethaw has only sparse stalagmite development, and collection options were limited.

One of the most surprising results of the reconnaissance, given that 36 analyses were made from 12 samples, is the lack

of any speleothem growth during the last interglacial (oxygen isotope substage 5e, *ca.* 125 ka), as shown by the arrow in figure 2. One possible explanation is that the data are real, and represent unfavorable conditions for speleothem growth during the last interglacial. Such a growth deficit would be most easily explained by aridity that limited the vadose groundwater flux into the existing caves. Another possible explanation is that such speleothem growth was simply missed by the rather scanty collection regime. Holocene speleothem growth (*i.e.* active growth) is obvious to the casual visitor in all of the caves, yet few samples from this study showed Holocene dates, indicating that major growth episodes can be missed by a selective and limited sampling regime.

Figure 2 does not show the Hollyhock Hollow data as part of the curve, as these samples were in debris from a collapse sinkhole and not truly inside a cave. These data are displayed as the two crosses on the figure. These crosses fall into gaps on the curve, but given that Hollyhock Hollow is the most southerly of the sites, speleothem growth there may have begun earlier, and lasted later, than that of more northerly samples displayed by the curve as centered on 58 ka. Such an interpretation is extremely speculative given the low sample frequency.

The dates are all alpha counts, which agrees with the overall reconnaissance purpose of the study. The data collected here suggest some further work be done to refine the broad outline revealed by the study. The initial collection regime was careful to sample in a manner so as not to destroy the esthetics of the caves. The result was a dependence on loose samples from sediment banks, digs, and cave streams. Future work should carefully select a long stalagmite that would be amenable to TIMS U/Th dating [Thermal Ionization Mass Spectrometer], which yields higher precision from smaller samples than alpha count dating. Stable isotope analyses (^{18}O and ^{13}C) could be done on the same sample in conjunction with the TIMS dates. Such stable isotope analyses have been done from the midwest and west, but not from the northeastern United States. Such studies, if done in the Helderberg Plateau, could assist in unraveling the timing and magnitude of ice advance and retreat in the northeastern part of the country.

CONCLUSIONS

The dates collected so far are insufficient in number to allow making detailed paleoclimatic interpretations. The dates do indicate that both pre- and post-glacial (last glaciation) caves exist in New York. The clustering of dates in the 100-56 ka and 207-160 ka range is a bit surprising, as is the lack of dates during the last interglacial time period (130-120 ka) which is possibly an artifact of the sample quantity. The existence of dates beyond equilibrium (>350 ka) indicate that New York caves, as has been shown elsewhere, can survive multiple glaciations.

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DISCUSSION: "GEOPHYSICAL STUDIES AT KARTCHNER CAVERNS STATE PARK, ARIZONA"

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These comments concern natural-potential (NP) survey anomalies as measured by Lange (1999) over portions of Kartchner Caverns. Lange attributes the anomalies to electrokinetic effects (streaming potentials) from downward filtration of meteoric water "through the more permeable rock comprising the cave roof" or, in dry conditions, to "evapotranspiration and capillary flow" upwards from water in the cave.

Meteoric water falls uniformly on the area over and surrounding the cave. This water should filter downward almost uniformly through the soil and rock. I do not understand why there is a filtration anomaly only over the cave. Where is the evidence that water would filter down more rapidly over the cave, or filter down only over the cave, or that the cave roof and the bedrock all the way to the surface consists of more permeable rock? Portions of Kartchner along the survey line do have vertical faults that may be conduits, but this is not the general case. Faults not associated with caves may also give rise to NP anomalies but such anomalies are not generally attributed to streaming potentials.

Every electrical-methods prospector is aware of natural potentials when water is poured onto dry ground to wet an electrode site for proper contact. However, the potential quickly dissipates. If the area has seen recent rain, no artificial wetting is necessary and there is rarely an associated natural potential from the downward seeping water. The only potentials seen are those from telluric currents.

Streaming potential anomalies from evapotranspiration are well known from valley areas where concentrations of willows or other phreatophytes cause large amounts of groundwater to be pulled to the surface. However, at Kartchner such concentrations of vegetation do not exist over the cave or surrounding area. If there is increased evapotranspiration over the cave because the cave contains water, then there should be a corresponding manifestation on the surface, either in type or quantity of vegetation. To my knowledge, this has not been demonstrated. If the vegetation is equally distributed, then there should not be any distinct anomaly due to evapotranspiration.

An alternate explanation is proposed as the cause of these observed NP anomalies. Natural telluric currents constantly flow through the earth. When flowing over voids, the currents are forced near the surface causing a change in the measured potential from a normal constant gradient. This possibility is discussed in a previous paper (Lange & Kilty 1991). In the Black Rock Desert of Utah, I have measured a NP anomaly over a lava tube where the possibility of streaming potentials is extremely remote. The roof thickness is very thin and no precipitation had fallen for months. This NP anomaly mimics a complex gradient-array resistivity anomaly in shape and location to an astonishing degree. It would seem impossible for such a NP anomaly to be caused by anything other than telluric currents—a "pseudo-resistivity measurement," so to speak. If so, a proper resistivity survey would reveal a more definite response to voids with consistent, repeatable results that would allow for computer modeling. Modeling cannot be done easily with NP surveys.

Lange's NP anomalies are most likely real and caused by voids in the earth but no experimental evidence has been performed to demonstrate that they are the result of streaming potentials.

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REPLY: GEOPHYSICAL STUDIES AT KARTCHNER CAVERNS STATE PARK, ARIZONA

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In his discussion, Dale Green raises some very cogent questions concerning the mechanisms responsible for natural-potential (NP) anomalies over caves. Space limitations prevented my elaborating on those mechanisms in the paper (Lange 1999), so I take this opportunity to do so here.

Downward filtration in the vadose zone is a function of the vertical hydraulic conductivity of the system, enhanced by the presence of a tension dome over an air-filled cave, particularly above its walls. According to Ford & Williams (1992: 313), infiltrating waters drain preferentially towards the domes and, if chemically aggressive, can result in stoping. Thus, preferential infiltration over the cave leads to a localized enhancement of the streaming potential within and around the cave roof.

Even if the hydraulic conductivity of the cave roof is equivalent to that of the surrounding country rock, water discharging from the cave ceiling enjoys a free fall to the floor, whereas water within the rock walls is confined to its resistive fracture pathway to the depth of the cave floor (Fig. 1a,b). In the analogous electric circuit connected to a battery, current flow through a resistor of a particular value (cave roof) in series with a straight wire (the void) will be nearly twice that of two such resistors in series (country rock lacking voids). The effect of enhanced roof-rock permeability is particularly evident in the NP lows associated with subsidence fractures over mapped galleries of West Virginia coal mines.

Dale Green makes a good point about the paucity of vegetation over Kartchner Caverns and its effect on evapotranspiration. The known cave occurs beneath limestone outcrop having little or no soil cover; hence, only a sparse desert flora grows on the surface. But though the transpiration component of upward water movement may be minimal, the evaporative component in summer is amplified by the "...profusion of fractures and faults crossing cave passages..." (Graf 1999: 63). Due to the high permeability of the cavern roofs, I would expect the top of the vadose water column to reside deeper over the voids than over the less fractured rock separating the galleries. The expected result is a more positive electric response over the wall rock than over the roof rock during the dry seasons. The above arguments assume vertical water movement. However, if most of the flow follows the dipping bedding planes (See Graf 1999: Fig. 2 or Jagnow 1999: Fig. 4), the NP anomalies at the surface could be displaced relative to their corresponding subterranean structures. A more substantive interpretation of the caverns' electrical expression at the surface requires additional NP measurements during different seasons.

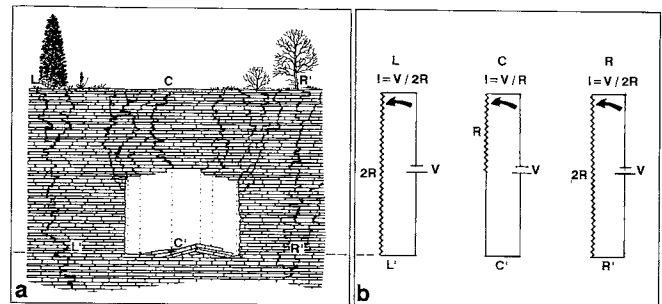


Figure 1:

- a) Two fracture pathways for downward percolating water in the country rock around an air-filled cave are designated L-L' (left) and R-R' (right). A similar pathway via the cave roof and void space is designated C-C' (center).
- b) Electrical equivalents for the three hydraulic flow paths, where the electric variables are V, battery voltage; R, path resistance; and I, current. The much larger current flowing in the center circuit simulates the greater hydraulic flux along path C-C'. This increased filtration velocity results in a magnified streaming potential over the cave, which is further enhanced by the higher incidence of fractures within the cave roof.

The telluric response, measured by the *gradient method*^{*}, over a resistant cylinder (void), is a sombrero-type anomaly, predominantly positive, as depicted in Keller & Frischknecht (1970: Figure 170). Green implies that the gradient method was employed over his desert lava tube. Using the *long-line method*, however, as applied at Kartchner Caverns, the corresponding telluric response (current normal to the cylinder) would have the form of the single cycle of a sloping sine wave, as illustrated in Lange & Kilty (1991: Fig. 3). This is the integral of the gradient anomaly. While telluric "noise" was recognized in the meter readings during the NP survey at Kartchner Caverns, it is unlikely that the alternating and erratic long-period telluric signals would be confused with the relatively systematic dc voltage response between one observation point and the next. Considering that in summer 1989 the apparent resistivity of the Escabrosa Limestone exceeded 1000 ohmmeters—beyond the resolving capability of the Geonics

^{*} In gradient mode, two closely-spaced electrodes are moved successively across the ground surface; in long-line mode, one electrode remains fixed while the other steps out to an ever-increasing distance of separation.

EM-34® instrument—telluric responses over Kartchner Caverns probably would be small. In a more conductive environment, large voids near the surface would more likely be detected by the telluric method, as demonstrated theoretically by Keller & Frischknecht (1970).

Natural-potential anomalies are frequently compounded from several mechanisms acting in different directions; for example, downward percolation over a lateral cave stream, tapped by a metal-cased well. Once the individual components are delineated, however, these components can be modeled by one or another method, such as that conceived by Sill (1983). Experimental work above and within an air-filled cavity has been performed by Quarto & Schiavone (1996). As a result of these measurements and observations over other cave sites, they concluded that air-filled cavities in sedimentary rocks give rise to NP anomalies. In their words: "...the anomalies have an electrokinetic origin generated by the percolation of the meteoric waters toward the cavity. The sign of the anomalies depends on the main water flow direction and is dictated by the geological environment." (Quarto & Schiavone 1996: 429).

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SELECTED ABSTRACTS FROM THE 1999 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN FILER, IDAHO

ARCHEOLOGY

SUBTERRANEAN CULTURAL RESOURCE MANIFESTATIONS OF THE ARIZONA STRIP

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Caves on the Arizona Strip, that area of land in Arizona that lies north of the Grand Canyon, have been used by humans for thousands of years. Paleo-Indians, Archaic Indians, Ancestral Puebloans, Southern Paiute, pioneer homesteaders, Civilian Conservation Corpsmen, and modern ranchers have left evidence of their use in caves of this area. The great variety of artifacts found includes rock art, ceramics, and grinding stones (metates). Sites may have been used for shelter, storage, or ceremonies.

BATS AND CAVES

IS ANGLE IRON CORRECT FOR BAT GATES? THE REBUILDING OF TORGAC AND FORT STANTON CAVE GATES

Mike Bilbo, Bureau of Land Management, Winnemucca Field Office, 5100 East Winnemucca Boulevard, Winnemucca, Nevada 89445 USA,

During the mid-1990s, caver and BLM volunteer Jim Cox built a series of excellent vandal-resistant cave gates that had several unique features, starting with schedule 80 round stock pipe. Round stock was used because Cox tested his designs in a wind tunnel against conventional angle-iron gates and found eddy currents to exist in the case of angle iron. To the author's knowledge, Cox is the only person who ever actually did such a study before designing his gates. Others the author has spoken with have quite subjectively made statements to the effect that angle iron is the most suitable. The round stock versus angle iron distinction may be critical in hibernacula roost site selection for certain bat species, notably Townsend's big-eared bat (*Corynorhinus townsendii*).

MYOTIS SODALIS WINTER POPULATION TRENDS IN INDIANA

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The Indiana bat (*Myotis sodalis*) has witnessed a dramatic population decrease throughout its range over the past fifty years, causing it to be one of the first species to be listed on the US Fish and Wildlife Service Endangered Species list. Current downward trends continue in most states, but known winter populations in Indiana caves have remained relatively stable. While some significant Indiana hibernacula have lost bats, other hibernacula have shown remarkable increases.

