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Front cover: Giant pool fingers from Hidden Cave, New Mexico, see Melim et al, this volume. Photo by K. Ingham.

EDITORIAL

Indexing the Journal of Cave and Karst Studies: The beginning, the ending, and the digital era

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In 1984 I was a new graduate student in geology at Penn State. I had been a caver and an NSS member for years, and I wanted to study karst. The only cave geology course I had taken was a 1-week event taught by Art Palmer at Mammoth Cave. I knew that I had to familiarize myself with the literature in order to do my thesis, and that the *NSS Bulletin* was the major outlet for cave and karst related papers (Table 1). So, in order to "get up to speed" I undertook to read every issue of the *NSS Bulletin*, from the personal library of my advisor, Will White, starting with volume 1 (1940). When I got through volume 3, I realized that, although I was absorbing a lot of the material, it would be difficult for me to relocate specific information again, because there was no comprehensive index available[1]. So, I decided to create an index as I read. This was the beginning of a 25-year effort to catalog the literature of the NSS for use by the scientific community.

Keith Wheeland from the Nittany Grotto told me about a computer program called KWIC (Key Word In Context), and this seemed appropriate to the task. Sitting in front of a terminal for an IBM 4341 mainframe computer running VM/CMS I would read through the journals, and enter keywords and control characters in a prescribed format in a text file. Cave names and states, of course, were important. Other terms included organism names, scientific disciplines covered, etc. I indexed volumes 1 through 45 of the *Bulletin*, along with the four *Occasional Papers of the NSS*. The effort took about 2,000 hours, and was published in 1986 by the NSS.

With the encouragement of Editor Andrew Flurkey I regularly compiled an annual index that was included in the final issue for each volume starting in 1987. The Bulletin went through name changes, and is currently the *Journal of Cave and Karst Studies* (Table 1). In 1988 I began using a custom-designed entry program called SDI-Soft, written by Keith Wheeland, which later became his comprehensive software package KWIX. A 5-year compilation index (volumes 46–50) was issued by the NSS in 1991. In 2003 all of the data files were used by Paul Stevens to create a searchable online database for the NSS website. With Paul's untimely death, and reorganization of the NSS webpages, this database appears to no longer be available.

Two things have happened in recent years that reduce the importance of an annual index. First, in 2002 the *Journal of Cave and Karst Studies* (the Journal) became included in the Science Citations Index. This massive database is an online resource that indexes and abstracts over 3,700 prominent journals. Inclusion of the Journal in this database makes the contents available to the many institutions that subscribe to this service. Secondarily, the rise of comprehensive search engines such as Google, along with an increased presence of the Journal on the World Wide Web, places the full-text contents of the journal at the fingertips of all karst scientists.

These changes mean that the annual index no longer fills a critical role. So, with the close of volume 70 in 2008, I will discontinue this effort. Through the years I indexed over 8,000 pages of scientific articles (Figure 1), represent-

[1] There were 2 semi-comprehensive indexes available at the time this project began. Ralph Stone prepared the first index, which covered volumes 1 through 6. The second index was by G.F. Jackson and included volumes 1 through 20.

Table 1. Names, volumes, and dates for the scientific journal of the National Speleological Society.

Scientific Journal Name	Volumes and Dates
Bulletin of the Speleological Society of the District of Columbia	Vol. 1 (1940)
Bulletin of the National Speleological Society	Vol. 2 (1941) through Vol. 13 (1951)
The American Caver — Bulletin of the National Speleological Society	Vol. 14 (1952) through Vol. 16 (1954)
Bulletin of the National Speleological Society	Vol. 17 (1955) through Vol. 35 (1973)
The NSS Bulletin — Quarterly Journal of the National Speleological Society	Vol. 36 (1974) through Vol. 45 no. 2 (1983)
The NSS Bulletin — A Quarterly Journal of Caves and Karst	Vol. 45 no. 3 (1983) through Vol. 45 no. 4 (1983)
The NSS Bulletin — Journal of Caves and Karst Studies	Vol. 46 (1984) through Vol. 57 (1995)
Journal of Cave and Karst Studies - The National Speleological Society Bulletin	Vol. 58 (1996) through Vol. 59 (1997)
Journal of Cave and Karst Studies	Vol. 60 (1998) through Vol. 70 (present)

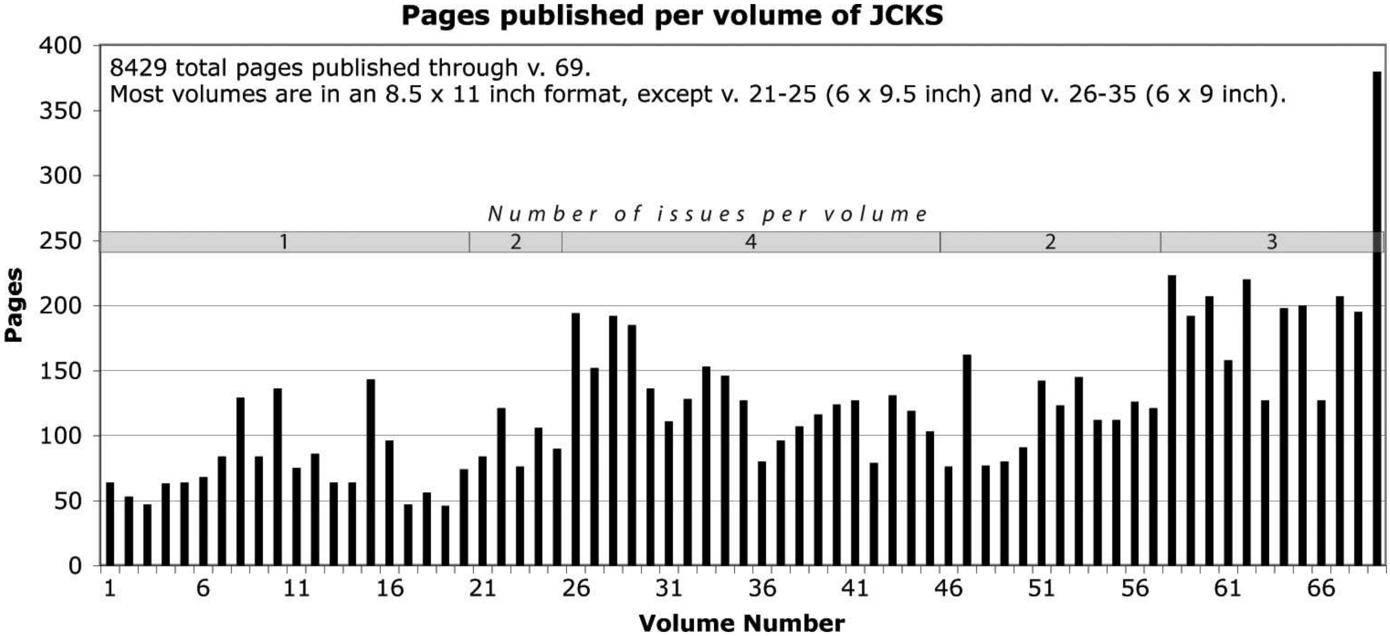

Figure 1. Histogram showing number of pages published per volume of the Journal for the last 69 years, along with other data on the Journal.

ing 65 cm (26 inches) of journals on the shelf. The work was only possible with the collaboration of the NSS and journal editors Andrew Flurkey, Louise Hose, and Malcolm Field. In addition, Will White, Keith Wheeland, Keena Tomko, Elaine Butcher, Kathy Sasowsky, Claire Sasowsky, and Megan Curry assisted in various ways throughout the years — their help is gratefully acknowledged.

L.A. Melim, D.E. Northup, M.N. Spilde, B. Jones, P.J. Boston, and R.J. Bixby – Reticulated filaments in cave pool speleothems: microbe or mineral? *Journal of Cave and Karst Studies,* v. 70, no. 3, p. 135–141.

RETICULATED FILAMENTS IN CAVE POOL SPELEOTHEMS: MICROBE OR MINERAL?

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Abstract: We report on a reticulated filament found in modern and fossil cave samples that cannot be correlated to any known microorganism or organism part. These filaments were found in moist environments in five limestone caves (four in New Mexico, U.S.A., one in Tabasco, Mexico), and a basalt lava tube in the Cape Verde Islands. Most of the filaments are fossils revealed by etching into calcitic speleothems but two are on the surface of samples. One hundred eighty individual reticulated filaments were imaged from 16 different samples using scanning electron microscopy. The filaments are up to 75 µm (average 12 µm) long, but all filaments appear broken. These reticulated filaments are elongate, commonly hollow, tubes with an open mesh reminiscent of a fish net or honeycomb. Two different cross-hatched patterns occur; 77% of filaments have hexagonal chambers aligned parallel to the filament and 23% of filaments have diamond-shaped chambers that spiral along the filament. The filaments range from 300 nm to 1000 nm in diameter, but there are two somewhat overlapping populations; one 200–400 nm in size and the other 500–700 nm. Individual chambers range from 40 to 100 nm with 30–40 nm thick walls. Similar morphologies to the cave reticulated filaments do exist in the microbial world, but all can be ruled out due to the absence of silica (diatoms), different size (diatoms, S-layers), or the presence of iron (*Leptothrix* sp.). Given the wide range of locations that contain reticulated filaments, we speculate that they are a significant cave microorganism albeit with unknown living habits.

Introduction

Microbes are well known from cave systems (Danielli and Edington, 1983; Northup and Lavoie, 2001; Barton et al., 2001; Barton and Northup, 2007). Scanning electron microscopy of the surface of speleothems commonly reveals a variety of spheroid or filamentous features, interpreted as either microorganisms or biofilms (mucous/EPS) (Jones and Motyka, 1987; Jones and Kahle, 1986; Jones, 2001; Vlasceanu et al., 2000; Baskar et al., 2006). Etching calcitic samples with weak acid sometimes reveals fossil microorganisms and/or biofilms that were entombed in the calcite (Melim et al., 2001; Boston et al., 2001). We report herein on an unusual reticulated filament found in modern and fossil cave samples that cannot be correlated to any known microorganism or organism part. Since all of our samples are from caves, we cannot comment on their possible wider distribution. We document here the morphology, distribution and context of these reticulated filaments.

Field Locations

The samples for this study (Table 1) came from caves in the Guadalupe Mountains of southeastern New Mexico, from a lava tube in the Cape Verde Islands, and a cave in Tabasco, Mexico (Fig. 1). All locations are from the aphotic zone of the cave; all but one are from speleothems that formed underwater (pool fingers) or in wet areas (cave pearls).

The Guadalupe Mountains include over 300 known caves (DuChene and Martinez, 2000) administered variously by Carlsbad Caverns National Park, the National Forest Service, and the Bureau of Land Management. Hidden Cave and Cottonwood Cave are located in the Guadalupe Ranger District of the Lincoln National Forest in southeastern New Mexico (Fig. 2). The samples from Hidden Cave are giant pool fingers (Fig. 3a), pendant features that form underwater (Davis et al., 1990; Melim et al., 2001). In Cottonwood Cave, the samples are thin pool fingers with abundant u-loops; curved connections between fingers (Fig. 3b; Davis et al., 1990). Both areas are currently dry but the features formed when the pools were full (unpublished data; Hill, 1987 Melim et al., 2001). Endless Cave is located on Bureau of Land Management property in the McKittrick Hill area of the Guadalupe Mountains (Fig. 2). The sample is a warclub (Hill and Forti, 1997) from the Warclub Room, a currently dry room. A warclub forms when the end of a stalactite is

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Table 1. List of locations containing reticulated filaments.

Cave	Location	Speleothem	Collector	Number of Imaged Filaments
Hidden Cave	Guadalupe Mountains, New Mexico, USA	Pool fingers	Authors	92
Cottonwood Cave	Guadalupe Mountains, New Mexico, USA	Pool fingers and U-loops	Authors	65
Endless Cave	Guadalupe Mountains, New Mexico, USA	Warclub	Authors	9
Carlsbad Cavern	Guadalupe Mountains, New Mexico, USA	Webulite	Authors	5
Cueva de Las Canicas	Tabasco, Mexico	Cave pearls	Arturo C. Conde	2
Fogo Island, Basalt Lava Tube	Cape Verde Islands	Coating on basalt lava flow	Peter Roe	11

submerged by a rising pool level and is then coated in pool spar. Our sample is a surface piece of this pool spar. Two more samples came from Carlsbad Cavern in Carlsbad Caverns National Park (Fig. 2). One sample is a thin pool finger from an active pool, whereas the other is webulite from a dry pool in Lower Cave, a portion of the cave generally closed to the public. Webulite is a thin draping calcite web that connects adjacent pool fingers (Davis et al., 1990, Queen and Melim, 2006).

The Cape Verde sample is from a small, unnamed lava tube on Fogo Island. The sample came from a purple and white crust on the wall of the basalt lava tube (Peter Roe, personal communication). The Mexican sample is a cave pearl collected from Cueva de Las Canicas, a cave in Tabasco famous for containing millions of cave pearls (Pisarowicz and Snow, 2003).

Methods

All samples were collected under permit from the appropriate agency (U.S. National Park Service, U.S. Forest Service, and Bureau of Land Management) or landowner permission (Sr. Arturo Cano, Cueva de Las Cañicas) and were selected from those broken by past visitors to avoid disturbance of intact speleothems. Thin sections were cut from all samples from Hidden Cave, Cottonwood Cave, and Carlsbad Cavern and examined for possible microbial fabrics in a standard petrographic microscope. The cave pearl was cut in half, ground flat, and then etched. For SEM analysis, samples were either etched with 5% hydrochloric acid for 10–15 seconds before rinsing in distilled water, drying and mounting on SEM stubs (Hidden Cave, Cottonwood Cave, Carlsbad Cavern

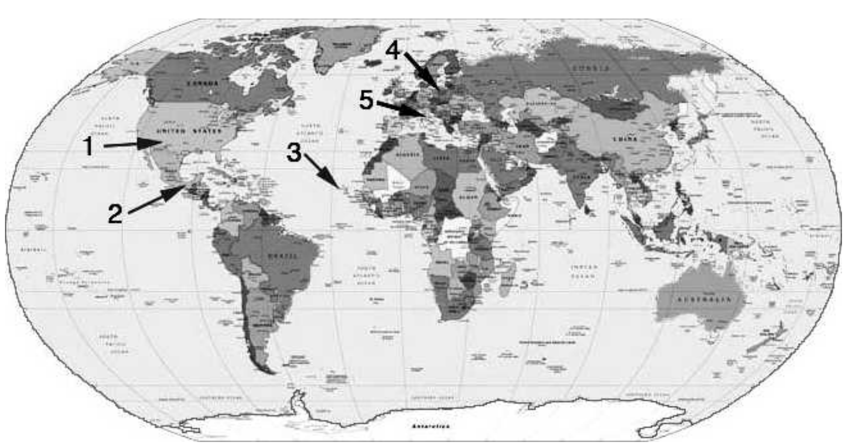

Figure 1. World map of locations where reticulated filaments have been found by this study: 1. Guadalupe Mountains, New Mexico, U.S., 2. Tabasco, Mexico, 3. Cape Verde Islands. Also shown are locations for two examples found by other workers: 4. Poland, Gradzinski (2003); 5. Frasassi Caves, Italy, Macalady (pers. comm.).

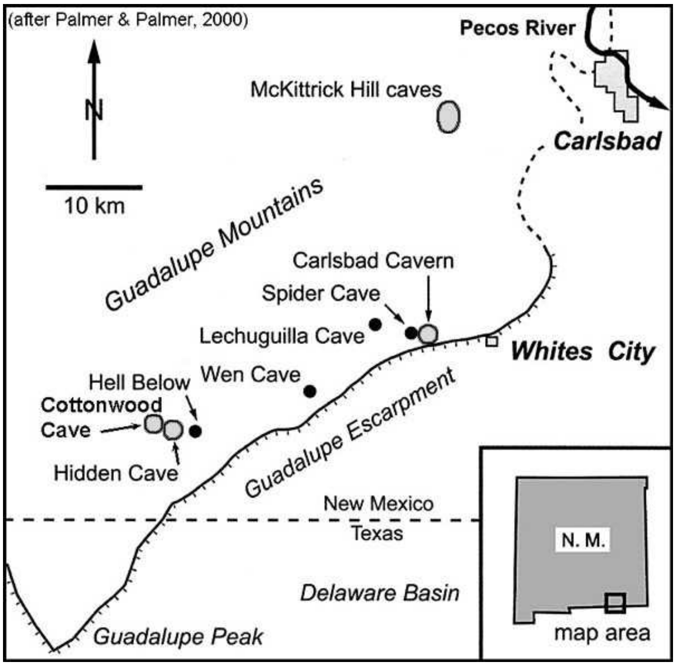

Figure 2. Locations of major caves in the Guadalupe Mountains. We have found reticulated filaments in samples from Hidden Cave, Carlsbad Cavern, Cottonwood Cave, and Endless Cave. (Map, after Palmer and Palmer, 2000.)

and Cueva de Las Canicas) or mounted without etching (Cape Verde lava tube and Endless Cave).

All samples were examined with either a JEOL 5800LV scanning electron microscope at the University of New Mexico (UNM) or a JSM 6301FXV field emission scanning electron microscope at the University of Alberta. The UNM samples were coated with approximately 200 angstroms of gold-palladium alloy in an evaporative coater. The thin film of gold-palladium provides a conductive layer that is relatively free of artifacts and allows light element x-rays of carbon to pass with only moderate attenuation. The University of Alberta samples were coated in gold alone, which resulted in minor artifacts at higher magnification. The UNM SEM is equipped with an Oxford Isis 300 Energy Dispersive X-ray (EDX) analyzer. This modern EDX system utilizes a thin polymer-film window, which allows the analysis of low-energy x-rays of light elements such as boron and carbon ($Z > 5$). The SEM was operated at 15 kV accelerating voltage, the beam current was 10 picoamps as measured in a Faraday cup. This gives a beam diameter of less than 50 nm. However, the beam samples a greater volume. With these operating conditions, the EDX provides a qualitative estimate of elements present in the upper 2–3 µm of a calcitic sample.

Three samples were analyzed for total organic carbon using a Carlo Erba elemental analyzer from samples dissolved in 6 N hydrochloric acid to remove carbonate.

Occurrence of Reticulated Filaments

Smooth, commonly hollow, filaments are locally abundant in our cave samples and have been interpreted as fossil microbes (Melim et al., 2001; Boston et al., 2001). We have also found a less common reticulated filament that is similar in size to the smooth filaments but has a reticulated form (Fig. 4). Over 180 individual examples of these unusual reticulated filaments were found in 16 different cave samples (out of 22 samples examined in this study). Most (87%) of these filaments are in pool fingers from Hidden and Cottonwood Caves (Figs. 2 and 3), but this at least partly reflects the extended time we have spent with these samples. In addition, Gradzinski (2000, 2003) imaged an example from Polish cave pearls and J. Macalady has found them in the Frasassi caves in Italy (Macalady, personal communication).

Filaments are preferentially found in dense micritic calcite, but can also occur in clear spar (Melim et al., 2001). All but two of our samples come from cave pool biothems,

Figure 3. (a) Giant pool fingers in Hidden Cave, NM. (b) Small pool fingers coating an earlier stalactite in Cottonwood Cave, NM (Spanish moss of Hill, 1987).

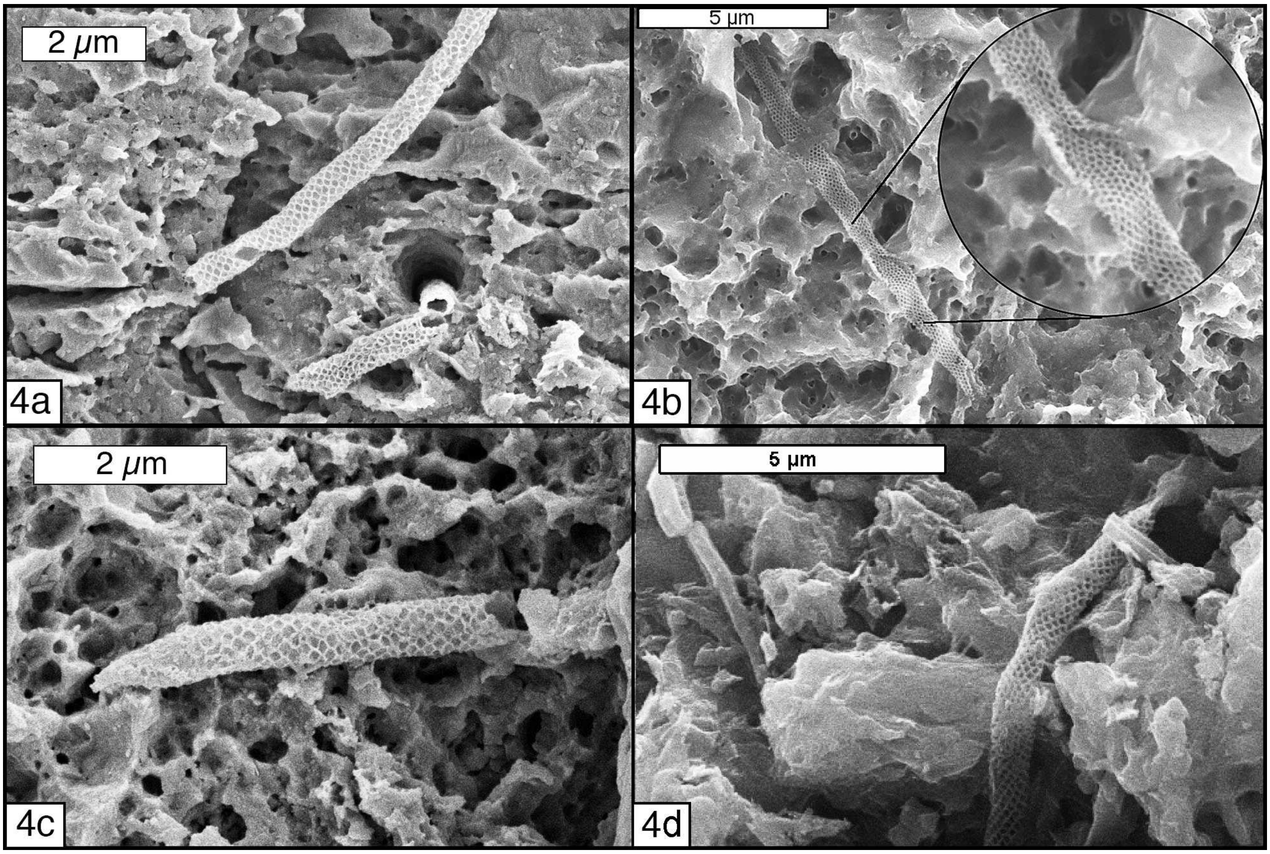

Figure 4. Scanning electron micrographs of reticulated filaments. (a) Hollow reticulated filament with diamond-shaped chambers that form a spiral. Hidden Cave pool finger, etched sample. (b) Reticulated filament that is hollow and torn open, with chambers that align along length of filament. Hidden Cave pool finger, etched sample. (c) Reticulated filament that is solid with diamond-shaped chambers that spiral. Hidden Cave pool finger, etched sample. (d) Reticulated filament from recently living sample (not etched). Note similarity to etched samples, particularly (a). Cape Verde lava tube.

features with external morphology suggestive of microbial involvement (Cunningham et al., 1995; Queen and Melim, 2006). This, however, could be an artifact of our study, as we have not closely examined many other cave pool precipitates, other speleothems or similar features in non-cave environments. Other speleothems or other environments may contain similar filaments, but etching of samples and meticulous, very high magnification SEM work is required to find them.