THE CURRENT STATUS OF BAT MONITORING STUDIES IN ILLINOIS

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Bat monitoring efforts have been conducted regularly in Illinois since the mid-1980s. Of the 12 bat species that occur in the state, 9 (including 2 federally endangered species and 2 state-endangered species) depend on caves or abandoned mines during at least part of the year. Two Priority II hibernacula for the federally endangered Indiana bat were discovered in Illinois during the 1990s. The Illinois Department of Natural Resources has established a schedule for conducting regular winter censuses at several caves and mines used by bats. There has been an increased focus recently on gating important cave and mine entrances, both on public and private land, and several significant sites also are protected as state nature preserves. In 1985, the Division of Natural Heritage and Illinois Natural History Survey (supported by the Illinois Department of Transportation, Shawnee National Forest, and US Fish and Wildlife Service) began a cooperative program to study the summer distribution of bats throughout the state, with an emphasis on the Indiana bat. Radiotelemetry identified numerous roost trees used by this species, including maternity colonies.

SURVEY WORK AND CONSERVATION EFFORTS FOR BATS IN IDAHO

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Fourteen species of bats have been confirmed in Idaho. Nine of the 14 species are listed as sensitive by the USDI Bureau of Land Management (BLM), USDA Forest Service, or Idaho Department of Fish and Game. An effort to gain a better understanding of bat species distribution, composition and population status was initiated by the Idaho Conservation Effort in 1995. Bats captured by mist nets were identified in a variety of habitats throughout Idaho during the summer months. One hundred and five sites were surveyed and 616 bats representing 14 species have been captured. Little brown myotis and big brown bats were captured commonly and at more than a fourth of all sites surveyed. California myotis, fringed myotis, hoary bat, pallid bat, and spotted bat were caught infrequently. Additionally, California myotis, fringed myotis, pallid bat, spotted bat, and western pipistrelle were caught at 5 or fewer sites. Fringed myotis were captured near older aged forest stands, however, they have also been documented using juniper woodlands in the Owyhee Mountains. Pallid bats and western pipistrelle were only detected at sites located in the southwestern and south-central regions of the state, mostly in steep, rocky canyons. Spotted bats were audibly detected at 9 locations, mostly in steep remote canyons. However, they were also detected at an internationally renowned rock climbing area containing numerous tall granite rock formations.

The species most frequently captured using caves were long-eared bats, Western small-footed bats and Townsend's big-eared bats. Loss of cave habitat due to disturbance and/or deliberate harassment is a threat to bats in southern Idaho. Monitoring of bat populations at several historical hibernacula caves during the winter has shown a significant decline in bat numbers. The BLM is working with local cavers to identify and monitor important bat caves. Signs and gates

are used to inform users and establish seasonal use closures at key roost sites. Educational presentations about bats and cave habitats are provided to local schools and community groups to raise awareness of the predicament of bats and potential human impacts from misinformation and disturbance at roost sites.

BIOLOGY

KARST WATERS INSTITUTE'S SECOND ANNUAL TOP TEN LIST OF ENDANGERED KARST ECOSYSTEMS

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In 1998, the Karst Waters Institute (KWI) published a list of the ten most endangered karst communities, a project that evolved out of the proceedings of a scientific conference held in February 1997 on the conservation and protection of karst biota. Nineteen karst locations were nominated in 1999 as candidates for KWI's "most endangered" list. Karst ecosystems selected exhibited (1) biological significance including rare, endemic or threatened species or communities rich in biodiversity; (2) significant threats to the communities; and (3) individuals or groups interested in protecting the threatened karst. The sites are: caves in central Cambodia; Church and Bitumen Caves, Bermuda; Edwards Aquifer, Texas, USA; Koloa Lava Tube System, Hawaii, USA; Kosciusko Island, Alaska, USA; Movile Cave, Romania; North-Northwest Karst Province, Puerto Rico; Organ Cave, West Virginia, USA; Snail Shell Cave, Tennessee, USA; and Zinzulusa Cave, Italy. The project has a web site that uses a Geographic Information System to publish an interactive map for the list for 1999. This site provides access to information on the site, including the size of the system, number of endangered species and a list of selected species from each site.

AMPHIPODS IN MINNESOTA CAVES

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No amphipods were reported from Minnesota caves in surveys of invertebrate cave faunas by Peck & Christiansen (1990) and Montz (1993). However, the author has observed *Gammarus pseudolimnaeus* Bousfield in abundance in Carvers Cave, the most historic cave in Minnesota, during the past decade, the entire period of his observation. Specimens were graciously identified by John Holsinger.

Carvers Cave is a sandstone cave, ~35 m long, located in the Mississippi River Gorge near downtown St. Paul, Minnesota. It contains a lake 2 m deep, supplied by a spring with a discharge of 100 L/min, for which the recharge area appears to be largely residential. The water temperature is 10°C and the chief source of organic matter appears to be leaf material carried in by the wind. *G. pseudolimnaeus* is not a cave-adapted species, having been documented at numerous surface-water localities in Minnesota by Muck & Newman (1992), who used it as an indicator of water quality.

A November 13, 1913, newspaper article in the St. Paul Pioneer Press entitled, "Blind Crayfish in Carver's Cave," is another reference to crustaceans in this cave.

INFLUENCE OF TEMPERATURE ON *TROGLOPHILUS ANDREINII* (ORTHOPTERA RAPHIDOPHORIDAE)

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We have recorded breeding *Troglophilus andreinii* (cave gryl-

lacrida) circadian locomotor activity at various temperatures (5.6-39.7°C) by a microactograph. In this way, we obtained a pattern of thermal optimum from which to deduce its euthermal grade. The values of temperature at which we have registered the maximum of activity coincide with the medium values of temperature of the apulian caves (18°C).

THE NEUROECOLOGY OF CAVE CRAYFISH: BEHAVIORAL AND ANATOMICAL COMPARISONS OF VISUAL SYSTEMS IN SIGHTED EPIGEAN AND TROGLOBITIC SPECIES

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The activity of visual systems is known to have an effect upon the development of the neural tissue associated with vision. We used three species of crayfish in examining the gross structures of the eye and underlying neural tissue for comparative purposes of the optic system associated with environmental adaptation. The troglobitic crayfish, *Orconectes australis packardii* Rhoades, and the two epigean crayfish *Cambarus tenebrosus* & *Procambarus clarkii* were used in these studies. *C. tenebrosus* raised in the cave are functionally blind although ommatidia do develop, indicating that the primary sensory structures still develop without normal input. Troglobitic crayfish have lost the genomic ability to form a functional visual system and, thus, would be expected not to possess normal ommatidial structures. Electrophysiological records from the sensory neurons of *O. australis packardii* Rhoades showed no response to light. The troglobitic and surface (epigean) crayfish found deep in caves are both behaviorally blind. The neuronal ganglia within the eye stalk of *C. tenebrosus* and *O. australis packardii* Rhoades reveal a disorganization which is likely the reason for the lack of a behavior response in *C. tenebrosus*. Cross sections of the protocerebral tract revealed that the troglobitic crayfish have more neurons of small axon profiles and fewer large axon profiles than the other two crayfish that contain ommatidia. Recent studies show that olfactory projection neurons, that arise from the central brain, send processes to ganglia within the eye stalk. The blind cave crayfish contain more olfactory projection neurons and fewer larger neurons within the protocerebral tract. (Supported by NSF grant IBN-9808631-RLC).

STYGOBITE DISTRIBUTION IN MISSOURI

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Missouri has ~5,700 known caves, of which about 600 have been studied biologically. In compiling the Missouri Biospeleological Database, we have enumerated ~51 species of stygobites (including phreatobites) and 27 terrestrial troglobites. An analysis of the number of stygobites versus the number of caves in each county shows almost no relationship.

ECOLOGICAL ASSESSMENT AND GEOLOGICAL SIGNIFICANCE OF MICROBIAL COMMUNITIES FROM A SULFIDIC CAVE SYSTEM

A.S. Engel, M. L. Porter & V. Shapiro, *Department of Biological Sciences, University of Cincinnati, Cincinnati, Ohio 45221-0006 USA*

Cesspool Cave is a small, non-thermal, sulfidic (average H₂Saq = 7 mg/L) feature formed in travertine deposits along Sweet Springs Creek, Alleghany County, Virginia. Previous research of microbial morphologies suggested the presence of sulfur bacterial communities.

To assess overall ecological potential for this subsurface ecosystem, microbial community activity was measured using radiotracer studies. Autotrophic productivity was determined through [^{14}C] bicarbonate incorporation while [^{14}C] leucine and [^{14}C] acetate assimilations were used to estimate heterotrophic activity. An estimate of total community diversity was determined using molecular cloning techniques employing 16S rRNA gene sequences. To address whether these microorganisms may influence geological processes, specifically sulfuric acid speleogenesis, isolates were obtained of sulfur-oxidizing bacteria using standard laboratory enrichment methods. Preliminary phylogenetic analysis of laboratory strains suggested the closest known relative is *Thiobacillus thermosulfatus*, a known sulfur-oxidizing bacterium that acidifies its surroundings because of sulfuric acid production. Additional physiological characterization of these strains indicated biological acid production may surpass strictly chemical, dissolutional processes for this cave system. This work provides framework for future investigations using a holistic approach to studying these sulfidic environments in an attempt to understand their ecological and geological significance.

MARK-RECAPTURE POPULATION SIZE ESTIMATES OF STYGOBITES IN A VADOSE STREAM AND A PHREATIC LAKE

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I used a mark-recapture method to estimate population sizes of the crangonyctid amphipod *Stygobromus emarginatus* in a headwater stream in Organ Cave, West Virginia, and of the cirolanid isopod *Antrolana lira* in the phreatic lake of Madison Cave-Stegers Fissure, Virginia. A 24-hour interval between marking and recapturing of specimens produced high recapture rates of *S. emarginatus*. Results showed that *S. emarginatus* occurred at a density of 11/m stream length, and yield a total estimated population size of 3300 individuals in the 300 m long stream. A 2-week interval between marking and recapturing was necessary to obtain high recapture rates of *A. lira*. Results showed that specimens found in Madison Cave and in Stegers Fissure are from the same population, and the population size was estimated to be ~6000 individuals.

FAUNA OF THE CHIQUIBUL CAVES, BELIZE

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The Chiquibul Cave System is in the Chiquibul Forest Reserve on the Vaca Plateau of the Cayo District, Belize. Biological collections were made on 5 expeditions since 1984. Eight species of troglobites and about 60 other cavernicoles have been collected. Troglobites include a pseudoscorpion, shrimp and crab that are described species, an isopod that awaits confirmation, and a spider, springtail, entotroph, and ricinuleid that await description. These species represent over half of the troglobite diversity of Belize which has a total of 13 identified species. The energy into these caves is primarily from a large sinking river, which carries surface debris and organisms into the 60-km long system. Much of the habitat sampled is large clay banks that border the main river, but also includes microhabitats formed by upper level inlets, dry historic stream passages, and entrance collapse areas with large energy inputs such as logs and bat guano. Recent

expeditions identified a large passage above flood levels that contains extensive bone remains including those of a spectacled bear, *Tremarctos sp. cf. ornatus*. This is a significant range extension from South America.

ECOLOGICAL POTENTIAL OF SUBSURFACE MICROBIAL PRODUCTIVITY FROM SULFIDIC ENVIRONMENTS

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Although numerous ecosystems utilizing chemoautotrophy as an energy source have been documented, the contribution of subsurface microbial productivity to ecosystem energy budgets is still poorly understood. Therefore, the rates of production of microbial communities from sulfidic karst systems and the potential energy transfer of this productivity to higher trophic levels was investigated. Microbial mat communities from four sites were used for determining productivity: the Frasassi Caves system, Italy; Movile Cave, Romania; Cesspool Cave, Virginia; and Lower Kane Cave, Wyoming. Microbial production was measured in each community using radiotracer studies and standardized using the dry weight of the sample (mg dry weight = mgdw). Autotrophic productivity was measured using [^{14}C]bicarbonate incorporation while heterotrophic productivity was measured using [^{14}C]leucine and [^{14}C]acetate. Autotrophic productivity was highest in the Frasassi Caves system (0.46 nmol ^{14}C bicarbonate/mgdw/day) and lowest in Cesspool Cave (0.003 nmol ^{14}C bicarbonate/mgdw/day). Heterotrophic activity was highest in Movile Cave (0.38 nmol ^{14}C leucine/mgdw/day, 6.69 nmol ^{14}C acetate/mgdw/day) and lowest in the Frasassi Caves (0.14 nmol ^{14}C leucine/mgdw/day, 0.44 nmol ^{14}C acetate/mgdw/day). The ecological impact of the measured productivity was examined in Movile Cave by estimating the ability of the terrestrial isopod *Armadillidium tabacaru* to assimilate the microbial mat. Preliminary results indicate that *A. tabacaru* assimilation efficiencies in Movile Cave fall between 51-90%.

GROUNDWATER CHEMISTRY AND BACTERIAL FAUNA OF FOUR LARGE CAVES IN ILLINOIS' SALEM PLATEAU

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As part of a biological evaluation of the federally endangered Illinois cave amphipod, *Gammarus acherondytes*, (Amphipoda: Gammaridae), we are examining groundwater and sediment chemistry and groundwater bacteria in 4 caves in Illinois' Salem Plateau. Results from the first four months of this study are discussed in light of potential sources of human impact on the amphipod populations (e.g., row crop agriculture, livestock, and urbanization). During high flow periods (February-April), fecal coliform counts were highest in water from Stemler Cave where the amphipod has not been found since 1965, and water from this cave tended to be more turbid than water from the other three caves. To date, agrichemicals have not been detected in water samples or sediments prior to the spring application of agricultural pesticides. High fecal bacterial counts in all four caves, and the abundance of taxa associated with both human and livestock waste, along with heavy sediment loads in Stemler Cave, suggest that several types of human impacts are having a negative impact on groundwater quality.

CONSERVATION & RESTORATION

VOLUNTEER VALUE FORMS

Val Hildreth-Werker, PO Box 1018, Tijeras, NM 87059

Generic forms have been created for documenting volunteer time contributed to any project. Forms can be used for recording our efforts in survey, science, conservation, photography, etc. The volunteer value system is based on government rates. It was created as an adjunct to the volunteer value agreement between the Forest Service and the NSS. However, the system can be applied to caves managed by other agencies, conservancies, or private owners. A web site is being created so we can easily report hours and value.

THE AMERICAN CAVE CONSERVATION ASSOCIATION AND HORSE RIVER CAVE

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The American Cave Conservation Association (ACCA) was founded in 1977 with a mission to protect caves and karstlands. This mission was to be accomplished through public education and professional seminars. In 1986, after a national search, the Association headquarters was relocated in Horse Cave, Kentucky. In 1993 the American Cave Museum opened its doors.

A former show cave (Hidden River Cave) is being redeveloped with environmentally sound methodologies. The ACCA also provides professional seminars, school programs, literature, and management consultation. The Association gated well over 100 caves over the years, mostly on federal land and all by invitation. Recent purchases of property will allow expansion of the museum, offices and the show cave tour in the near future.

EXPLORATION - INTERNATIONAL

CAVING IN THE BORDERLANDS - TABASCO AND CHIAPAS, MEXICO

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Twelve caves were explored and mapped along the border between the Mexican states of Tabasco and Chiapas. The caves ranged from just a hundred meters above sea level to high elevation caves at ~1200-1300 m msl. Many of the caves were highly decorated, notably Cueva de Arroyo Azul. A complex of five caves around Grutas Cuesta Chica was mapped and explored. Locals indicated that perhaps 50 more caves could be found in this same area. A trip into the Sierra Madrigal located a vertical cave that was explored down two drops and the cave continues going down. Local rumors of the Sierra Madrigal tell of another pit that breathes sulfurous odors. Near Arroyo Magestic, Chiapas, an interesting cave formed in sandstone was explored and mapped. Several caves were near Kolem Jaa, including a muddy, crawly cave that has yet to be completed. A trip into a disputed area near Agua Blanca, Tacotalpa, yielded a fine nacimiento which was not entered due to the politically fluid situation along the border in this area.

CAVES OF AUSTRALIA: CAVING IN QUEENSLAND'S CHILLAGOE REEF

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Australia's dry climate restricted karst development mostly to the wet fringes of the continent. One example of such karst is in the northeastern part of Queensland in the Chillagoe-Mungana National Park. In addition to Chillagoe, limestone caves in Queensland are in

the Mitchell-Palmer karst (120 km northeast of Chillagoe) and the Camooweal karst to the southwest. To the south, the Undara lava tubes (volcanic in origin) form a spectacular underground complex. Most of the 500 Chillagoe caves are confined inside limestone towers. Chillagoe tower karst is underlain by a marble plain. Because caves did not form in the marble, they are generally short and can only extend vertically within the towers, whose maximum heights are typically under 100 m. The Chillagoe karst towers formed in limestone that was deposited as a coral reef during the Late Slurian (434-416 Ma). The Chillagoe Formation consists of alternating limestone, sandstone and chert strata. These strata, originally deposited horizontally, were tilted nearly vertical by tectonic forces. Subsequently they eroded, leaving behind parallel, linear-strike ridges composed of less soluble rock. This valley and ridge topography allows relatively easy access to the towers. Because of the extended dry season in this area, bottle trees, relatives of African baobab tree, often grow above subterranean chambers into which they send their roots in search of water. Local caves are also home to children's python, huntsman spiders and several species of bats. Chillagoe caves offer immense opportunity for further study and exploration.

CAVE EXPLORATION IN INDIA: AN INTERNATIONAL EFFORT TOWARDS UNDERSTANDING A NEW KARST REGION.

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Expeditions that began in 1992 have shown that the northeastern Indian state of Meghalaya contains significant cave systems. Known as "Abode of the Clouds", Meghalaya is rich in limestone and receives record precipitation. Warm subtropical climate further enhances speleogenesis of extensive river caves. Expedition members from UK, Germany, India, and US have explored and surveyed 125 km of caves by early 1999. The expeditions have been organized in collaboration with the Meghalaya Adventurers Association. The February 1999 expedition extended survey in Pielkhlieng Pouk, the third longest cave in India, to 9.7 km in length. The main passage of this cave features huge gour dams up to 8 m high. The dams define a series of lakes and canals necessitating over three kilometers of swimming on the through trip. Synrang Pamiang was extended to just over 14 kms, making it India's second longest cave. Trips to 21 km-long Kotsati-Umlawan System, currently the longest cave in India, completed photographic and biological surveys of the cave. These efforts resulted in a discovery of two potentially unknown species of blind cave fish in Synrang Pamiang and Pielkhlieng Pouk. In the Cherrapunjee area, several new caves were explored adding 2.5 km of new cave passage and the promise of more to come. The expedition also conducted reconnaissance trips to other areas in preparation for return trips that are planned for 2000. The success of these explorations would not be possible without the hospitality of the Meghalayan people.

EXPLORATION - UNITED STATES

MALHEUR CAVE

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In March 1999, Tom Miller and Larry Hill traveled to Malheur Cave, located in the desert southeast of Burns, Oregon. Malheur Cave is a lava tube with an opening large enough to drive a vehicle into (~2 m high by 6 m across). The cavern opens into a lava tube ~6 m high and 12 m across. The cave is currently owned and used by the Masons for meetings. The cave has historical uses dating back more

than 300 years, when Indians used the cave for shelter.

The cave system consists of ~250-300 m of dry cave, 600 m of partially submerged cave, and 670 m of totally submerged cave. There are numerous springs located along the walls of the submerged portion of the cave. The most recent mapping of the cave was in 1973 by the Oregon Grotto. The 1973 mapping effort ended where the lava tube becomes totally submerged.

RECENT CAVE EXPLORATION IN THE SAN JUAN MOUNTAINS, SW COLORADO

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Colorado's San Juan mountain contains over 930,000 hectares, most of which consist of volcanic and other igneous rock. Mississippian and Pennsylvanian limestones are in the western San Juans. Recent cave discovery and exploration activities have resulted in identification of 40 previously unreported caves and pits. About half of these discoveries have been surveyed, and several limestone outcrops have yet to be investigated. Most of the San Juan caves are in Pennsylvanian limestones of the Hermosa Group (middle Honaker Trail Fm.) that are usually no more than 9 m in thickness. These beds contain a variety of small, cold, wet caves at elevations of 3000-3400 m. The largest of these, Surprise Cave, has over 1100 m of surveyed passage, another (Twin Pit/Sunset Slide) has 370 m surveyed, and several other caves also have the potential for having over 300 m of passage.

DISCOVERY AND EXPLORATION OF COYOTE CAVE, SOUTH DAKOTA

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Discovered by Tom Miller in 1974, Coyote Cave is the second longest cave known within Wind Cave National Park, South Dakota. The cave is formed within a thin limestone bed in the Minnelusa Formation, which overlies the cavernous Madison Limestone. Even though the cave has strong airflow that hints at the cave's potential, exploration has been sporadic and currently only 370 m of survey have been completed. The cave's small passages and tight squeezes have not made exploration easy or appealing. In late 1997, Joel Despain, Merrilee Proffitt, and Greg Stock squeezed through the cave's most intimidating squeeze to discover going cave beyond.

DEFINING THE TROUT LAKE SYSTEM

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The Trout Lake caves are probably the largest, unrecognized lava tube system in the United States. In 1853, Captain George McCellan, later General of the Army of the Potomac during the Civil War, explored the lava fields while searching for a railroad route. Later, cavers explored the area and found numerous caves. The 1972 NSS Convention at White Salmon, Washington, focused interest on the caves. Until recently, cavers thought the caves, featured in the 1972 and 1991 NSS Convention guidebooks, were randomly located. We can now establish the connectivity of the caves with 32 km of mapped passages and the aid of geologic studies. While the picture is but half complete, the study is driving the exploration for new caves and passages. Northwest cavers discovered new passages in Dynamited, Dead Horse, and Poachers caves. We have placed Chubby Bunny, Technonine, Down Draft, Three Sinks, and Skamanic caves in their correct locations relative to other caves in the system. By filling in the gaps in the system, it is hoped that new caves will be discovered.

GEOLOGY & GEOGRAPHY

COMPARISON OF KARSTIFICATION AND SOLUBILITY OF THE LOYALHANNA LIMESTONE, CHESTNUT RIDGE AND LAUREL HILL, WESTERN PENNSYLVANIA

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The Mississippian Loyalhanna Limestone is the primary cave-forming unit in the geologically similar Chestnut Ridge and Laurel Hill anticlines. Exploration and mapping show Chestnut Ridge has more and larger caves than Laurel Hill. The Loyalhanna Limestone is a massive, cross-bedded rock unit that varies in composition from a calcareous sandstone to a sandy limestone. Even though Laurel Hill has more Loyalhanna Limestone exposed and appears to receive more precipitation, Chestnut Ridge contains 178 solutional caves compared to Laurel Hill's eight. The discrepancy could reflect exploration bias. However, the caves that have been discovered on Laurel Hill are significantly smaller and less extensive than those on Chestnut Ridge. This study examined the amount of outcrop, precipitation, and solubility of the limestone in order to explain this difference. The amount of outcrop was determined from published maps by Berg and Dodge (1981). Qualitative analysis of satellite imagery was used to estimate relative amounts of precipitation. The rates of dissolution of 15 rock samples from Chestnut Ridge and 14 samples from Laurel Hill were measured in 5-7% acetic acid (vinegar) over 91 hours. This experiment showed a higher rate of dissolution in the limestone of Chestnut Ridge than in the limestone of Laurel Hill. Solubility of the limestone, probably caused by facies change, thus appears to be the controlling factor that favors karst development on Chestnut Ridge over Laurel Hill. Other factors may include the number and density of joints and fractures, differences in grain size, and variations in stratigraphy and lithology.

ALPINE KARST DEVELOPMENT AND SPELEOGENESIS IN THE LIME CREEK HYDROLOGIC SYSTEM, EAGLE COUNTY, COLORADO

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This study determined the controls on and the nature of alpine karst development in Lime Creek, Eagle County, Colorado. The major controlling factors on karst development in the Lime Creek/Tellurium Park area are lithology and structure. Paleokarst and mineralization affect individual passages, but have little control on overall cave morphology. In general, water is captured in sinkholes and follows fractures, bedding planes, and open conduits until encountering major faults. Flow continues along these faults to the karst conduit that feeds into Clark Spring in Lime Creek Canyon.

Detailed mapping of cave sediment distribution and composition was used to assemble a depositional history for caves in the study area. Cave development probably began about 130-95 ka and continues to the present. Sediment deposition was strongly controlled by glacial advances and retreats in the Lime Creek Valley.

During glacial periods, caves overrun by glacial ice were characterized by calcite deposition and roof breakdown. Periglacial caves were marked by active stream erosion and deposition, and calcite deposition in abandoned cave passages. Meltwater from glaciers increased stream energy and completely filled some passages with glacial materials. During interglacial periods, speleogenesis in most of the caves was probably characterized by roof collapse, calcite precipitation, and sediment deposition.