Reticulated filaments have an open cross-hatched pattern reminiscent of a fish net or a honeycomb (Fig. 4). Preservation of filaments varies substantially between individuals. The best preserved are hollow tubes that are partly collapsed (Fig. 4a). Others are torn open (Fig. 4b) or completely filled with calcite (Fig. 4c). Recently living filaments are hollow tubes (Fig. 4d). The filaments are up to 75 μm (average 12 μm) long. The measured length, however, is largely an artifact of preservation as virtually all of the specimens are torn, broken or have their ends buried in the matrix. Filament diameter is 300–1000 nm (average 590 nm) but this overall range encompasses two overlapping populations; one with an average diameter of 200–400 nm and the other with an average diameter of 500–700 nm. Both populations are found in the same samples (Fig. 5).

The filaments are characterized by two different styles of cross-hatched patterns, both with individual chambers 40 to 100 nm long and walls between chambers that are 30–40 nm wide. The larger diameter filaments typically have larger chambers, but not always. The more common form (77% of imaged filaments) has approximately hexagonal chambers that align in rows parallel to the length of the filament (Figs. 4b, 5). The less common form (23%) has more diamond-shaped chambers that spiral along the filament (Fig. 4c). The cross-hatch pattern does not correlate to filament size.

Composition of Filaments

In etched samples, the reticulated filaments occur within the sample and are partially revealed by the removal of the surrounding calcite (Fig. 4). Preliminary data show 1–2% organic carbon in the sample containing the most filaments (from Cottonwood Cave). EDX analysis of individual

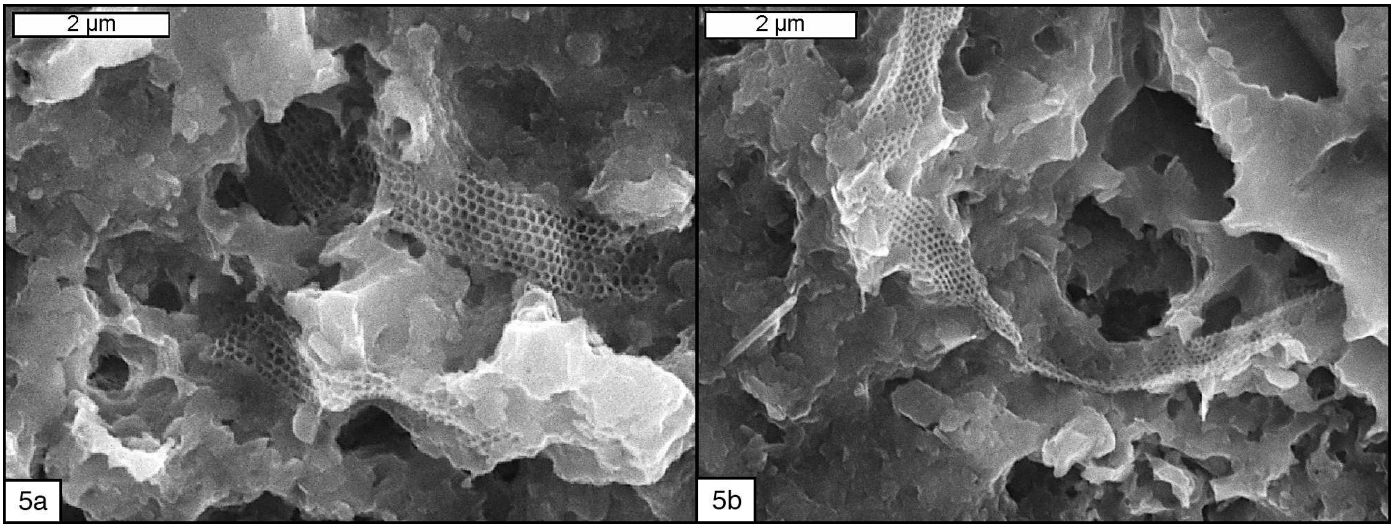

Figure 5. Scanning electron micrographs showing the two different sizes of reticulated filaments with parallel hexagonal chambers. Note the scale is identical in these images. (a) Larger filament. (b) Smaller filament. Hidden Cave pool finger.

filaments commonly shows calcium, oxygen, and more carbon than the surrounding calcite (Fig. 6). Since the depth of analysis (2–3 μm) is greater than the thickness of the filament, the results are a mixture of the surrounding calcite and the filament. We speculate that the extra carbon found is either a coating on the filament, protecting it from the acid etch (Melim et al., 2001), or the filaments are simply composed of a carbon-rich (hence organic) material and the etch has removed the surrounding calcite. Since the filaments from surface samples (not etched, Fig. 4d) and the embedded samples (etched out, Fig. 4a–c) have identical textures, it seems more likely that the filaments are preserved organic material and not carbon-coated calcitized filaments.

Possible origins

The morphology and high carbon content of these filaments suggests that they are biogenic. An extensive survey of known microorganisms and associated structures, and consultation with colleagues who work with a number of different microbial forms, however, shows nothing similar to the reticulated filaments in the same size range. Although the general filament shape is a common morphology, reticulated chambers are not. We are uncertain as to the origin of the reticulated chambers, as known microbes lack any structure of comparable size. Larger chambers are common; for example, some diatoms (Bacillariophyceae) have similar complex structures in their cell walls (areolae), but they are far larger in scale and very different in aspect ratio. Filamentous diatoms such as those in the genus *Aulacoseira* have similar cell morphology with regular patterns of pores termed areolae, but these filaments are significantly larger in diameter (3–30 μm

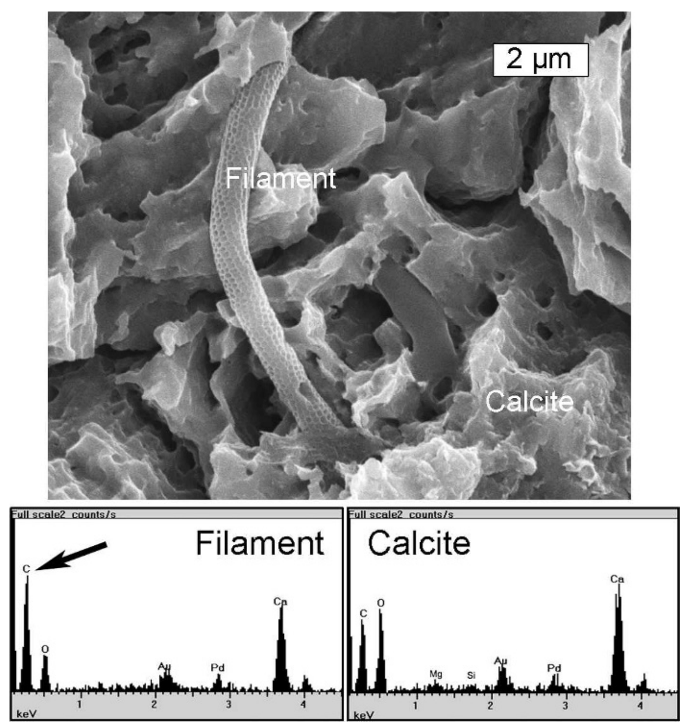

Figure 6. Scanning electron micrograph of reticulated filament and two EDX analyses; one centered on the filament and one centered on the calcite next to the filament. The analyses extend 2–3 μm into the sample so both plots show calcite (Ca + C + O), trace amounts of clays (Mg + Si + O) and the gold-palladium coating medium (Au + Pd). Note that the filament contains more carbon than the calcite sample indicating that the filament itself is carbon-rich.

diameter, 2.5–24 µm mantle height; Krammer and Lange-Bertalot, 1991). In general, diatoms in valve view range from eight or ten microns to a millimeter in length and are commonly 10–20 microns in diameter. At the extreme size ranges, diatoms can be as small as one micron in diameter (rarely) and as wide as 30–40 microns in diameter (Round et al., 2000). Some diatoms, including *Aulacoseira*, produce resting cells of similar sizes to the normal cells (Round et al., 2000). Thus, there is only the most marginal overlap in size with our observed structures. More importantly, all diatoms contain biogenic silica as a major component of their cell walls (Round et al., 2000). The reticulated filaments found in the cave samples completely lack silica.

Fungi, especially the filamentous, microscopic forms, were eliminated from consideration due to their larger size, generally two microns in diameter or larger. Thus, while they are often tens of microns in length, their diameter is insufficiently small to qualify as a bona fide candidate. The fungal morphologies we examined, or with which we are experienced, lack this form of reticulated patterning.

Actinomycetes, a filamentous group of bacteria, commonly occur in caves, are tens of microns in length at times and have similar diameters, but all known strains that we have investigated in the literature lack this kind of reticulated patterning. The authors have examined many cultures and environmental samples of actinomycetes using scanning electron microscopy and have never observed this morphology nor seen it in the literature

There is the possibility that the reticulate structure is a form of S-layer, a symmetrical arrangement of hexagonal protein units in the outer cell surface layer that has been observed in some Gram-negative bacteria (e.g. Schultze-Lam et al., 1992) and in *Archaea* (Messner et al., 1986). Interestingly, S-layers have a cross-hatched pattern when imaged using TEM (Phoenix et al., 2005) that is akin to the chamber patterns found in the reticulated filaments. The hexagonal units of the S-layer, however, are generally <50 nm wide (Messner et al., 1986; Schultze-Lam et al., 1992; Phoenix et al., 2005) and are therefore smaller than 70–100 nm long hexagonal units found in the reticulated filament. In the reticulate filaments, the center-to-center distance between adjacent chambers is generally two to three times larger than found in S-layer units. In addition, images of S-layers give the impression of a solid lattice layer rather than the open chambers of the reticulated filaments that we have observed in our cave samples.

In reviewing bacteria described in *Bergey's Manual of Systematic Bacteriology* (Holt, 1984–1989; Garrity, 2001–), only three bacteria were found with a similar morphology. The first of these is *Nitrosomonas*, which is pictured with "an additional cell wall layer" with units that are <20 nm (see Holt 1984–1989, p. 1824). The units in this extra cell wall layer in *Nitrosomonas* are three to four times smaller than the hexagonal units found in the cave reticulated filaments and also give the impression of a solid layer. *Nitrosomonas*' additional layer may represent an S-layer, as it is similar in morphology. The image of *Prosthecomicrobium polyspheroidum* (Garrity, 2001–) depicts cells with numerous short prosthecae that give the appearance of a corn cob, superficially resembling the reticulate structures, but the comparison breaks down on closer inspection. The third possibility is an image of *Helicobacter bilis* (Garrity, 2001–) with "tightly wound periplasmic fibers and multiple sheathed flagella." Although this organism is similar in diameter, it is only three microns in length.