LUMINESCENCE BANDING IN YOUNG FLOWSTONE: COMPARISON WITH CONTEMPORARY CLIMATIC RECORDS

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Most calcite speleothems display a blue-white to green-white luminescence under excitation by ultraviolet light. The brightness of the luminescence varies along the growth direction of the speleothem producing alternating light and dark bands with a thickness on the order of 20-60 μm . These have been associated with annual wet and dry cycles so that the luminescence banding, if it can be properly interpreted, forms a paleoclimatic record that can extend through the Holocene and into interglacial periods. To read the climatic record, it would be useful to compare luminescence banding with known climatic data. Woodward Cave, Pennsylvania, contains thin layers of flowstone over bare limestone walls that are known to have grown since mud and silt were cleaned out of the passage during commercialization in 1924. Likewise, there is recent flowstone forming in limestone mines of western Pennsylvania. Luminescent banding was measured on slabbed and polished samples of Woodward Cave and limestone mine flowstone using laser excitation focused through a microscope to a 1-2 μm spot. Luminescence radiation emitted from the spot was transmitted back through the microscope, through a monochromator, to a photomultiplier for quantitative intensity measurement. The specimen was mounted on a precision stage that could be advanced in micrometer intervals for high spatial resolution. By this means, luminescence banding records have been obtained which can be compared with actual climate records for central and western Pennsylvania.

STATISTICAL ANALYSIS OF CAVE TEMPERATURE VARIATIONS IN SALTPETRE CAVE, CARTER COUNTY, KENTUCKY: A POTENTIAL REFERENCE FOR ASSESSING THE APPLICABILITY OF THE THREE-ZONE CAVE TEMPERATURE MODEL

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Past workers have discussed three-zone models for temporal and spatial variations of temperature within caves. With the recent introduction of inexpensive data loggers capable of recording temperature changes with high resolution and precision, the opportunity to quantitatively reassess the three-zone model exists. Recent investigations indicate the three-zone model insufficiently explains temperature variations in caves situated in tropical climates and/or containing active streams, multiple entrances, etc. As a point of comparison, high resolution data on the temperature structure of a cave adhering to the three-zone model would be useful. However, such an analysis is unavailable. To provide such a reference, a statistical examination of temperature variations in Saltpetre Cave, Carter County, Kentucky is presented.

Temperatures at 14 locations along a 200 m horizontal transect into the cave were recorded every five minutes for 7 days in January 1998 using HoboTM® data loggers. Additionally, temperature was recorded outside the cave providing a reference for external meteorological patterns. Statistical analysis of these data show decreasing variance (7.2-0.0 °C), range (10.9-0.0 °C), standard deviation (3.3-0.0 °C), and standard error (0.07-0.0 °C) away from the cave entrance. These patterns suggest that external influences on cave temperature decrease with increasing distance from the entrance. As expected during the winter season, the mean temperature increased with increasing distance from the entrance. In agreement with the model, three cave zones were determined to exist in Saltpetre Cave: twilight cave (0-~18 m), middle cave (~18-~60 m), and deep cave (>60 m).

However, truly static temperature conditions are not found until 183 m.

GEOMICROBIOLOGY OF SULFURIC ACID SPELEOGENESIS

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Oxidation of reduced sulfur compounds (e.g. H_2S , S^0) to sulfate, and ultimately sulfuric acid, controls development of sulfidic karst. Traditionally, sulfidic cave systems were believed to originate by primarily chemical karstification mechanisms. More recently, a host of complex microbial biofilms, which have the potential to oxidize reduced sulfur to sulfate, have been identified in some systems. Previous work has speculated that these bacteria may be directly involved with sulfuric acid speleogenesis, but this work is the first to test those hypotheses.

Geomicrobiological interactions occurring during sulfuric acid speleogenesis were investigated from active sulfidic caves, including Movile Cave (Romania), the Frasassi Cave (Italy), Cesspool Cave (Virginia), and Lower Kane Cave (Wyoming). Strains of sulfur-oxidizers were isolated using standard laboratory enrichment techniques and their acid production potential was screened for using two unique plating methods. The first method detected acid production through introduction of a pH indicator, bromocresol green, into the growth medium. The bromocresol green plates indicated that strains lowered the pH of the media to values below 3.8. The second method introduced CaCO_3 within the growth medium. As the bacterial colonies grew and produced acid, the CaCO_3 was cleared from the plates in the vicinity of the colonies. Although preliminary, gypsum precipitation was also linked to microbial sulfur oxidation in the laboratory strains. Attempts to identify the cultures indicated that they are new species, with their closest known relatives being acid-producing, sulfur-oxidizing bacteria, such as *Thiobacillus*.

CHARACTERIZATION OF KARST GROUNDWATER BASINS USING NORMALIZED BASE FLOW ANALYSIS, FORT KNOX, KENTUCKY

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Fort Knox occupies an upland sinkhole plain bounded on three sides by base level streams. The karst aquifer is developed within a 60-m thick sequence of St. Louis Limestone and is constrained by an underlying aquitard, the Salem Limestone. To evaluate groundwater quality concerns from hazardous materials facilities located throughout Fort Knox, karst groundwater basins were characterized and delineated using a combination of dye tracing (visual, qualitative, and quantitative), spring flow characterization (discharge, temperature, pH, and conductivity), and structural and topographic controls.

Normalized base-flow (NBF) was calculated for both the entire study area and for 28 individual basins. Projected basin areas were measured by planimeter from topographic maps. Discharge measurements collected in October 1997, representing 5-10% of peak discharge, were used for base-flow conditions. NBF calculations yielded a site-wide value of 1.53 (0.33 L/s/km² or Lsk), with individual basins ranging from 1.86 to 1.09 Lsk, and were comparable to published results from similar terrains. Comparison of NBF values between individual basins and the site-wide result proved an effective indicator for groundwater flow characterization. Basins with higher than average NBF have less-developed conduit systems and greater storage potential. Alternatively, further investigation in several basins with unusually high NBF found artificial contributions to groundwater flow from leaking water and sewer lines. Basins with lower NBF have well-developed conduit systems that efficiently transport

groundwater through the basin, limiting storage. Additionally, NBF results were used to refine the basin limits and to establish boundary zones in areas of uncertainty or potentially overlapping basins

ESTIMATES OF SEEPAGE RATES OF REDUCED, SALINE GROUNDWATER INTO THE DRAGONS LAIR TUNNEL OF THE CRYSTAL BEACH SPRING CAVE SYSTEM

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Crystal Beach Spring is a freshwater, submarine spring in the intracoastal waterway of the Gulf of Mexico to the east of Honeymoon Island and ~300 m offshore (west) from Crystal Beach in Pinellas County, Florida. A unique ecosystem exists within the Crystal Beach Spring cave system at a penetration of 700-820 m and a depth of 37 m salt water in a tunnel known as the Dragons Lair. This area of the cave is characterized by a pycnocline, a distinct thermocline/halocline in the water column separating freshwater flowing toward the entrance from warmer, stagnant saltwater. Just above the pycnocline, a "cloud" of sulfur oxidizing bacteria is present. These bacteria use hydrogen sulfide from the saltwater as an energy source (electron donor) and oxygen as the electron acceptor. This allows primary production to be performed without photosynthesis. The saltwater in the Dragons Lair is seeping up through the carbonate sediments covering the floor of the cave in the Dragons Lair. The vertical hydraulic gradient of the saltwater was measured using a piezometer and submersible manometer. The manometer data showed an upward hydraulic gradient, and water quality data demonstrated that the Dragons Lair saltwater was significantly different from the Gulf saltwater. A specific discharge of 2.92×10^{-5} m/s for the saltwater was obtained using a saltwater/freshwater mixing model. This model was based on the change in total dissolved solids of the freshwater as it flows across the saltwater in the Dragon's Lair.

COMPARATIVE OBSERVATIONS FROM TWO ACTIVE SULFUR-RICH SPRING CAVES: LOWER KANE CAVE AND CUEVA DE VILLA LUZ

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Lower Kane Cave (LK), Wyoming, USA, provided much of the evidence Egemeier (1973) cited in his "replacement-solution" model of hypogenic speleogenesis. Recent work in Cueva de Villa Luz (VL), Tabasco, Mexico, has expanded our knowledge about erosive processes in sulfur-rich spring caves, prompting several new observations in Lower Kane Cave.

The two caves display similar features, including: 1) Springs rising from the floor form sulfur-rich streams; 2) Spring waters have pH values between 6-7 and pHs of the streams are 7-7.5; 3) White bacterial stringers undulate in the streams; 4) Bright red microbial mats line the bedrock and stream bottoms adjacent to and for ~20 m downstream of some springs in each cave; 5) Actinomycetes are common; 6) "Biovermiculations" are abundant in stream passages of Villa Luz and near the entrance of Lower Kane; 7) Small snails (LK <5 mm and VL <2 mm across) are abundant in the stream sediments; 8) Spiders are plentiful in Villa Luz and present in Lower Kane; 9) Gypsum crystals ranging from microcrystalline pastes to macrocrystalline blades coat most of the walls and ceilings. Gypsum pastes consistently display pH values of 1-3.

Atmospheric H₂S levels are markedly higher in Villa Luz (maximum recorded value of 158 ppm versus 3 ppm in Lower Kane). Carbon monoxide has also been recorded (V.L. = 58 ppm; L.K. = 24 ppm). Unidentified gas bubbles, thought to be CO₂, rise from some

springs in both caves. Apparent "corrosion residue" near one spring in Kane resembles deposits from Lechuguilla Cave.

TOWARD A SUITABLE CONCEPTUAL MODEL OF THE NORTHERN GUAM LENS AQUIFER

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The Northern Guam Lens Aquifer is a carbonate island aquifer in an uplifted limestone sequence consisting of a Miocene-Pliocene detrital facies grading upward into a Pliocene-Pleistocene coral-algal reef-lagoon facies. The limestone sequence rests atop a Eocene-Oligocene submarine volcanoclastic basement. Basement topography is complex, varying from a maximum elevation of ~200 m, where it crops out to form the highest point above the limestone plateau, to a minimum of more than 150 m below sea level. The island has been generally emergent over Pleistocene time; the entire Pleistocene section is currently above sea level, the highest elevation of the plateau being about 180 m. Relative sea-level still-stands are recorded in several notches and marine terraces incised in cliff faces surrounding the plateau. The entire sequence has undergone fresh-water diagenesis as it was uplifted through the fresh water lens. How karst processes have modified the subsequent porosity is of fundamental concern to those attempting to interpret or predict aquifer behavior. Three especially compelling questions include: (1) What is the relative importance of cavernous, fracture, and diffuse porous flow in the current vadose and phreatic zones, and what controls the occurrence of each type of porosity? (2) How strongly has horizontal conductivity been modified by water table dissolution at previous still-stand levels? (3) What is the relative importance of concentrated versus diffuse infiltration? Answers to such questions are crucial for assessing the reliability of models for evaluating pump test results and predicting groundwater flow directions, fresh water lens geometry, and response to withdrawal.

HYDROLOGIC INSIGHTS FROM A FINITE ELEMENT MODEL OF THE YIGO-TUMON SUB-BASIN, NORTHERN GUAM LENS AQUIFER

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The Northern Guam Lens Aquifer (NGLA) is a Pleistocene karst aquifer in an uplifted Cenozoic limestone sequence forming a plateau about 60-180 m high. The climate is tropical wet-dry, with average rainfall about 2.5 m/a, 80% of which falls between July and January. Monthly recharge estimates for 1982 through 1995 based on positive-definite daily differences of rainfall minus pan evaporation suggest a relationship between monthly precipitation and recharge of $N = \max(0, -1.7 + 0.87P)$, where N and P are estimated minimum monthly recharge and precipitation, respectively, in inches. We used a two-phase fresh water/saltwater flow model to simulate transient regional-scale responses of the fresh water lens to monthly variations in natural recharge in the Yigo-Tumon sub-basin of the NGLA. Boundary conditions included monthly-averaged mean sea-level changes. Recharge rates were based on the assumption that 100% of monthly recharge infiltrated to the fresh water lens within each one-month time step. Comparison of observed well water elevations with elevations simulated for various values of hydraulic conductivity, K, sug-

gest a regional K of about 6100 m/day, consistent with previous studies. Variations of 20% around this value produced calculated water levels consistent with observed water levels. The most significant result from the modeling study, however, is that even for best-fit simulations, simulated water levels are consistently higher than observed levels for wet season months and lower than observed levels during the dry season months. The simplest explanation is that vadose storage is sufficient to dampen monthly-scale variations in recharge.