In a study of putative *Leptothrix* sp. from a pool enriched in iron oxides in Carlsbad Cavern, Caldwell and Caldwell (1980) described filaments with "a hexagonal matrix over the surface of the cells." These hexagonal subunits, 0.1 microns in diameter, are more irregular in shape and are composed of iron, thus ruling out *Leptothrix* as a candidate for our filaments.

Thus, similar morphologies to the cave reticulated filaments do exist in the microbial world, but all can be ruled out due to the presence of silica (diatoms), size (diatoms, S-layers), or the presence of iron (*Leptothrix* sp.), leading us to conclude that this is a heretofore unreported morphology probably bacterial in nature.

CONCLUSIONS

Reticulated filaments are common in speleothems from moist or wet environments. These reticulated filaments are tubes of cross-hatched mesh with either hexagonal or diamond-shaped chambers. They are up to 75 µm in length (avg. 12 µm) but this size range is partly an artifact of preservation. Two overlapping populations occur, one 200–400 nm in diameter and the other 500–700 nm. EDX indicates that the filaments are composed of predominantly carbon, hence they are not mineral. We speculate that reticulated filaments are from an unknown, but possibly common, subsurface type of microorganism or group of microorganisms that prefer moist cave environments. We continue to look for more examples, particularly living examples, in the hope of culturing and/or obtaining DNA in order to more precisely identify their phylogenetic position and to understand their role in the cave ecosystem.

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References

Barton, H.A., Spear, J.R., and Pace, N.R., 2001, Microbial life in the underworld: Biogenicity in secondary mineral formations: Geomicrobiology Journal, v. 18, p. 359–368.

Barton, H.A., and Northup, D.E., 2007, Geomicrobiology in cave environments: Past, current, and future: Journal of Cave and Karst Studies, v. 69, p. 163–178.

Baskar, S., Baskar, R., Mauclait, L., and McKenzie, J.A., 2006, Microbially induced calcite precipitation in culture experiments: Possible origin for stalactites in Sahastradhara Caves, Dehradun, India: Current Science, v. 90, p. 58–64.

Boston, P.J., Spilde, M.N., Northup, D.E., Melim, L.A., Soroka, D.A., Kleina, L.G., Lavoie, K.H., Hose, L.D., Mallory, L.M., Dahm, C.N., Crossey, L.J., and Scheble, R.T., 2001, Cave biosignature suites: Microbes, minerals and Mars: Astrobiology Journal, v. 1, p. 25–55.

Caldwell, D.E., and Caldwell, S.J., 1980, Fine structure of *in situ* microbial iron deposits: Geomicrobiology Journal, v. 2, p. 39–53.

Cunningham, K.I., Northup, D.E., Pollastro, R.M., Wright, W.G., and LaRock, E.J., 1995, Bacteria, fungi and biokarst in Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico, Environmental Geology, v. 25, p. 2–8.

Danielli, H.M.C., and Edington, M.A., 1983, Bacterial calcification in limestone caves: Geomicrobiology Journal, v. 3, p. 1–15.

Davis, D.G., Palmer, M.V., and Palmer, A.N., 1990, Extraordinary subaqueous speleothems in Lechuguilla Cave, New Mexico, National Speleological Society Bulletin, v. 52, p. 70–86.

DuChene, H.R., and Martinez, R., 2000, Post-speleogenetic erosion and its effects on caves in the Guadalupe Mountains: National Speleological Society Bulletin, v. 62, p. 75–79.

Garrity, G.M., 2001–, Bergey's Manual of Systematic Bacteriology, New York, Springer, 3521 p.

Gradzinski, M., 2000, Cave pisoids — genetic and environmental conditions of their origin [Ph.D. thesis]: Institute of Geological Sciences, Jagiellonian University, 90 p.

Gradzinski, M., 2003, Role of micro-organisms in cave pearls formation: Journal of Conference Abstracts, v. 4, 924 p.

Hill, C.A., 1987, Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas: Socorro, New Mexico, New Mexico Bureau of Mines and Mineral Resources, 150 p.

Hill, C.A., and Forti, P., 1997, Cave Minerals of the World, 2nd Edition, Huntsville, Ala., National Speleological Society, 463 p.

Holt, J.G., 1984–1989, Bergey's Manual of Systematic Bacteriology, Baltimore, Williams and Wilkins, 2648 p.

Jones, B., 2001, Microbial activity in caves—A geological perspective, Geomicrobiology Journal, v. 18, p. 345–358.

Jones, B., and Kahle, C.F., 1986, Dendritic calcite crystals formed by calcification of algal filaments in a vadose environment: Journal of Sedimentary Petrology, v. 56, no. 2, p. 217–227.

Jones, B., and Motyka, A., 1987, Biogenic structures and micrite in stalactites from Grand Cayman Island, British West Indies: Canadian Journal of Earth Science, v. 24, no. 7, p. 1402–1411.

Krammer, K., and Lange-Bertalot, H., 1991, Bacillariophyceae 3. Teil: Centrales, Fragilariaceae, Eunotiaceae, *in* Ettl, H., Gerloff, J., Heynig, H., and Mollenhauer, D., eds., Süsswasserflora von Mitteleuropas, 2/3, Jena, Gustav Fischer Verlag, p. 1–576.

Melim, L.A., Shinglman, K.M., Boston, P.J., Northup, D.E., Spilde, M.N., and Queen, J.M., 2001, Evidence of microbial involvement in pool finger precipitation, Hidden Cave, New Mexico: Geomicrobiology Journal, v. 18, p. 311–330.

Messner, P., Pum, D., Sára, M., Stetter, K.O., and Sleytr, U.B., 1986, Ultrastructure of the cell envelope of the archaebacteria *Thermoproteus tenax* and *Thermoproteus neutrophilus:* Journal of Bacteriology, v. 166, p. 1046–1054.

Northup, D.E., and Lavoie, K., 2001, Geomicrobiology of Caves: A Review. Geomicrobiology Journal, v. 18, no. 3, p. 199–222.

Phoenix, V.R., Renaut, R.W., Jones, B., and Ferris, F.G., 2005, Bacterial S-layer preservation and rare arsenic-antimony-sulphide bioimmobilization in siliceous sediments from Champagne Pool hot spring, Waiotapu, New Zealand: Journal of the Geological Society, London, v. 162, p. 323–331.

Pisarowicz, J.A., and Snow, A., 2003, Millions of cave pearls and other caving adventures in Tabasco, Mexico: Florida Scientist, v. 2003, 35 p.

Queen, J.M., and Melim, L.A., 2006, Biothems: Biologically influenced speleothems in caves of the Guadalupe Mountains, New Mexico, USA, *in* Raatz, W., Land, L., and Boston, P., eds., Caves and Karst of Southeastern New Mexico, New Mexico Geological Society Guidebook, 57th Field Conference, p. 167–174.

Round, F.E., Crawford, R.M., and Mann, D.G., 2000, The Diatoms: Biology and Morphology of the Genera, Cambridge, U.K., Cambridge University Press, 747 p.

Schultze-Lam, S., Harauz, G., and Beveridge, T.J., 1992, Participation of a cyanobacterial S layer in fine-grain mineral formation: Journal of Bacteriology, v. 174, p. 7971–7981.

Vlasceanu, L., Sarbu, S.M., Engel, A.S., and Kinkle, B.K., 2000, Acidic cave-wall biofilms located in the Frasassi Gorge, Italy: Geomicrobiology Journal, v. 17, p. 125–139.

J. Kadlec, M. Chadima, L. Lisá, H. Hercman, A. Osintsev, and H. Oberhänsli – Clastic cave deposits in Botovskaya Cave (Eastern Siberia, Russian Federation). *Journal of Cave and Karst Studies,* v. 70, no. 3, p. 142–155.

CLASTIC CAVE DEPOSITS IN BOTOVSKAYA CAVE (EASTERN SIBERIA, RUSSIAN FEDERATION)

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Abstract: Botovskaya Cave is a typical example of a two-dimensional maze with a total length of explored passages exceeding 60 km, which represents the longest limestone cave system in the Russian Federation. The clastic cave sediments filling the cave passages differ in both mineral and mineral magnetic properties and were deposited under different hydrological conditions. The older portion of the clastic cave fills was derived from overlying sandstones, whereas the properties of younger cave sediments show closer affinity to the soils and weathering products originating on the plateau above the cave. The cave sediments underwent repeated periods of deposition and erosion during the Tertiary (?) and Pleistocene. The last catastrophic erosion event occurred in the cave more than 350 ka based on flowstone dating. Water seeping through the overlying sandstone body causes collapses of sandstone slabs from the cave passage ceilings, forming the youngest portion of the clastic cave fills.

Introduction

It has been demonstrated that the study of the clastic cave deposits can contribute to better understanding of the cave system development as well as to the local hydrological processes. Sedimentological and mineralogical studies together with radiometric or paleomagnetic datings of both clastic and chemogenic deposits have commonly been applied in cave sediment research (e.g., Häuselmann et al., 2007; Kadlec et al., 2001). The mineral magnetic approach has been used only occasionally to understand climatic, hydrological and anthropogenic processes controlling sediment deposition in caves (Ellwood et al., 1996, 2004; Sroubek et al., 2001, 2007). The assemblage of magnetic minerals found in sediments is controlled by the character of the source rocks, weathering, mode and energy of transporting medium, and by depositional as well as post-depositional processes.

The aim of this paper is an examination of Botovskaya Cave deposits using methods operating with magnetic and heavy minerals and with quartz grain exoscopy. Obtained mineral characteristics were used for correlations from the point of view of sediment source and mode of transportation into the cave passages. Radiometric and paleomagnetic datings of the cave carbonate bed allowed us to estimate the age of both depositional and post-depositional processes.

Geographical and Geological Settings

Botovskaya Cave (55° 18′ N, 105° 20′ E) is located on the Angarsko-Lensky Plateau of the southern Siberian Craton about 500 km north of Irkutsk City (Fig. 1). The area reaches altitudes of 1100 m a.s.l., and belongs to the Zhigalovo District of the Irkutsk Area. The plateau is dissected by river valleys up to 400 m deep. Cave entrances lie at a relative elevation of 310 m above the Lena River level, in a valley of the Garevogo Creek, the left tributary of the Boty River, which joins the Lena River. The cave system, dipping gently to the north, has developed in an Early Ordovician limestone formation with a thickness of 6 to 12 m. The limestone bed is underlain by Middle and Late Cambrian sandstone, siltstone, marl and gypsum and overlain by Middle Ordovician sandstone, limestone and argillite (Filippov, 2000).

The cave system developed under confined (artesian karst) settings (Klimchouk, 2000, 2003; Filippov, 2000). The speleogenesis of the Botovskaya Cave system was interpreted by Filippov (2000) and is due to two different processes, (i) corrosion involving meteoric artesian water and (ii) ascending deep circulating artesian water spanning the time period between Late Mesozoic and Early Neogene. The clastic cave deposits fill the bottom portion of the cave passages and are not usually exposed sufficiently for study. The deposits from the cave were preliminarily described by Filippov (2000). Breitenbach (2004) described in detail a recently excavated section of cave sediments (the same section is labeled Section 1 in this paper).

The cave is divided into two parts: the Old World and the New World. All studied sections of cave sediments are situated in the Old World, 200–400 m east of the Central and Medeo entrances (Fig. 2). The key Section 1 and Section 2 are exposed in two test-pits excavated in the sedimentary fill close to survey stations PK0122 and PK042. The smaller Section 3 and Section 4 are located

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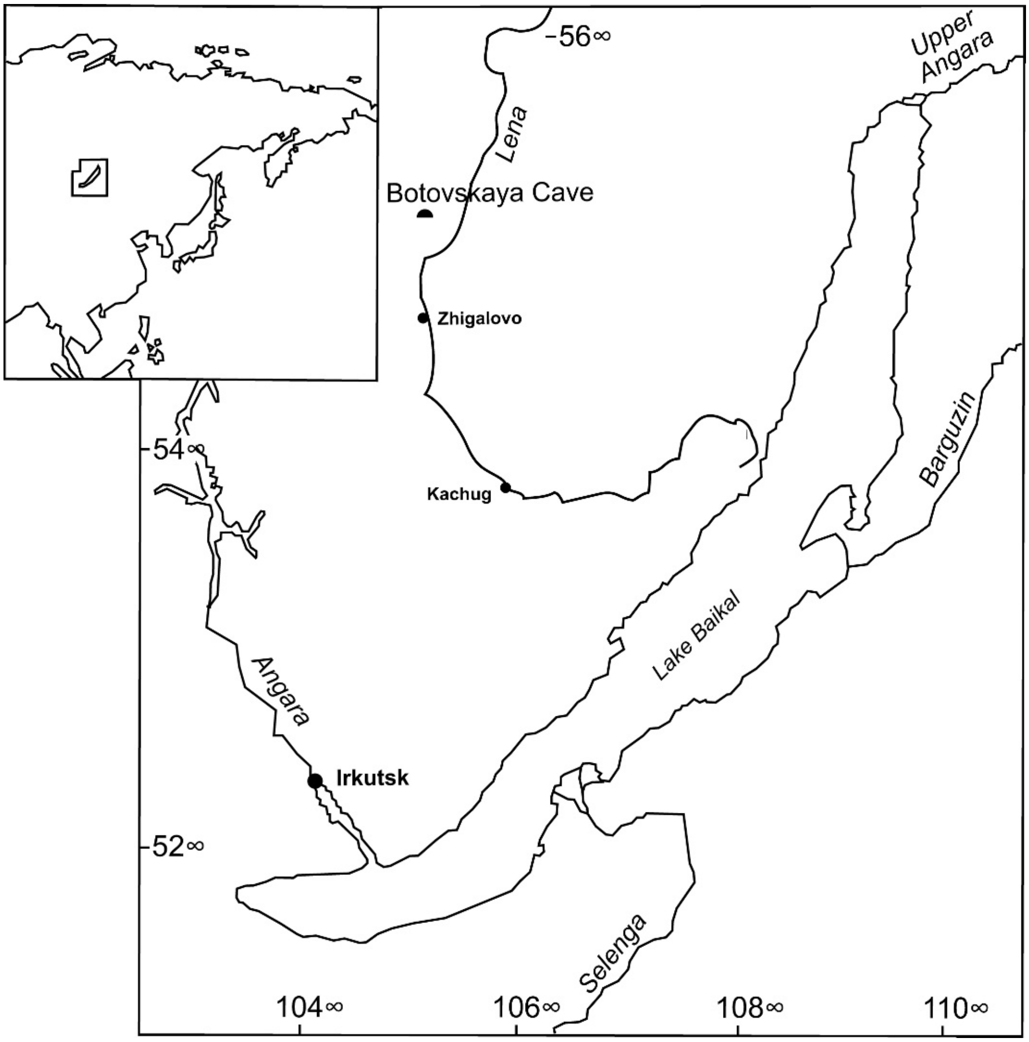

Figure 1. Location of Botovskaya Cave in Eastern Siberia.

close to survey stations PK0186 and PK0342, respectively. A small relic of flowstone bed used for Th/U dating is preserved on the limestone wall W of Section 1 ca 1.7 m above the present passage floor.

Materials and Methods

The studied sections of the cave deposits were documented with special reference to lithology, sedimentary structures and aggradation and erosion event records. Mineral magnetic characteristics such as low field bulk magnetic susceptibility (MS) and anhysteretic remanent magnetization (ARM) together with anisotropy of magnetic susceptibility (AMS) help to find the source of the cave fills and estimate a mode of sediment transport to the cave passages. While MS values are influenced by the concentration of magnetic particles, mineralogy and grain size of the minerals (ferro-, para-, and diamagnetic) in the sediments, ARM is sensitive only to the concentration, mineralogy and grain size of ferromagnetic minerals present in sediments. AMS reflects the preferred orientation of magnetic minerals and can be used for texture interpretation in sedimentary rocks. Magnetic anisotropy can be visualized by an ellipsoid with three perpendicular principal axes ($k_1 \geq k_2 \geq k_3$). The maximum axis (k_1) is denoted as magnetic lineation and the plane perpendicular to minimum axis (k_3) defines a magnetic foliation. The AMS ellipsoid magnitude can be presented as a ratio k_1/k_3, known as the degree of anisotropy, P (Nagata, 1961). The AMS ellipsoid shape can be described by the shape parameter, T (Jelínek, 1981); oblate shapes correspond to $0 < T \leq 1$, prolate shapes correspond to $-1 \leq T < 0$. The degree and shape of the AMS depend on the lithology and compaction imposed on the deposit.

Oriented samples of clastic cave sediments were collected in plastic boxes (volume 6.7 cm^3). For each sample MS and AMS were measured using Agico KLY-4 Kappagridge (alternating field amplitude of 425 A/m and operating frequency of 875 Hz) in the Paleomagnetic Laboratory of the Institute of Geology AS CR, v.v.i. in

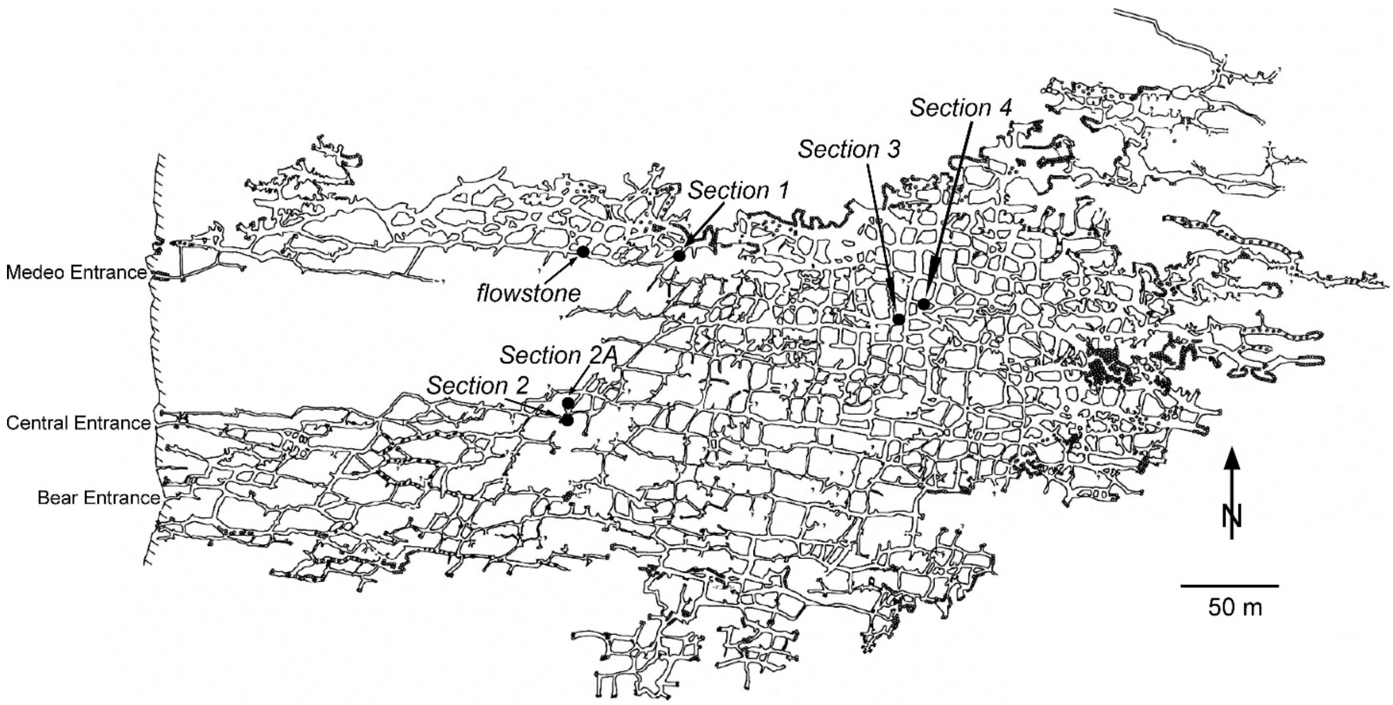

Figure 2. Botovskaya Cave (The Old World) map (adopted from Göbel and Breitenbach, 2003) with indication of studied sections and dated flowstone.

Prague. The ARM was imparted on demagnetized samples (using an Agico AF demagnetizer/magnetizer LDA-3/AMU-1A and measured on an Agico JR-6A spinner magnetometer). Frequency dependent magnetic susceptibility as a proof for the presence of superparamagnetic particles was tested in low- and high-frequency measurements conducted on a Bartington MS2 magnetic susceptibility meter. For the purpose of paleomagnetic polarity measurements three 8 cm^3 samples were cut from the flowstone bed. Samples were thermally demagnetized and measured using a 2G Enterprises superconducting rock magnetometer in the Laboratory for Natural Magnetism ETH Zurich.

The character of quartz grain surfaces indicates transportation and post-depositional history of clastic sediments. Exoscopic observations were performed on quartz grains larger than 0.25 mm separated from either clastic cave deposits or from the Ordovician sandstone bedrock after wet sieving and boiling in HCl. The cleaned grains were stuck on a carbon tape and observed using the BS 340 electron microscope. Heavy minerals were separated after wet sieving from the grain-size fraction of 0.25–0.063 mm using tetrabromethane (density 2.964 g cm^{-3}) and observed in Canadian balsam. At least 300 grains of transparent heavy minerals were determined in each sample.

The flowstone bed used for the paleomagnetic polarity measurements was also dated by the $^{230}Th/^{234}U$ radiometric method. Uranium and thorium were separated from three samples using a standard chemical procedure (Ivanovich and Harmon, 1992). The samples were dissolved in 6 M nitric acid, and uranium and thorium were separated by a chromatographic method using the DOWEX 1 × 8 ion exchanger. The efficacy of chemical separation was controlled by addition of a $^{228}Th/^{232}U$ spike. Activity measurements (alpha spectrometry) were taken with the OCTETE PC device of the EG&G ORTEC company. Spectral analysis and age calculation were performed using URANOTHOR 2.5. software (Gorka and Hercman, 2002).