THE HISTORICAL IMPORTANCE OF THE BAUMANNSHÖHLE/HARZ ILLUSTRATED BY THE REPORT OF ZÜCKERT (1763)

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The Baumannshöhle, in Rübeland, Harz, Germany, is one of the most important caves in early scientific literature. First mentioned in 1546, it was the first natural cavern from which a picture of its interior (1654) and a map (1665) was made. It also was the first cave to be protected by decree and for which a guide was appointed (1668). In the 18th and 19th century, it was the focus of investigations by numerous scientists, and appeared in many publications and in most of the natural science overviews. Here I report about a description published in 1763 by Johann Friedrich Zückert (1731-78), a physician and author, so far unknown to speleological literature. Zückert appears to have been a critical observer. He not only described the individual flowstone figures, taking account of previous reports, but he also discussed the question of their formation, showing a thorough knowledge of the chemistry of his time. Furthermore, he deals with the bone deposits in the cave, however, without identifying them as bear bones, even though Horst (1656) and Brückmann (1734) had already stated that the bones from the Einhornhöhle were bear. Walch (1769) was the first to acknowledge Baumannshöhlen bones as bear bones. In 1774, Esper suggested that they belonged to the ice bear, and, in 1794, Rosenmüller finally realized that they represent an extinct species: *Ursus spelaeus*, the cave bear. Using the most recent survey of the Baumannshöhle (Fricke 1998), we were able to identify many of the historical flowstone figures discussed by Zückert.

MIXING CORROSION AT MANITOU SPRINGS, COLORADO

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Precision measurements of the anion and cation content of myriad springs of Manitou and a surface stream along with their flow rates were used to calculate the mass balance of the conservative and non-conservative anions and cations entering and leaving the mixing zone beneath the city of Manitou Springs. The conservative cations and anions are nitrate, sodium, potassium, lithium, sulfate, bromide, fluoride, and chloride. The non-conservative cations are calcium, magnesium, iron and manganese. The calcium and magnesium content of the water increases from the mixing of two different groups of waters. When one group, which has elevated total dissolved solid and very high CO₂ content mixes with another group, which has low total dissolved solid and low CO₂ content, a solution is created that has the ability to dissolve ~71 tonnes/a of the dolomitic limestone that hosts the mixing zone.

The iron and manganese content of the water decreases in the mixing zone from the mixing of the same two groups. In this case the first group of waters is rich in dissolved iron and manganese and the second group is rich in oxygen. When these two waters mix, the manganese and iron precipitate out in the mixing zone. The nearby Cave of the Winds along with the manganese- and iron-rich sediments in

the cave are excellent proof that the mixing corrosion taking place at present had been actively dissolving limestone for millions of years.

DOES CRYSTAL SPLITTING PLAY A PART IN THE CURVATURE OF HELICTITES?

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At straight segments of calcite helictites, the crystal axis of fastest growth maintains a constant orientation, whereas at curved segments it follows the curvature. Three mechanisms for rotated crystals are (1) the long axes of the crystals in conical stalactites always point toward their curved outer surface, because they crowd out slower growing seed crystals of other orientations; (2) Russian investigators explain radiating crystals by crystal splitting, the insertion of molecular wedges to divide an initial crystal; and (3) microorganisms cause a non-typical diagonal orientation of calcite moonmilk grains. Helictites are nourished by a capillary at the tip. The growth increments consist of nested cones, but thin sections show that the crystal units are wedges that diagonally cross the whole helictite. The youngest wedge points toward the intersection between two faces of the helictite's 3-sided pyramidal tip. The wedges grow toward that intersection (the trace of a scalenohedral tip) and by crystal overgrowth at the edges of older wedges. Deposition follows the crystal lattice of the wedges but is greatest near the capillary, leading to an increased angle. When water flow stops periodically, subsequent growth is controlled by crystal crowding. It is perpendicular to the outside of the curve next to the capillary, and its crystal orientation differs slightly from that of the previous wedge. I cannot, with certainty, distinguish crystal crowding from crystal splitting near the orifice of the capillary, but crystal splitting ought to cause a fanning from the orifice, whereas the wedges are planar across the entire helictite.

THE ROLE OF MAPPED AND UNMAPPED IMPERMEABLE UNITS IN CONTROLLING CAVE DEVELOPMENT AND CONTAMINANT TRANSPORT IN CENTRAL TENNESSEE: THE "PERCHED WATER TABLE THEORY" REVISITED

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Studies by the authors have shown that thin, impermeable shaly and sandy units occur in central Tennessee that prevent the downward migration of groundwater and contaminants. In the Highland Rim, four impermeable units exist. The Chattanooga Shale is mapped and is obvious, but the Warsaw Limestone contains an upper and lower clay- and sand-rich limestone member that perches contaminated groundwater. Dye trace studies substantiate this hypothesis. These two members have not been depicted on geology maps. Large, horizontal caves occur above the two impermeable Warsaw members. Higher in the stratigraphic section, there is an unmapped non-continuous green shale that occurs in the Monteagle Limestone. Where present, this shale perches water causing many deep pits to terminate at this unit.

In the Central Basin, the mapped Hermitage Formation and Pierce Limestone are shaly, and major horizontal caves are developed above them. Groundwater tracing from two state-listed Superfund sites demonstrates the importance of the Pierce in perching potential contaminants above it. Less conspicuous is the unmapped Lower Ridley Confining Unit which has been mistakenly identified and mapped as the Pierce throughout many areas of the Central Basin. Mis-identification of the Pierce and Lower Ridley Confining Unit has caused cross-contamination of aquifers by monitoring wells.

IDENTIFICATION AND DEPOSITION OF METATYUYAMUNITE AND RELATED MINERALS IN CAVERNS OF SONORA, TEXAS, USA

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A new mineral association composed of metatyuyamunite, celestite, opal, and several minor additional mineral phases has been identified from Caverns of Sonora, Sutton County, Texas. Metatyuyamunite, $\text{Ca}(\text{UO}_2)_2(\text{VO}_4)_{2-3}\text{H}_2\text{O}$ occurs as patches of bright lemon yellow crystalline crusts on a limestone substrate that has the appearance of dried and cracked lime mud. The yellow crystals luminesce the characteristic bright green from the uranyl ion. Blue 200-300 μm prismatic crystals of celestite, SrSO_4 , occur in association with the metatyuyamunite and nearby gypsum crusts. Metatyuyamunite takes the form of platy crystals about 50 μm in diameter. In some places, a thin layer of botryoidal opal covers the metatyuyamunite. Associated with the opal are stringy masses of silica that appear to be the residue of bacteria. Mineral identification was by X-ray diffraction with crystal habit determined by scanning electron microscopy. Several other minor mineral phases were observed in the SEM images but were too sparse for X-ray identification. The ultimate source of uranium and vanadium may be from deep seated hydrogen-sulfide rich waters supported by other evidence that the primary excavation of Caverns of Sonora was by the sulfuric acid mechanism now generally accepted for the caves of the Guadalupe Mountains. If this is so, the deposition of metatyuyamunite and associated minerals is much older than the deposition of the calcite speleothems that decorate Caverns of Sonora.

INTERPRETING PREGLACIAL KARST WITH THE AID OF GRAVITY SURVEYS
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Late Pleistocene glaciation in New York State buried most of its karst landscapes beneath as much as 100 m of till, outwash, and lake deposits. Nearly all the karst is preglacial, so this process had a profound effect on groundwater flow and the relation of caves to the surface. Gravity surveys reveal preglacial karst topography by making use of the density contrast between bedrock and overlying glacial sediment. Calibration with well logs suggests densities of 1.7, 2.0, and 2.5-2.65 g/cm^3 for unsaturated sediment, saturated sediment, and bedrock. Because of the broad extent of the gravity traverses, terrain and latitude corrections are essential. Theodolite surveys provide the necessary precision for elevation corrections. Approximate bedrock depths can be estimated with the Bouguer equation, but they must be refined by finite-difference calculations, which reveal far greater local relief than do the initial approximations. We have devised interactive computer software for this purpose. Results show that much of the present karst drainage was adjusted to topographic conditions quite different from those of today. Glacial deposits filled major valleys to roughly half their depth, and topographic relief was reduced by about a third. Many small valleys were completely filled and now show little or no topographic expression. The gravity surveys help to reveal the origin and distribution of artesian springs, filled-valley barriers between neighboring cave systems, blocked inputs, and deranged upland recharge.

FOSSILIZED BACTERIA IN THE RUSTICLE STALACTITES OF LECHUGUILLA CAVE

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We investigated iron oxide filaments in two sections of unusual iron-oxide stalactites from Lechuguilla Cave, New Mexico. The filaments were reported by Davis *et al.* (1990) as fossilized bacteria. We investigated further to characterize their material and biological aspects. Outer layers of these stalactites consist of calcite with thin bands of iron oxide, while their inner cores consist predominantly of iron oxide. The filaments are reddish to yellowish brown and mostly encased in calcite, dolomite, or quartz within the central canal of the stalactite where they are restricted. The filaments vary in diameter from 1-6 μm , and in length from 10 to >100 μm . They have a curved, sinuous to helical morphology, and optical examination shows that they have a central tube. Electron microscopy images clearly show that the filaments are constructed of radial laths of crystalline iron oxide around a "pre-existing" central tube. X-ray diffraction of the stalactite core indicates that the crystalline phase of the iron oxide is goethite. Crystallinity of these laths is confirmed by electron diffraction. Central tube diameters were measured up to 0.5 μm at which size the tube is most distinct. Smaller diameter central tubes in these filaments are probably the result of goethite laths growing into the tubes. The 0.5 μm diameter of central tubes in these filaments is consistent with the diameter of most iron-depositing filamentous bacteria. The filaments may be fossils of *Leptospirillum ferrooxidans*, which grew in an acidic environment, somewhat similar to acid mine drainage settings.

KARST HYDROLOGY OF THE LOGAN CANYON AREA, BEAR RIVER RANGE, NORTHERN UTAH

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Recharge areas and residence time were determined for water from four springs in Logan Canyon, in the Bear River Range of northern Utah. Dewitt, Wood Camp Hollow, Ricks, and Logan Cave Springs discharge from Paleozoic carbonate rocks into the Logan River, east of Logan, Utah. The Logan River is base level for groundwater that discharges from this alpine region.

Dewitt Spring discharges from 0.28-0.99 m^3 and has a recharge area that largely coincides with a regional syncline. Wood Camp Hollow Springs discharge less than 0.1 m^3 to at least 1.4 m^3 from two outlets. Ricks Springs discharge along a normal fault and range in flow from about 0.28-2.1 m^3 . Recharge areas for these springs are at least 26 km^2 and as much as 980 m higher than the springs.

Recharge to the springs occurs primarily during snowmelt, resulting in peak discharge from late spring to early summer and base flow during the winter months. Qualitative dye tracing indicates maximum groundwater travel times of 2-4 weeks from more than 11 km.

Specific conductance of water from all springs during peak discharge ranges from 250-290 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) and temperature ranges from 5.5°-6.0°C. Conversely, specific conductance of water during base flow ranges from 340-420 $\mu\text{S}/\text{cm}$ and temperature ranges from 6.5°-7.75°C. Differences between these values result from mixing of snowmelt with groundwater with a longer residence time.

DEVELOPING A CAVE & KARST INFORMATION SYSTEM USING ARCVIEW® GIS

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A Cave and Karst Information System (CKIS) is a specialized type of geographic information system (GIS). Common tasks and issues are found in developing a CKIS when compared with other types of GISs, but developing a CKIS also presents a unique set of problems, issues, and considerations. ArcView® GIS is a popular desktop GIS software product that includes tools, extensions, and customization capabilities that provide a robust framework for data management and visualization of cave survey data and inventories, as well as a substrate for both analytic and interpretive applications. Several prototypes have been implemented that have demonstrated the usefulness of cave and karst information systems and ArcView® GIS. Preliminary work has yielded specialized code and techniques for visualization and data management. This work has also identified issues and shortcomings that future work will need to address.