Description of the Cave Deposits

Section 1

The section is exposed in the excavated test-pit 2.8 m deep (Breitenbach, 2004). A SW face of the test-pit shows dark gray to black, medium-grained sand deposited on the bedrock bottom of the passage (Bed 15 in Fig. 3). The sand layer contains rare laminae of light medium-grained brown sand and sporadic aggregates of SiO_2-cemented sand up to 1 cm large. The overlying gray to yellow brown sand bed contains frequent, up to 2 cm large aggregates of sand cemented with SiO_2 (Bed 14). Deposition continued with brown clayey medium-grained sand with laminae and lenses of light brown sand (Bed 13), light brown, medium-grained sand (Bed 12) and with overlying dark gray clayey medium-grained sand with small lenses to laminae of light fine-grained sand (Bed 11). This bed was partly eroded before the deposition of brown laminated clayey medium-grained sand (Bed 10) with fragments of brown clay on the

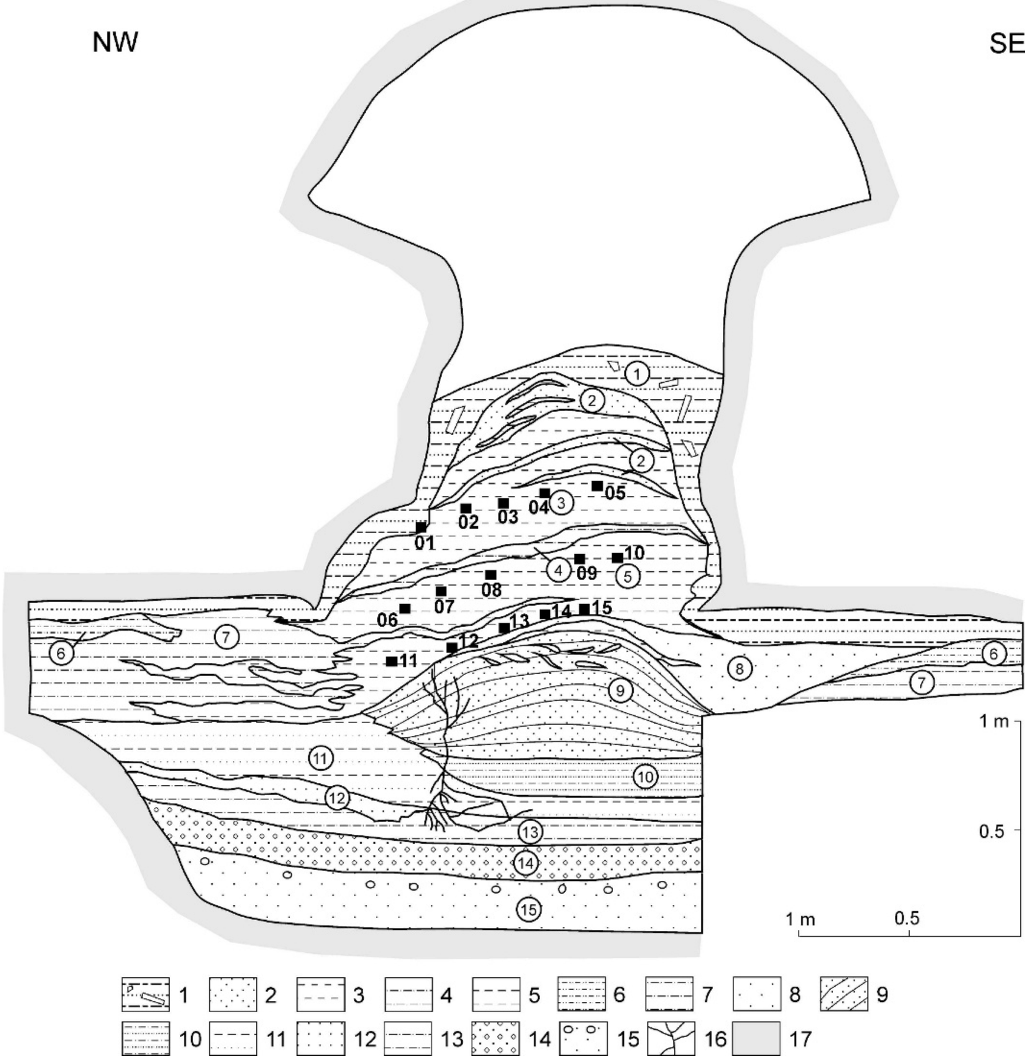

Figure 3. Section 1 — SW face

1 – clay, sporadic angular clasts of sandstone; 2 – sand; 3 – clay; 4 – sandy clay to clayey sand; 5 – clay; 6 – sandy clay; 7 – slightly sandy clay; 8 – sand; 9 – sand, fine-grained; 10 – clayey sand, laminated; 11 – clayey sand; 12 – sand; 13 – clayey sand; 14 – sand with sandy aggregates; 15 – sand; 16 – carbonate cementation along fissures; 17 – bedrock wall; black squares with numbers – collected samples. For more detailed description see text.

erosional top of the bed. The above lying loaf-like bed (Bed 9) is formed by light and dark brown laminae of fine-grained sand 1–15 mm thick with brown clay fragments of up to 2 cm in size at the erosional surfaces and relics of cemented laminae (up to 7 mm thick) in the upper portion of the bed. Beds 9 to 13 were disturbed by fissures filled with carbonate-cemented fine sand. Bed 8 is formed by light brown fine-grained sand with chaotic small lenses or laminae of darker medium-grained sand and rare fragments of light gray fine-grained sand. This is followed by light brown, slightly sandy clay with black smudges at the base (Bed 7) and red sandy clay preserved only in relics (Bed 6). The above lying brown to brown-red clay (Bed 5), massive in the lower portion and containing 1–3 mm thick laminae in the upper portion, is overlain by gray to yellowish sandy clay to clayey medium-grained sand (Bed 4) and brown clay (Bed 3) containing lenses of light brown, medium-grained sand (Bed 2). The section is covered with brown-red clay with sporadic angular clasts of sandstone up to 7 cm in size filling the space formed by water running along the limestone walls.

The NE face of the test-pit shows a similar succession as the opposite SW face of the section (Fig. 4). Minor unconformities and clay fragments are noticeable in the laminated fine-grained sands forming Bed 9 (Fig. 3). Laminated sediments in the left part of the bed were disturbed by a fissure. Small fragments (< 1 mm) of disintegrated darker laminae concentrate along this fissure.

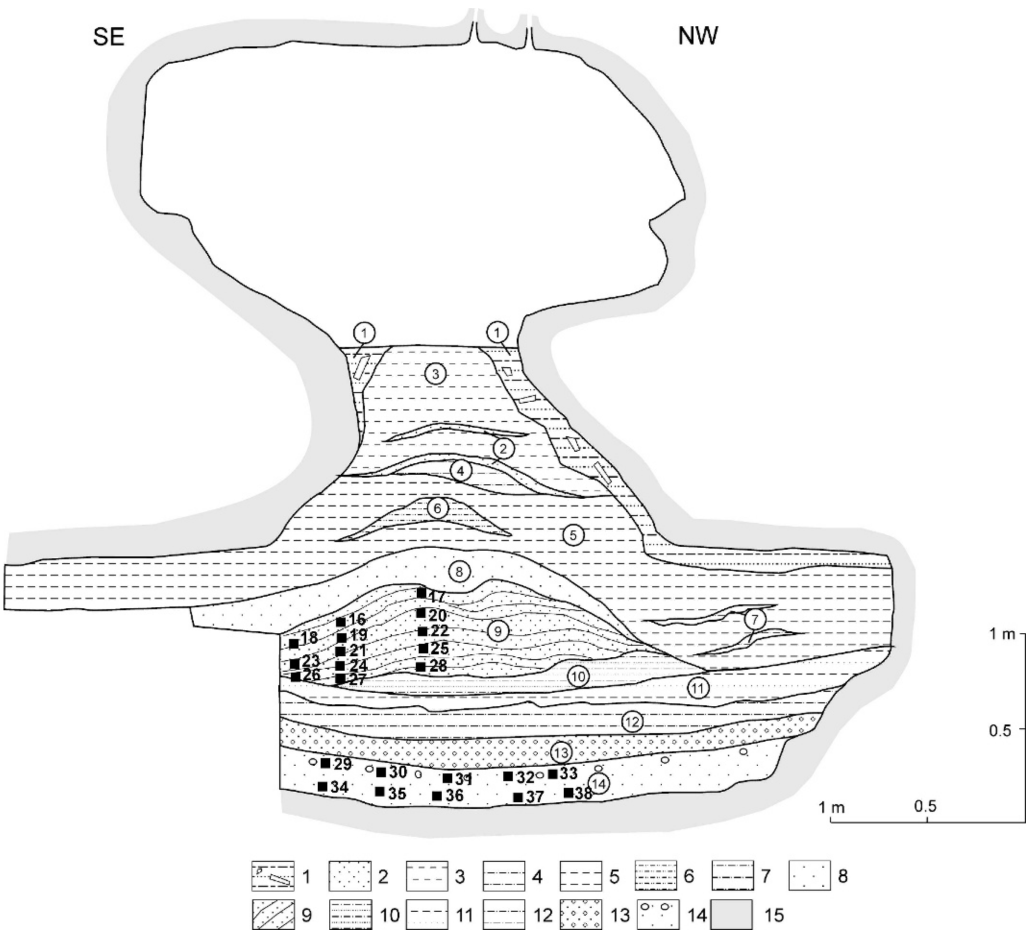

Figure 4. Section 1 — NE face

1 – clay, sporadic angular clasts of sandstone up to 7 cm large; 2 – sand; 3 – clay; 4 – clay; 5 – clay; 6 – sand; 7 – slightly sandy clay; 8 – sand; 9 – sand, fine-grained; 10 – clayey sand, laminated; 11 – clayey sand; 12 – clayey sand; 13 – sand with sandy aggregates; 14 – sand; 15 – bedrock wall; black squares with numbers – collected samples. For more detailed description see text.

Section 2

The section is exposed in an older excavated test-pit. Dark brown to gray, medium-grained sand with sporadic clasts of SiO_2-cemented sand up to 1.5 cm in size and rare fragments of brown clay up to 4 cm in size were deposited at the bedrock bottom (Bed 7 in Fig. 5). The above lying gray to yellow brown medium sand with sandy aggregates (Bed 6) contains aggregates of SiO_2-cemented sand up to 1.5 cm in size. Dark gray medium-grained clayey sand layers with lighter stains containing irregular lenses of yellow-brown sand and fragments of brown massive clay up to 1.5 cm in size deposited on the surface of the bed designated as Bed 5. The younger Bed 4 is formed by dark gray, fine-grained silty sand, partly laminated with 1 mm thick laminae of yellow-brown fine sand in the lower portion and lenticular fragments of brown clay indicating erosional surfaces of laminae. The above lying light brown, slightly clayey, medium-grained sand contains relics of cemented sand on its surface (Bed 3). Brown to slightly red laminated clay colored by Mn-oxides in the upper portion represents Bed 2. The top of the succession is formed by light brown to yellow-brown, medium-grained clayey sand containing angular sandstone clasts 5–15 cm in size and fragments of brown and black clay coloured by Mn-oxides (Bed 1). A limestone block up to 0.5 m large is present in the youngest bed.

Section 2A

This sedimentary section is exposed in a phreatic conduit about 0.5 m above the top of Section 2. It consists of brown-red, medium-grained sand (Bed 2) and is overlain by light brown clay (Bed 1 in Fig. 5).

Section 3

The lowermost Bed 3 of the section is formed by dark gray medium-grained sand beds (1–1.5 cm thick) with brown clayey medium-grained sand and brown clay (0.5–2 cm thick) (Fig. 6). The above lying Bed 2 comprises

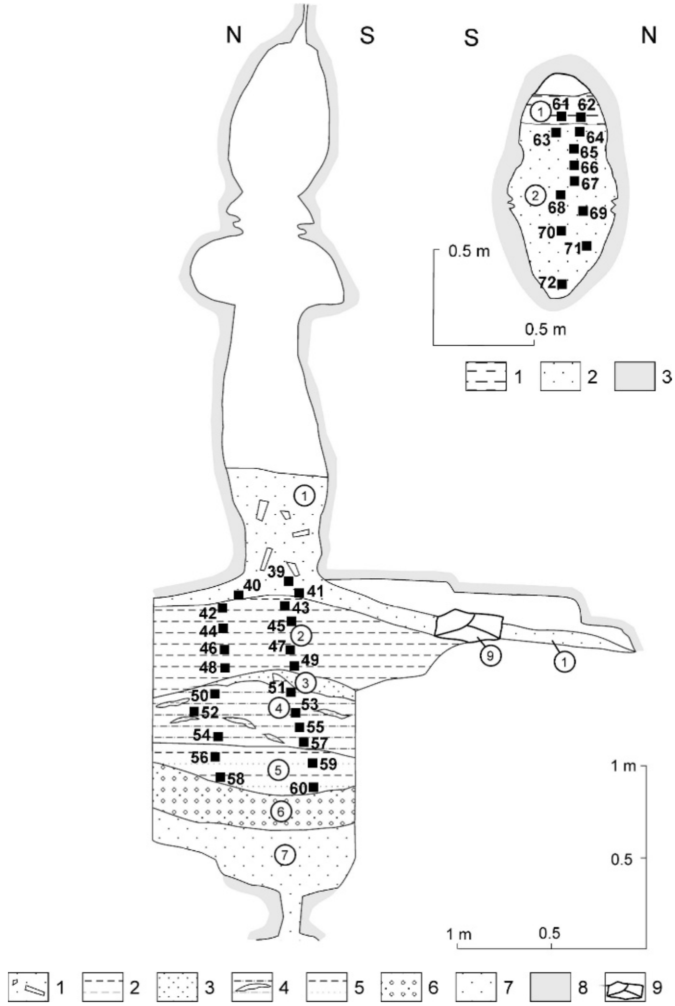

Figure 5. Section 2

1 – clayey sand, rare angular sandstone clasts 5–15 cm large and fragments of clay; 2 – clay, laminated in the upper portion; 3 – slightly clayey sand; 4 – silty sand; 5 – clayey sand; 6 – sand with sandy aggregates; 7 – sand, sporadic sandy concretions up to 1.5 cm large and rare fragments of brown clay up to 4 cm large; 8 – bedrock wall; 9 – block of bedrock; black squares with numbers – collected samples. For more detailed description see text.

Section 2A (top right)

1 – clay; 2 – sand; 3 – bedrock wall.

alternating dark gray laminae of medium-grained clayey sand. The deposition was terminated by a gray to gray-black, medium-grained sand bed with irregular lenses of light brown sand (Bed 1).

Section 4

Yellow-gray, medium-grained sand is exposed in the lowermost Bed 4 (Fig. 7). Light brown, medium-grained sand with gray-brown lenticular stains was deposited in the above lying Bed 3. Bed 2 is formed by dark gray, fine- to medium-grained sand laminae alternating with light brown

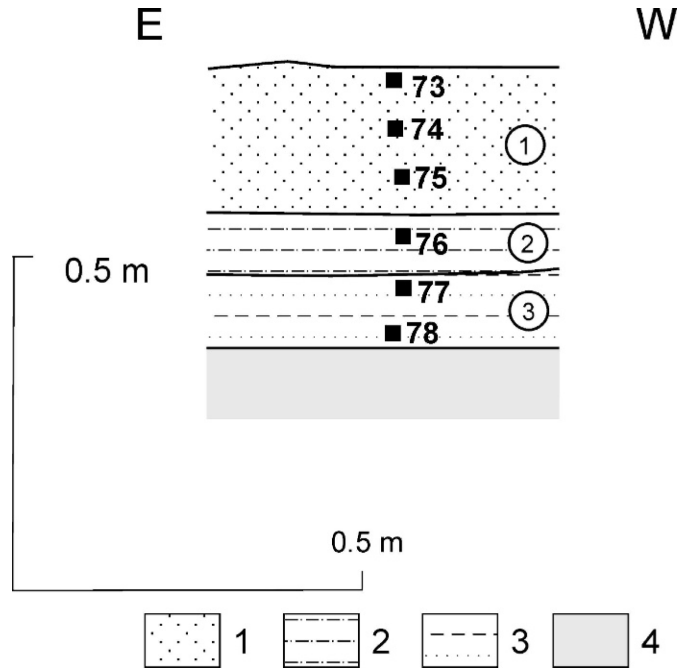

Figure 6. Section 3

1 – sand; 2 – clayey sand; 3 – alternating of layers of sand with clayey sand and clay; 4 – bedrock bottom; black squares with numbers – collected samples.

sand laminae. The section is topped by brown clay alternating with irregular beds of gray, medium-grained clayey sand (Bed 1). A black lamina coloured by Mn-oxides occurs at the base of this bed.

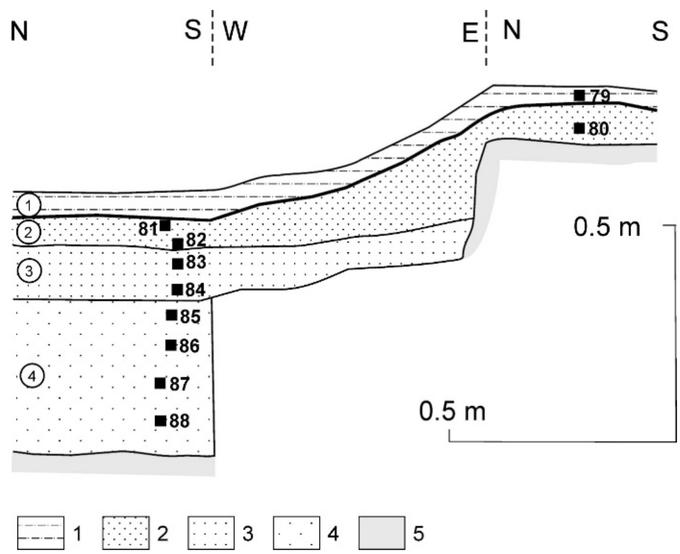

Figure 7. Section 4

1 – clay; 2 – sand; 3 – sand; 4 – sand; 5 – bedrock bottom; black squares with numbers – collected samples.

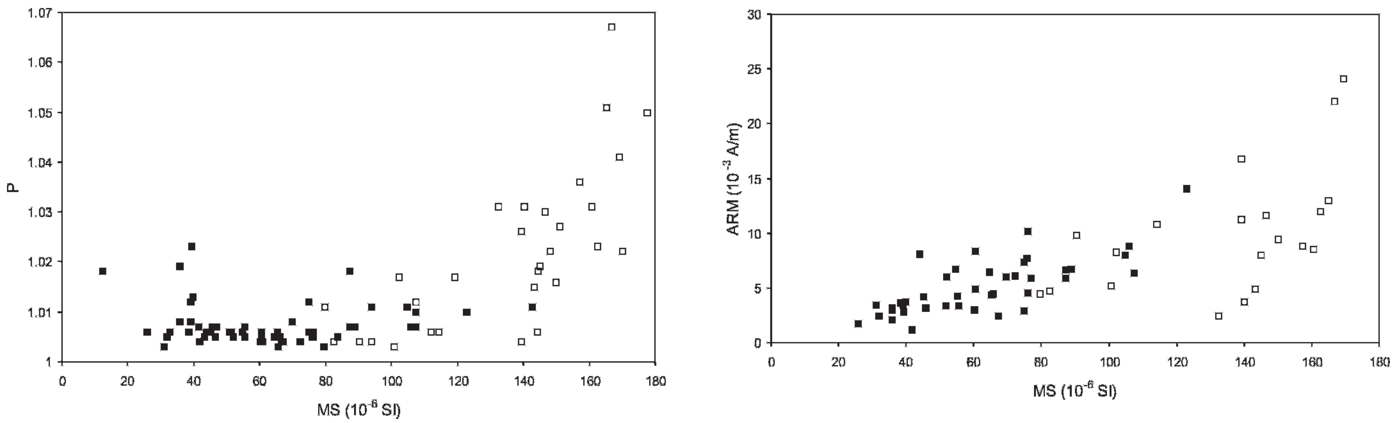

Figure 8. Correlation between magnetic susceptibility (MS) and degree of magnetic anisotropy (*P*) – left; correlation between magnetic susceptibility (MS) and anhysteretic remanent magnetization (ARM) – right. Black squares – bottom sedimentary beds (samples 16–41, 50–60, 63–72, 79–88); empty squares — top sedimentary beds (samples 01–15, 42–49, 61–62, 73–78).

RESULTS

MINERAL MAGNETIC CHARACTERISTICS AND MAGNETIC FABRIC

The MS values slightly increase from sandy bottom sediment beds to the above lying clay dominating sediments (Fig. 8). In Section 1, the values range from 23–63 × 10^{-6} SI (Bed 14) to 30–119 × 10^{-6} SI (Bed 9) and 90–149 × 10^{-6} SI (Beds 3 and 5). Similar variations were measured in Section 2 with 37–73 × 10^{-6} SI (Beds 4 and 5), 67–127 × 10^{-6} SI (Bed 2) and 56–90 × 10^{-6} SI (Bed 1). Basal sands in Section 2A yielded MS values of 22–55 × 10^{-6} SI (Bed 2), whereas the above lying clay bed has MS values of 121–123 × 10^{-6} SI (Bed 1). MS values of sediments exposed in Section 3 range between 76 and 124 × 10^{-6} SI, whereas the values in Section 4 slightly increase from 10–35 × 10^{-6} SI (in beds 3 and 4) to 26–94 × 10^{-6} SI (Bed 2). The highest MS values (up to 410 × 10^{-6} SI) were measured in the modern topsoil collected above the Medeo Entrance, whereas the bedrock sandstone showed MS values between 7 and 25 × 10^{-6} SI and MS values of limestone are about 10 × 10^{-6} SI. The ARM values ranging between 1 and 22 × 10^{-3} A/m plot versus the MS show steep increase in the top beds (Fig. 8). The AMS degree also increases in these beds (Fig. 9). The magnetic fabric of the sediments is mostly oblate. Basal sands in sections 1, 2 and 4 show more prolate fabric as expressed by negative *T* values (Fig. 9).

The magnetic lineation directions in the top sedimentary beds show concentration in NW to SW directions (Fig. 10, top left) with the mean direction tending to the WSW. The poles to magnetic foliation are usually concentrated around the center of the projection. N-S elongation of the pole directions was found in sediments from Section 3 (Fig. 10, top right). The magnetic lineation directions measured in the bottom sedimentary beds show almost random distribution accompanied by large dispersion of poles to magnetic foliation (Fig. 10, bottom).