KARST INVENTORY OF THE NORTHERN GUAM LENS AQUIFER

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The population of Guam is rapidly growing. Over 70% of its water supply is drawn from the carbonate Northern Guam Lens Aquifer. This project is the first attempt to comprehensively inventory, map, and interpret the aquifer's karst features. Guam exhibits characteristic island karst features, but karst evolution and hydrologic behavior have been influenced in important ways by rapid uplift (up to 180 m in Pleistocene time). Moreover, in spite of the aquifer's relatively small size and young age, it also exhibits, on some terrain, some well-developed classic karst features more typical of continental settings (e.g., blind valleys and disappearing streams). Features on which this investigation is focused include epikarst, closed depressions, caves, and coastal springs. Epikarst on Guam appears identical to epikarst of other carbonate islands. Dissolutional closed depressions include large sinkholes mimicking cockpit karst, small collapsed sinkholes, and blind valleys. The largest closed depressions are probably constructional. Exposed caves on Guam include pit caves, stream caves, and flank margin caves. Numerous pit caves vary widely in size and reach depths of 50 m. Stream caves are associated with allogenic rainwater catchment by volcanic rocks. Flank margin caves are exposed on the cliffs in Northern Guam and indicate previous sea-level still stands. Additional types of caves include voids created on the top, bottom, and within the freshwater lens. These voids, not exposed at the surface, are often intercepted during well drilling. Coastal springs include discharging caves, fractures, and underwater vents along cliff lines, and springs and seep fields along beaches.

KARST GEOARCHAEOLOGY OF PIEDRAS NEGRAS, PETEN, GUATEMALA
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Piedras Negras is the modern name for an ancient Mayan city in the karst lowlands of Guatemala's Peten region. The city's location was determined by a geologically favorable location along the Usumacinta River, on a low-relief platform above seasonally flooded valleys, and part of an arch across a regional syncline. Black chert exposed along the river provided the community a rich deposit of tool making material, and along with rocks stained black from manganese

dioxide, was the source of the town's modern name. The site is within a cone-karst setting; cockpits are not associated with the cones, and there is little apparent internal drainage. Caves are small, less than 10 m in length and mostly collapse-formed shelters. However, one pit is possibly the largest in Guatemala at 100 m in diameter by 66-120 m deep. These contrasts result from the late Cretaceous and Paleocene units underlying the site. The uppermost unit is a cliff-forming dolomite to dolomitic limestone that supports little solutional enlargement for caves. It is underlain by an easily eroded carbonate chalk that forms no caves. Karst cones are partly formed by solution of the dolomitic limestone and partly from weathering of the chalk, undercutting and collapsing the dolomitic limestone. The pit formed by the collapse of both units into a deeper limestone where large phreatic conduits are apparently present. The Maya, known for attributing religious significance to caves, used them for rituals and important burials, but not as intensively as in other locations where caves are larger.

STRONTIUM ISOTOPES OF REDMOND CREEK CAVE, WAYNE COUNTY, KENTUCKY

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Redmond Creek Cave is near Monticello, in Wayne County of south-central Kentucky. The cave cuts through the Kidder and Ste. Genevieve limestones and is overlain by the Hartselle, Bangor Limestone, Pennington, Breachitt, and Lee formations.

Strontium isotopes have been used to evaluate the sources of Sr in groundwater and to see if they changed over time. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and Sr concentrations have been analyzed in bedrock and water samples taken from the surface, the cave, and its main resurgence and resurgence. Water from both the dry and wet seasons were analyzed. Also, different growth layers of a stalactite were analyzed to evaluate long-term variations.

Significant variations are observed with $^{87}\text{Sr}/^{86}\text{Sr}$ ranging from 0.7082 to 0.7078 for limestone bedrock and from 0.71307 to 0.70837 for water. Sandstone of the Hartselle and Lee Formations have the highest $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, up to 0.7337. In contrast, limestone of the Kidder and Ste. Genevieve limestones have the lowest $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, near 0.7080; the limestone values are consistent with the seawater $^{87}\text{Sr}/^{86}\text{Sr}$ during the Mississippian Period when these rocks formed. All water samples are intermediate, indicating that they have mixed sources of Sr. Some changes in these over time are apparent. Waters from dripping speleothems have ratios closer to the limestone. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in a stalactite show only minor variations. Overall, the values of $^{87}\text{Sr}/^{86}\text{Sr}$ in water and the stalactite appear to reflect the paths of water flow and the degree to which the water interacted with bedrock of various types.

AIRFLOW AT THE DOYAL VALLEY ENTRANCE OF THE MAMMOTH CAVE SYSTEM, KENTUCKY: IMPLICATIONS ON CAVE CLIMATOLOGY

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Around-the-clock studies of airflow at the Doyal Valley entrance to Mammoth Cave, Kentucky, indicate that the temperature of outside air at ground level correlates most closely with movement of cave air at this site. Barometric pressure changes of multiple origin also affect

airflow. Change in humidity plays a minor role. Other factors are not significant here. Each main factor has been analyzed to show its contribution to airflow and its relation to the other factors. We suggest that this information can be used to advantage in controlling the climate of the cave.

Installation of sensors and a remote controlled airgate would allow for control from a central point. Such control could be automated to help achieve the desired changes in cave climate. A network of such controls operated over time would have a beneficial effect on the cave climate. These include modification of cave temperature, increased cave humidity, and increased ventilation of tourist routes, if desired, to reduce radon levels. If indicated for the protection of visitors, who may number a million a year, fans and in-cave baffles could be discreetly installed to augment natural flow.

HISTORY

BEYOND THE SUMP: THE BURNLEY MAP OF CARVERS CAVE

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Carvers Cave is a sandstone cave, ~35 meters long, at the foot of Dayton's Bluff near downtown St. Paul, Minnesota. Containing a spring-fed lake, it became the "baptismal font" of Minnesota caving when explorer Jonathan Carver visited it in 1766-67 and subsequently published his account, one of the first descriptions of a cave in the Upper Mississippi Valley. Since then, the cave has gone through the cycle of being shut by talus and then dug open again several times per century.

Carvers Cave was most recently reopened with a front-end loader in 1977 by city officials and was thereafter secured with a steel door. Since then, a 2 m thick deposit has accumulated below the bluff, burying the door and deepening the lake. Although still accessible today through a small opening, the cave will again be lost to view early in the next millennium.

The 1913 reopening of Carvers Cave by Colwell, however, generated the most publicity. At that time, a journalist named Burnley drafted a conjectural map showing large rooms beyond the sump at the rear of the cave. Probing the sump with poles today, there is good reason to believe that Burnley's rooms exist. After failed scuba and pumping efforts to crack the sump in the 1990s, local cavers resorted to trenching the talus in the hope of draining the lake that fills the cave and exposing the rooms.

THE REDISCOVERY OF HEISKELL CAVE: A CONFEDERATE NITRE BUREAU WORKS

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Heiskell Cave is the Civil War name of a cave near Rose Hill area of Lee County, Virginia, within the boundaries of Confederate Nitre District No. 1. Payroll records for a saltpeter mining operation in this cave are known from October 1862 through August 1863. The exact location and modern name of this cave remained a mystery to speleohistorians until November 1994, when the names of three Civil War miners were matched between payrolls and cave graffiti. The inscriptions "John R. Fitts 1863," "A.P. Waterman Mar 7 1863," "A.P. Waterman March 10 1863," and "1863 Andrew J. Milbourn CSA March 24 1863" were found on the walls of Jones Saltpeter Cave and correlate with the Heiskell Cave payroll names of John R. Fitts (laborer) January-August 1863, Alfred P. Waterman (laborer) February-August 1863, and Andrew J. Milbourn (laborer) January-April 1863.

Other mining evidence observed includes piles of rocks culled from sediment, old sediment levels on walls, mattock marks, torch perch sooting, taley marks, and old leach vat cast piles.

Jones Saltpeter Cave is once again closed to visitation by cavers and researchers alike.

SURVEY & CARTOGRAPHY

SPELEOMORPH COMPUTER-ASSISTED CARTOGRAPHY

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As computer-assisted drafting becomes more popular with cave cartographers, the problem of entering and manipulating sketches becomes problematic. The optimum solution would be to have a computer program that would scale, rotate, and move the sketch on the computer to match the entered data. SpeleoMorph is the first program to fully automate this process. This talk discusses the Kolstad Algorithm, which is the key for achieving the non-linear transformations required, and presents the results from the SpeleoMorph program on a one-mile (1.6 km) long cave system.

CREATING A SUCCESSFUL COMPUTER GENERATED CAVE MAP WITH FREEHAND®

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As home computer hardware and software becomes cheaper and easier to use, graphics software is replacing the manual cartography methods used by cavers in the past. The use of FreeHand® software is one such package available to cave cartographers. Understanding how to set-up and execute using a variety of FreeHand® tools is essential in creating a successful computer generated map.

FreeHand® is an object oriented drawing application that is robust and boasts many more features than the original version that first appeared 12 years ago. Cross platform and menu driven, the latest version, FreeHand 8®, enables one to draw high quality cave maps and graphics. Creative tools like freeform tool and reshaping tool allow you to edit paths interactively without using Bezier control points. Transparency effects, blends, shadow tools, and graphics hose are just a few of the new features that can give your cave maps a professional look.

Computer generated maps have the advantage of easily adding color to a cave map. Proper use of color can add visual impact to your map. The use of color is added quickly and easily with graphics software. As more cavers start using FreeHand® and other illustration programs, computer generated maps will be the preferred choice and method to draw and display cave maps.

THE DEVELOPMENT OF A "GRID-STYLE FORM": A NEW WAY TO COMBINE CAVE INVENTORY WITH CAVE SURVEY

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Despite the diversity in objectives, forms, procedures and data reduction techniques, there are four basic types of cave inventory methods:

1) "whole cave, open-ended" methods, 2) "whole cave, checklist" methods, 3) "location-based, open ended" methods, and 4) "location-based checklist" methods. Each of these methods has its advantages and limitations. In the process of developing a cave inventory system for Sequoia and Kings Canyon National Parks, we have designed a new style of cave inventory form that has multiple advantages over many of the methods currently in use. Our "location-based, grid-

style" form is simpler and easier to use than standard "checklist style" forms. The grid-style form also facilitates the detection and recording of resource information in the cave and the data transfer and manipulation afterwards. Using this form, it is easy to combine cave inventorying with cave surveying or to return and inventory the cave after the mapping is complete.

PALEONTOLOGY

FOSSILS AND BONES FROM THORN MOUNTAIN CAVE, PENDLETON COUNTY, WEST VIRGINIA

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Thorn Mountain Cave is developed in the very fossiliferous, upper Devonian Helderberg Limestone. A collection of invertebrate fossils free from the limestone matrix was made in the 1950s and has been examined and identified. The fauna consists of brachiopods, crinoids, corals, and gastropods. Additionally, a few bags of floor matrix (primarily aragonite crystals) was also collected in the 1950s and has now been partially screened for bones. Preliminary identification of the fauna includes bats, shrews, and voles.

THE PLEISTOCENE PECCARY *PLATYGONUS VETUS* FROM POORFARM CAVE, POCAHONTAS COUNTY, WV

Fredrick Grady, Arlington, VA, Ray Garton, WV Geological Survey, Morgantown, WV & Marshall G Homes, Snow Shoe, WV USA

A virtually complete, articulated skeleton of the extinct peccary *Platygonus vetus* has been recovered from an obscure passage in Poorfarm Cave, Pocahontas County, West Virginia. *Platygonus vetus* dates from the early to middle Pleistocene at about 0.4 to 1.5 Ma. Based on other associated fauna, the Poorfarm specimen probably dates at the younger part of this time span. *Platygonus vetus* is much less frequently found than its younger and smaller relative, *Platygonus compressus*. The Poorfarm skeleton is only the second relatively complete skeleton of *Platygonus vetus* ever found in the United States. *Platygonus vetus* has also been found in other West Virginia caves such as Rennick Quarry Cave, Greenbrier County, Hamilton and Elias Davis Caves in Pendleton County, and, possibly, Bowden Cave in Randolph County.

VULCANOSPEOLELOGY

ESTIMATING DEPTHS AND VOLUMES OF LAVA TUBE PLUNGE POOLS – AN ONGOING STUDY

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Modeling thermal erosion in paraffin produces similar features to those commonly found in lava tubes. Of particular interest are extremely deep plunge pools melted into the paraffin "substrate". These paraboloid-shaped pits are only formed where plunge pools are stationary and the otherwise aggressive headward backcutting cannot occur. If we assume mature (not backcutting while active) lava plunge pools are dimensionally proportional to the paraffin models, the original depths of the pools are approximately twice their maximum pool width.

Ten mature plunge pools were studied in Kazumura Cave, Hawaii. Their sunken surfaces were measured to calculate the volume of contraction that had occurred during the slow cooling of the lava tube. Contraction volumes are figured using an equation for spherical segments. We can then calculate for the depth and volume of the pool, and test the feasibility of the depth estimate based on

twice the pool width. For some mature pools, depths calculated from contraction volumes are 9-25% deeper than depth estimated from pool width alone. Several reasons are given for discrepancy using the expected 9% contraction volume. Those fully mature plunge pools with shallower than expected contraction appear to have been partially filled by falling breakdown during their cooling, which would lessen their contraction volumes.

SOME UNUSUAL CAVES IN HAVO (HAWAIIAN VOLCANOES NATIONAL PARK)

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Recent exploration in HAVO turned up two unusual caves for which I had the good fortune to do photo-documentation. The first cave, Lae' apuki, is only 2.5 years old and formed from the Pu'u O'o flows from Kilauea. Portions of the cave were measured at 42°C. The cave has extensive mineral deposition, including white depositional stalactites up to a foot long. Longer stalactites seen in December had vanished by April, suggesting some of these minerals are short-lived. The second, unnamed cave was found in a 400-year-old flow. It contains massive amounts of red-tinted Pele's Hair encrusting stalactites and "stretched" stalactites. Above a 6m lava falls, a fist-sized clump hangs free from a stalactite, flapping in the cave wind. Additionally, portions of the cave are splattered with various colors of intrusive lava. Some of the "spattermites" also grade into thin strands of Pele's Hair.

STUDIES IN YOUNG LAVA TUBES OF HAWAII VOLCANOES NATIONAL PARK

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Recent work in Hawaii Volcanoes National Park has included exploration and analyses of features in recently formed lava tubes. During the last 13 years, numerous lava tube systems have developed between various vents and the sea, a straight-line distance of 11 km, in the active flow field on the southeast flank of Kilauea. Tubes on the coastal flats form by inflation of surface flows rather than by roofing over of lava channels. While some tubes were buried soon after their formation, a few others have remained accessible and have cooled sufficiently to allow exploration. Two caves near the coast have been a focus of our attention. The first, formed in 1995, provided us with samples of soda straws as well as secondary minerals. The second, active in 1996, contained spectacular stalactites, stalagmites, and other features composed of secondary minerals. Materials collected were analyzed with the cooperation of scientists at the USGS Hawaiian Volcano Observatory.

Mineral crystals such as ilmenite, magnetite, plagioclase, copper titanium oxide, and iron titanium oxide were identified by petrographic and scanning electron microscopic studies of soda straws. These studies demonstrate that straws form while tubes are active as well as during the initial cooling process. Minerals such as bloedite, thenardite, mirabilite, gypsum and others are often spectacularly developed on walls, floors, and roofs of young, hot caves. These relatively low-temperature-phase minerals are unstable and are observed to grow and dissolve as a result of changing environmental factors.

GEOPHYSICAL DETECTION OF ENTRANCELESS LAVA TUBES

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Entranceless lava tubes possess two characteristics that enable them to be detected by geophysical methods from the surface.

1. Volcanic rocks are weakly magnetic because they contain the mineral magnetite. A cavity in volcanic rocks, therefore, causes a distortion of the earth's magnetic field that can be measured with a sensitive magnetometer. However, the distance between the magnetometer sensor and the center of the void cannot be much larger than the void's diameter or detection may not be possible. Non-uniform fields from various causes, and magnetization caused by lightning strikes also limit the depth of detection.

2. Lava tube roofs generally lie a near-constant depth from the surface for long distances. This characteristic allows detection by gradient-array resistivity surveys. A circular tube may be reliably detected under favorable conditions provided the depth from surface to the ceiling is not more than the diameter. A major limiting factor is geologic noise mainly due to other small cavities in the area that are nearer to the surface. Natural-potential survey, another geophysical electrical-method, was tried in a few areas using the same survey grid as the resistivity surveys but was found to have limited application over lava tubes.

CONDUIT FLOW OF WATER IN VOLCANIC PSEUDOKARSTS

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Conduit flow of lava in some volcanic pseudokarsts is so commonly observed as to be taken for granted. Yet conduit flow of water in the same or similar pseudokarsts is omitted from conceptual diagrams and models of their hydrology. Due to a variety of factors, conduit flow of lava and of water are of different orders of magnitude here. Yet, much of the water supply of a town in Terceira (Azores, Portugal) is obtained from conduit flow through a lava tube cave, with municipal water works constructed in the cave. The extent of similar occurrences in Hawaii is unknown. However, Kaumana Cave demonstrates varying levels of conduit flow in response to different quanta of rainfall. It has striking parallels to karstic water flow, from a wetland or bog recharge area to floodwater filling of major sections of the cave. Due to increasing urbanization of some sparsely inhabited, "substandard" subdivisions on Hawaiian pseudokarsts, an increasing threat of groundwater contamination and pollution exists from such conduit flow. Groundwater dye tracing is increasingly needed in certain critical areas.

THE ROOTS OF VULCANOSPELEOLOGY KEYNOTE ADDRESS

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The American root of vulcanospeleology is in the Pacific Northwest, but an Italian root is more than 2000 years old. Only on Mt. Etna did lava tube caves exist in the geographic mainstream of Western civilization and culture. The first recorded visit to a volcanic cave in Japan was in 1203, but as late as 1959, studies of such caves were barely begun in Japan.

Participants in early European voyages encountered lava tube caves in Iceland, then other oceanic islands. Finally, they reached those of Hawaii in 1823. A map of Iceland's Surtshellir was published by 1757. In Hawaii, James Dana was the first American scientist to discuss such caves, but he was preceded by both British and American missionary-savants.

In the 1940s, Bischoff and Rhodenbaugh independently focused attention on lava tube caves of the Pacific Northwest. My 1963 *Caves of Washington* has been given credit for beginning descriptions of lava tube caves "in general" and for introducing much of today's terminology. However, it was only one part of a world-wide flowering of vulcanospeleology in the latter half of the century. Reflecting the dual roots of this new subsience, the 1st and 3rd International Symposia of Vulcanospeleology were in the Pacific Northwest; the 2nd, 4th, and forthcoming 9th in Italy at the foot of Mount Etna. They constitute the "cutting edge" of the field.

LAVA SURFACES AND FORMATION OF LAVA TUBES

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Recognition of types of lava surfaces is useful in understanding how lava tubes form. Pahoehoe, aa, and fracture (broken) surfaces are common. Sheared or grooved lava indicates that relative movement took place between two pieces of lava, at least one of which was still plastic during the movement. Separation of a crust from molten lava below it leaves spiky projections on the underside of the crust. Some stretched stalactites likely are spiky projections. Gas pockets may be lined with similar spiky projections. Presence of remelt glaze indicates that the surface was exposed to intense heat. Lenticular chips of earlier rock and stringy bits of spatter are commonly embedded in cast surfaces. A cast surface indicates cooling while in contact with some earlier formed solid. The thickness of a lava layer, defined by surfaces, relates directly to the amount of time required for the layer to have solidified. Black color of a lava surface indicates a lack of available oxygen at the time of cooling; red lava indicates that cooling occurred in the presence of steam. Identification of lava surfaces helps to reduce larger problems into simpler elements. Individual lava layers, and their surfaces, remain from the processes that emplaced the layers. Those processes are, in part, recorded on the lava surfaces. Observation of specific lava surfaces in walls around caves can clarify the overall formation mechanism. Surfaces of lava layers in a cave roof can tell certain details of the roof formation.

CHANNEL AND CAVE SYSTEMS OF THE PUHIA PELE FLOW, HUALALAI, HAWAII, AND ITS RELATION TO THE 1801 (HUEHUE) FLOW
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Hualalai, the only active volcano in its terminal alkali basalt phase on Hawaii, erupted last in 1801. The precise size of this flow was, however, unclear. With the exploration of the 10.8 km long Huehue Tube and the analysis of its geologic structure, a long-standing riddle was solved. The flow field formerly attributed to the 1801 eruption is a composite of three individual flows: the contemporary Huehue and Mystery Flows, and the underlying and older Puhia Pele Flow. The Huehue 1801 flow reached the ocean and formed a large lava delta, partly occupied by the Kona airport. The upper part of the flow is, however, covered by the Mystery flow, which originated about 50 m north of the inconspicuous Huehue vent from a low shield. Two caves are attributed to the Mystery Flow, Zoes Puka, 428 m long, and Puka-4-Cave, 292 m long. Both flows interacted. The Mystery Flow consists of shallow flows, grading from fast flowing pahoehoe to sluggish aa within a few hundred meters below the vent, transgressing much of the upper Huehue Tube and partly draining into it. The underlying Puhia Pele Flow was gas richer and, therefore, spatter cones and spatter ramparts formed along the vent fissure at 490 m msl. Below the vents, a large tube and trench system formed, which we now mapped

by DGPS. Several blockages occurred, causing the trench to overflow, forming two side channels. Below 80 m msl, a tube developed feeding a large delta about 10-15 m thick. The tube is only partly accessible because of ponding and collapse.

WAIPOULI AND KAMAKALEPO, TWO SECTIONS OF A LARGE AND OLD MAUNA LOA TUBE ON HAWAII

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Exploration and survey of a large tube near South Point, Hawaii, yielded several interesting results. Two large collapse holes, Lua Nunu O Kamakalepo (Pigeon Hole of the Common People) and Waipouli (Dark Waters), 560 m apart, give access to four individual caves (upslope to downslope): Kamakalepo (305 m long), Kamakalepo Makai (155 m), Waipouli Mauka (125.5 m) and Waipouli (260 m). The tube is up to 13 m high and 23 m wide. The lava is picritic tholeiitic basalt, with abundant large olivine phenocrysts. The tube is one of the oldest accessible in Mauna Loa lavas. In Waipouli, sea level is reached 34 m below ground. The tube is filled by a 200 m long lake, before the ceiling drops below the water level. After 127 m a large block, 12 m wide, 6 m high, and 8 m long, originally floating on the lava river, is jammed into the ceiling. The water is 10 m deep and a halocline is found at its bottom. We found an individual whale backbone in the water. Next year we will conduct a diving expedition to explore the 600 m long section remaining to the seashore. The Kamakalepo sections feature splendid archeological remains (Bonk 1967), among them two large defense walls and over 100 sleeping platforms. Mauka, a very narrow crawl, leads into a 111.5 m long continuation. Charcoal shows that it was already visited by ancient Hawaiians, a remarkable deed. It is geologically unclear why this large tube simply pinches out upslope and between the entrances.

ROCK RING/LAVA TUBE RELATIONSHIPS ON HUALALAI VOLCANO, HAWAII

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Two rock rings are found in a prehistoric flow (2140 years BP) on the northwest rift zone of Hualalai volcano at elevations of 290-270 m msl. These rings have been called collapsed tumuli by Kauahikaua, who hypothesized that they formed over widened parts of a tube. Following collapse, vertical flexure of this material in response to variations in lava flowing within the tube resulted in deposition of a shattered rock ring at the perimeter of the collapse. The Hualalai rock rings do not match these observations. Surveys of the tubes beneath the rings show that the tube traverses the eastern perimeter of the lower ring rather than passing beneath it and a bifurcated tube passes beneath the upper ring with both arms of the branched tube terminating beneath trenches in the floor of the ring. Tube widths beneath the upper ring are up to 9 m while the diameter of the ring is about 100 m. Evidence of a pre-existing, widened tube that led to development of the ring has not been seen in the existing tubes.

KA'ELEKU CAVERNS AND OTHER RECENT SURVEY ACTIVITIES IN LAVA TUBES ON MAUI

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For the past two years, members of the Hawaii Speleological Survey have started surveying caves on the lower slopes of Haleakala on the island of Maui. Along its East Rift Zone is where the last major stage of volcanics on the island ended some 10 ka. It is here that Ka'eleku Caverns was formed in a flow that has been radiocarbon dated at 30 ka.

In January-February 1998 and April 1999, there were several survey trips into Ka'eleku Caverns. This is Maui's largest lava tube and it is currently a cave-for-pay operation run by Maui Cave Adventures near Hana. About 3 km have been explored and mapped to a depth of 220 m. Exceptionally "daggerlike" lavacicle ceilings and "botryoid" formations are in the upper portions of the cave.

This April, exploration and mapping has started on the dry southern slopes of Haleakala. An 8 m deep skylight entrance near the coast gives access to a large lava tube. A couple hundred meters downslope leads to a sump that probably connects to the ocean. Mapping has started upslope in this lava tube, which is quite large and has passages up to 10 m in diameter. We are just beginning to study and understand these older lava tubes on the "Valley Isle" of Maui.

Cave Science News

TAYLOR NAMED NEW LIFE SCIENCES ASSOCIATE EDITOR

Biospeleologist Steve Taylor, Ph.D., has accepted the position of Associate Editor for Life Sciences of the *Journal of Cave and Karst Sciences*. Dr. Taylor assumes duties from David Ashley, who retired his editorship at the first of the year. Taylor is a researcher in the Center for Biodiversity at the Illinois Natural History Survey, a part of the Illinois Department of Natural Resources. His primary professional duties involve assessing aquatic invertebrates in stream habitats throughout Illinois. More information on Taylor is available at his website: <http://www.inhs.uiuc.edu/~sjtaylor/>

JCKS ADVISORY BOARD UPDATE

The *Journal of Cave and Karst Sciences* relies on a nine-person advisory board to help set policy. Board members serve a non-renewable, three-year term. We are pleased to announce the inclusion this year of three people who have served the *Journal* extremely well in the past and will continue to contribute valuable insight and wisdom. David Ashley, PhD, is the retiring Life Science Associate Editor of the *Journal*. Rane Curl, PhD, led a task force in the 1980s that proposed many of the changes we now see in the *Journal*. Andy Flurkey, PhD, served as Editor of the *Journal* from 1986 through 1995.

The *Journal* also thanks the three members stepping off this year, Horton Hobbs, PhD, James Mead, PhD, and James Nepstad. Each contributed to the decision-making process of the *Journal* and helped improved the look and substance of the publication.

UIS DEADLINES APPROACH

If you contemplate attending the International Congress of Speleology in Brasilia, Brazil, in July 2001, remember some important deadlines approaching. Abstracts are due July 31, 2000. Significant pre-registration discounts are available until June 30, 2000. (Registration will continue to be discounted for the rest of the year but will cost \$40 more). Further information is available (in English) at:

http://www.speleobrazil2001.org.br/br2001_i/index.html

INTEGRATED WEB INFORMATION ON KARST

The IAH Karst Commission, IGU Commission for "Sustainable Development & Management of Karst Terrain", and the UIS Commission on Karst Hydrogeology and Speleogenesis have established a single joint Web page. From this page links lead to the particular sites of each body, as well as to a common Info-Board that provides details of meetings, publications, and other news directed to a wide karst commu-

nity. They wish to make it easier for our speleologists to find their information resources while facilitating the further integration of activities and avoiding duplication of efforts.

The joint Karst Page can be accessed by using one of the following URLs:

<http://www.karst-hydrogeology.de/>

http://happy.carrier.kiev.ua/~klim/UIS_KHS/

Submitted by:

John Gunn, Heinz Hoetzel and Alexander Klimchouk

TWO NEW RESEARCH PROJECTS FUNDED BY THE RESEARCH AND ADVISORY COMMITTEE

The projects "The Phantom Menace: Temporal and Spatial Components of Perceived Predation Risk and Their Impact on Cave Cricket Foraging Strategies" by Kurt Helf of the University of Illinois at Chicago, and "The Human Use of Caves in Madagascar" by Joe Hobbs of the University of Missouri at Columbia, were awarded research grants from the Research and Advisory Committee of the NSS. Those interested in applying to NSS research grants should visit RAC's web page at <http://www.macalester.edu/~envirost/nss>.



Members of the NSS Geology and Geography Section and the Biology Section participated on a pre-convention field trip last summer to the Kane Caves in Wyoming. The trip, organized by Louise Hose and Dave Lester, brought together speleologists specifically interested in sulfur-related speleogenesis. Front row: Doug Soroka, Lynn Kleina; Center row: Carol Hill (standing), Peggy Palmer, Louise Hose, Dave Lester, Art Palmer, Bob Richards, Kathy DuChene, Harvey DuChene, Mike Taylor; Back row: Paula Provencio, Victor Polyak. Photo by Alan Hill.

HELP WANTED - JOURNAL OF CAVE AND KARST STUDIES EDITOR

The NSS *Journal of Cave and Karst Studies (JCKS)* Committee is accepting curriculum vitas for a new Editor.

The *JCKS* is published three times annually during April, August and December. It is the refereed, multi-disciplinary publication of the National Speleological Society accepting papers on cave and karst related research. The Editor's responsibilities include maintaining the level of scientific integrity with the seven associate editors (Life Sciences, Conservation, Exploration, Earth Sciences/Journal Index, Social Sciences, Anthropology, Book Reviews), confirmation of publication via the Production Editor and interfacing with the nine member Advisory Board. The *JCKS* Editor submits and is responsible for an annual budget and reports to the Executive Vice President three times per year. *JCKS* annual meetings are generally held during NSS Conventions.

If you are interested in the position, please contact Ray Keeler, NSS Executive VP, rkeeler@pcslink.com.

LETTER TO THE EDITOR:

Just a few comments on the announcement of a newly discovered cave *Orconectes* from Missouri that appeared on p. 150 of the December 1999 *Journal of Cave and Karst Studies*:

1. The latest American cave crayfishes to be described were *Orconectes sheltae* AND *Cambarus veitchorum*, both of which were described in December 1997 by John E. Cooper AND Martha R. Cooper.
2. The statement that *O. sheltae* "males mature after the age of 40, and individuals may live to 100 years" was based on an incorrect interpretation of data from our studies in Shelta Cave, AL. Those data applied only to *Orconectes australis*, not to *O. sheltae*. Very little is known about the age of maturity or the longevity of *O. sheltae*.

None of this, of course, is meant in any way to detract from the striking discovery of a cave *Orconectes* in Missouri. I'll be very interested to ultimately learn what its closest relatives might be.

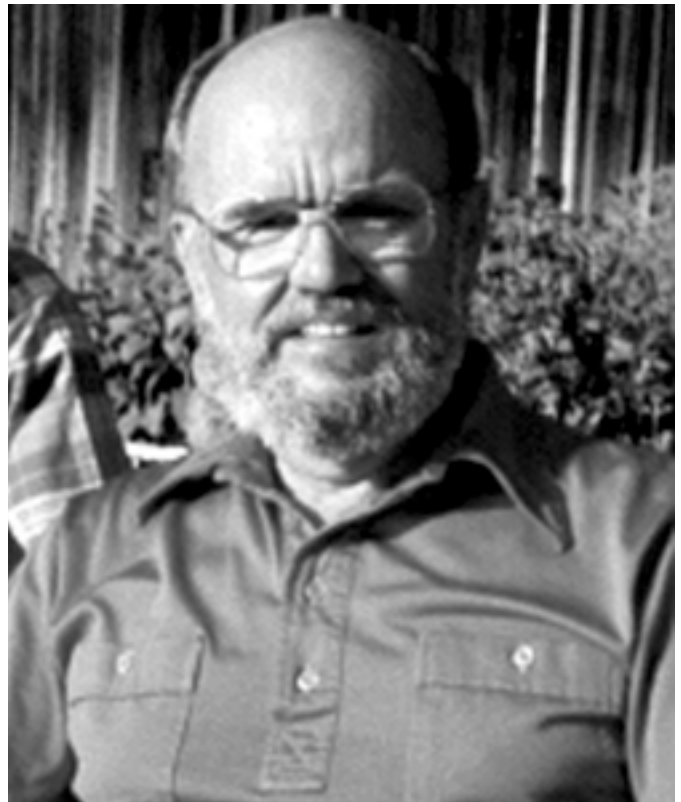
John E. Cooper, Ph.D.
Curator of Crustaceans
North Carolina State Museum of Natural Sciences
Research Lab, 4301 Reedy Creek Road
Raleigh, NC 27607 U.S.A.
John.Cooper@ncmail.net

Will Reeves was raised in the Republic of Panama and started caving in the Maje Mountains near Colombia during the mid-1980s. He moved to the United States in 1989 and attended the Georgia Institute of Technology. After receiving his bachelors degree in Applied Biology, he obtained his MSc degree at Clemson University in 1999. His thesis research involved an ecological study of cave-dwelling invertebrates. Will is currently a PhD student in entomology at Clemson University and maintains an interest in cave fauna and ecology.

Dr. Stein-Erik Lauritzen is Professor of Quaternary Geology and Speleology at the University of Bergen in Norway. He is Norway's leading cave specialist, and for over 25 years he has worked in caves all across Europe, Asia, Australia and North America. He is a leading worker on cave geochronology and paleoclimate, and an advocate for cave conservation. He received the NSS Honorary Member Award in 1997 for his speleological accomplishments.



Dr. John E. Mylroie is Professor of Geology at Mississippi State University, specializing in karst processes. A three-decade member of the NSS, he is the founding President of the Karst Waters Institute, and currently a Board member. His karst interests have taken him far afield, most recently to Guam and Saipan, where he is working on cave development in complex island settings.



Dale Green graduated in 1956 from the University of Utah, B.S.E.E., and later did graduate work in electrical engineering and geophysics. Green was employed for 35 years in industry and by the University of Utah Research Institute, designing geophysical prospecting instruments. An active caver since 1955, he presently devises methods for geophysical prospecting for caves.



Dr. Philip Reeder is the Principal Investigator and Project Director for the Vaca Plateau Geoarchaeology Project. He earned his doctorate at the University of Wisconsin at Milwaukee and is now an Associate Professor in the Department of Geography and Geology at the University of Nebraska at

Omaha. His research interests include soils geography, hydrology, water resources, geoarchaeology, GIS, karst studies, speleology, Latin America, and Southeast Asia.



Jim Webster is a PhD Candidate in geography at the University of Georgia. He holds a B.S. in geology and a M.S. in geography from Western Kentucky University. He has served as a hydrologist with the Center for Cave and Karst Studies and as

an Environmental Scientist with U.S. Environmental Protection Agency. Jim's academic and research interests are geomorphology, karst hydrogeology, late Quaternary climate change, geoarchaeology, and Latin America.



Pierre Robert Colas, known simply as "Clint" to members of the research group, is the Project Illustrator, and Epigrapher. He is a veteran of the 1997, 1998 and 1999 expeditions to the Vaca Plateau. Additionally, Robert served as an Assistant Illustrator and Project Epigrapher in the 1997 Western Belize Regional Cave Project (under Dr. Jaime Awe,

University of New Hampshire), and as Field Supervisor, Assistant Illustrator, and Epigrapher with the 1998 Western Belize Regional Cave Project. Robert's interests lie in archaeology, ceramic analysis, and the decipherment of hieroglyphs found on ceramics found in caves. He received his masters degree in anthropology from the University of Hamburg (Germany), and is currently a doctoral student in archaeology at the University of Bonn.



Boris Sket is professor of zoology and speleobiology at the University of Ljubljana, Slovenia. His main speleological research is on the biogeography and origin of cave faunas. He has also been the rector of the University and president of the Speleological Association of Slovenia.

David Culver received his undergraduate training at Grinnell College and his graduate training at Yale University. Thus, he had the great fortune to study under two of the biospeleological masters: Kenneth Christiansen and Thomas Poulson. He is President of the Karst Waters Institute and an Honorary Life Member of the NSS. His current research interests focus of biogeography of cave faunas, conservation biology of cave faunas, and groundwater ecosystem services. Culver is Professor of Biology at American University.

Next Issue: Guadalupe Mountains

Introduction to the Guadalupe Mountains Symposium

Harvey R. DuChene and Carol A. Hill

Overview of Geologic History of Cave Development in the Guadalupe Mountains, New Mexico and West Texas

Carol A. Hill

History of Sulfuric Acid Theory of Speleogenesis in the Guadalupe Mountains, New Mexico and West Texas

David H. Jagnow, Carol A. Hill, Donald G. Davis, Harvey R. DuChene, Kimberley I. Cunningham, Diana E. Northup, and J. Michael Queen

Summary of the Timing of Sulfuric Acid Speleogenesis for the Guadalupe Caves Based on Ages of Alunite

Victor J. Polyak and Paula P. Provencio

Post-Speleogenetic Erosion and its Effect on Cave Development in the Guadalupe Mountains, New Mexico and West Texas

Harvey R. DuChene and Ruben Martinez

Hydrochemical Interpretation of Cave Patterns in the Guadalupe Mountains, New Mexico

Arthur N. Palmer and Margaret V. Palmer

Bedrock Features of Lechuguilla Cave, Guadalupe Mountains, New Mexico

Harvey R. DuChene

Extraordinary Features of Lechuguilla Cave, Guadalupe Mountains, New Mexico

Donald G. Davis

Clays in Caves of the Guadalupe Mountains, New Mexico

Victor J. Polyak and Necip Güven

Geochemistry of Carlsbad Cavern Pool Waters, Guadalupe Mountains, New Mexico

Jeffrey R. Forbes

Lechuguilla Cave Pool Chemistry, 1986-1999

H. Jake Turin and Mitch A. Plummer

Behind Every Good Speleothem There's a Microbe: Geomicrobiological Interactions in Lechuguilla Cave, New Mexico

Diana E. Northup, Clifford Dahm, Leslie A. Melim, Michael N. Spilde, Laura J. Crosse, Kathy H. Lavoie, Lawrence M. Mallory, Penelope J. Boston, Kimberley I. Cunningham, and Susan M. Barns

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