EXOSCOPY OF QUARTZ GRAINS

Three types of microstructures were observed on quartz grain surfaces: (i) precipitation of SiO_2 on the surface of grains in lace-like patterns, (ii) corrosive etched microstructures, and (iii) overgrowth with quartz crystals. The bedrock Ordovician sandstone forming the ceiling of the cave passage above Section 2 contains rounded quartz grains about 1 mm in diameter (Fig. 11, top left). The grain surfaces show weak dissolution and precipitation of SiO_2 (Fig. 12, bottom left). The cross-bedded sandstone forming intercalations in the limestone contains smaller quartz grains cemented with SiO_2 into aggregates with an average length of 1 mm (Fig. 11, top right). The basal sand in Section 1 consists of separate rounded grains with average size of about 0.5 mm (Fig. 11, bottom left). Surfaces of many grains are modified by conchoidal fractures and corrosion features. Grain aggregates with weakly corroded

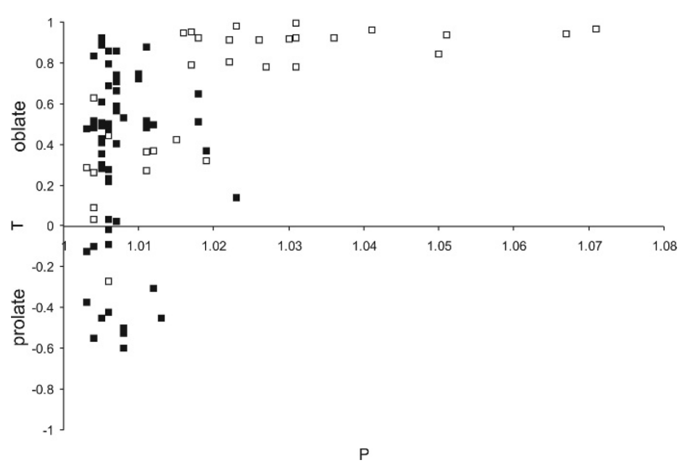

Figure 9. Correlation between degree of anisotropy (*P*) and shape of anisotropy ellipsoids (*T*). Sample symbols are the same as in Fig. 8.

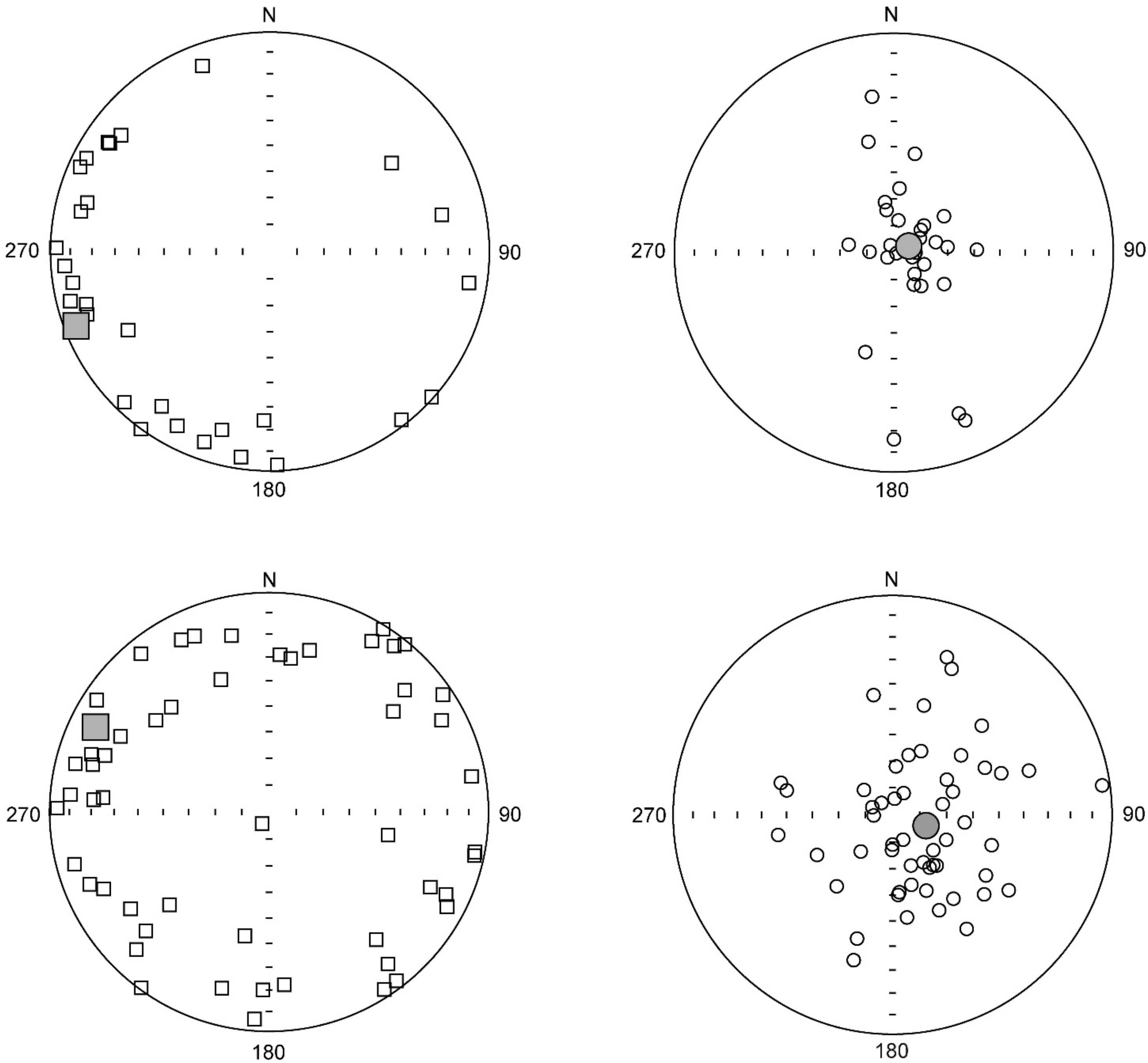

Figure 10. Principal directions of magnetic fabric of sediments indicated by anisotropy of magnetic susceptibility; equal-area projection on the lower hemishere. Top left – magnetic lineation in bottom sedimentary beds; top right – pole to magnetic foliation in bottom sedimentary beds; bottom left – magnetic lineation in top sedimentary beds; bottom right – poles to magnetic foliation in bottom sedimentary beds; larger gray squares and circles represents mean directions.

surfaces dominate in the above lying Bed 9 (Fig. 11, bottom right). Angular flat mineral particles (micas?) dominate in Bed 3, separate quartz grains and aggregates are present in smaller amounts (Fig. 12, top left). Quartz grains in sand deposited in the bottom beds in Section 2 (Beds 6 and 7 in Fig. 5) form cemented aggregates up to 1 mm large as in the bottom beds of Section 1. Grain surfaces often bear lace-like silica coatings. The above lying Bed 4 in Section 2 is composed of a mixture of free grains (30 %) and cemented aggregates (70 %) with lace-like silica coatings. Angular mineral particles are rarely present in the bed. Sub-angular to rounded grains up to 1 mm in size prevail in Bed 1 against cemented grain aggregates showing weak roundness. Sand from Bed 2 in Section 2A shows predominantly free rounded quartz grains coated with lace-like silica (Fig. 12, bottom right). Exoscopic analyses were completed with images from modern soil collected at the Medeo Cave entrance. Free rounded quartz grains up to 1.5 mm in size dominate in the soil (Fig. 12, top right).

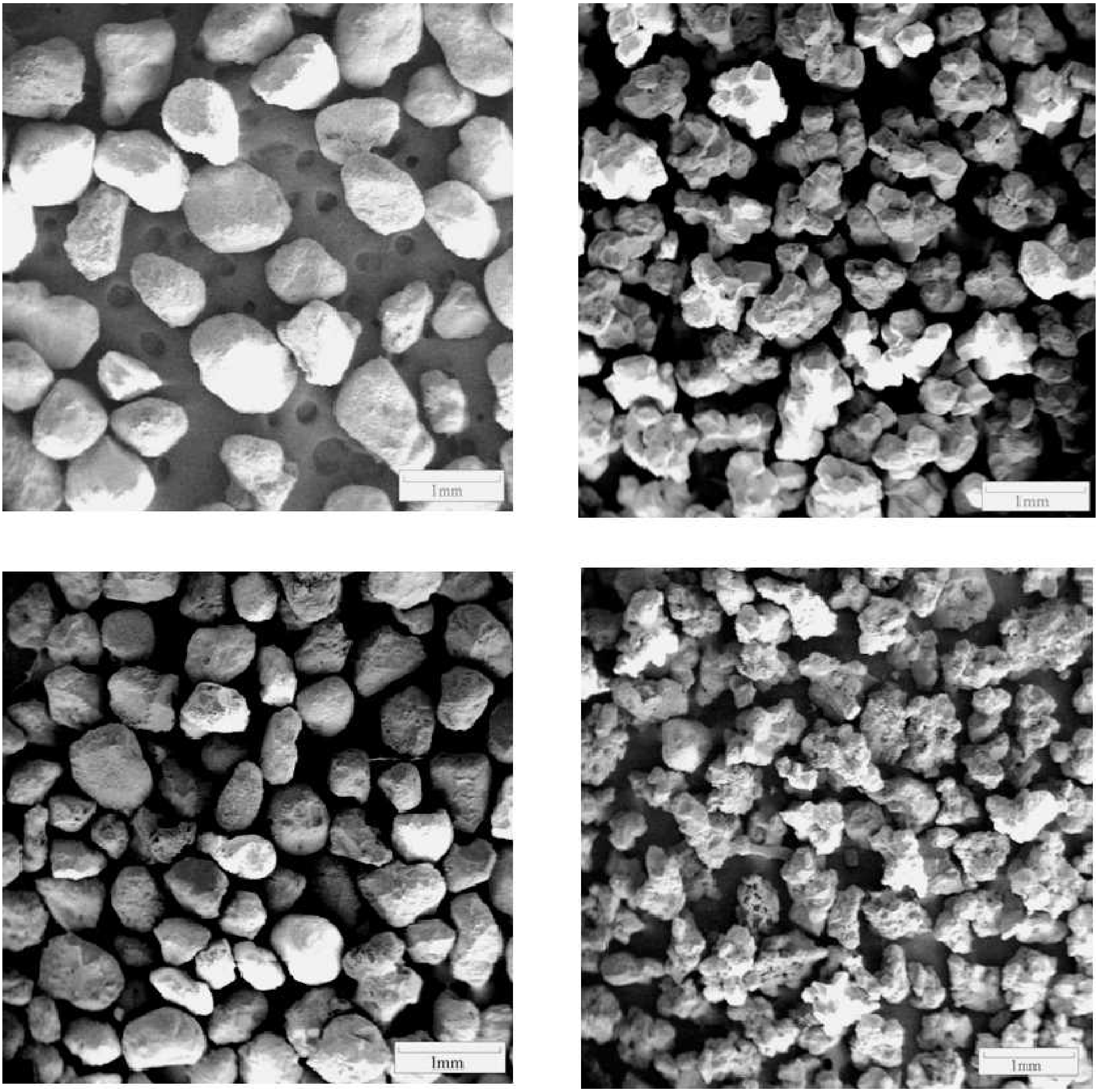

Figure 11. Surface of quartz grains. Top left – quartz from bedrock sandstone; top right – quartz aggregates from cross-bedded sandstone intercalated within the limestone; bottom left – quartz from Bed 15 in Section 1; bottom right – quartz aggregates from Bed 9 in Section 1.

The quartz grain aggregates isolated from Bed 14 in Section 1 were put through an experiment using a kitchen blender simulating transport of sediments in a turbulent flow. The aggregates were almost completely disintegrated after 5 minutes of mixing. The silica coatings on grain surfaces were destroyed after 15 and 30 minutes of mixing.

Heavy Mineral Content

The studied samples of the bedrock and cave deposits show monotonous association of stable heavy minerals. Grains of transparent heavy minerals are rounded, while the opaque mineral grains are mostly angular. Beds in the upper portions of Sections 1 and 2 contain greater amounts of garnet, similar to modern soil (Table 1).

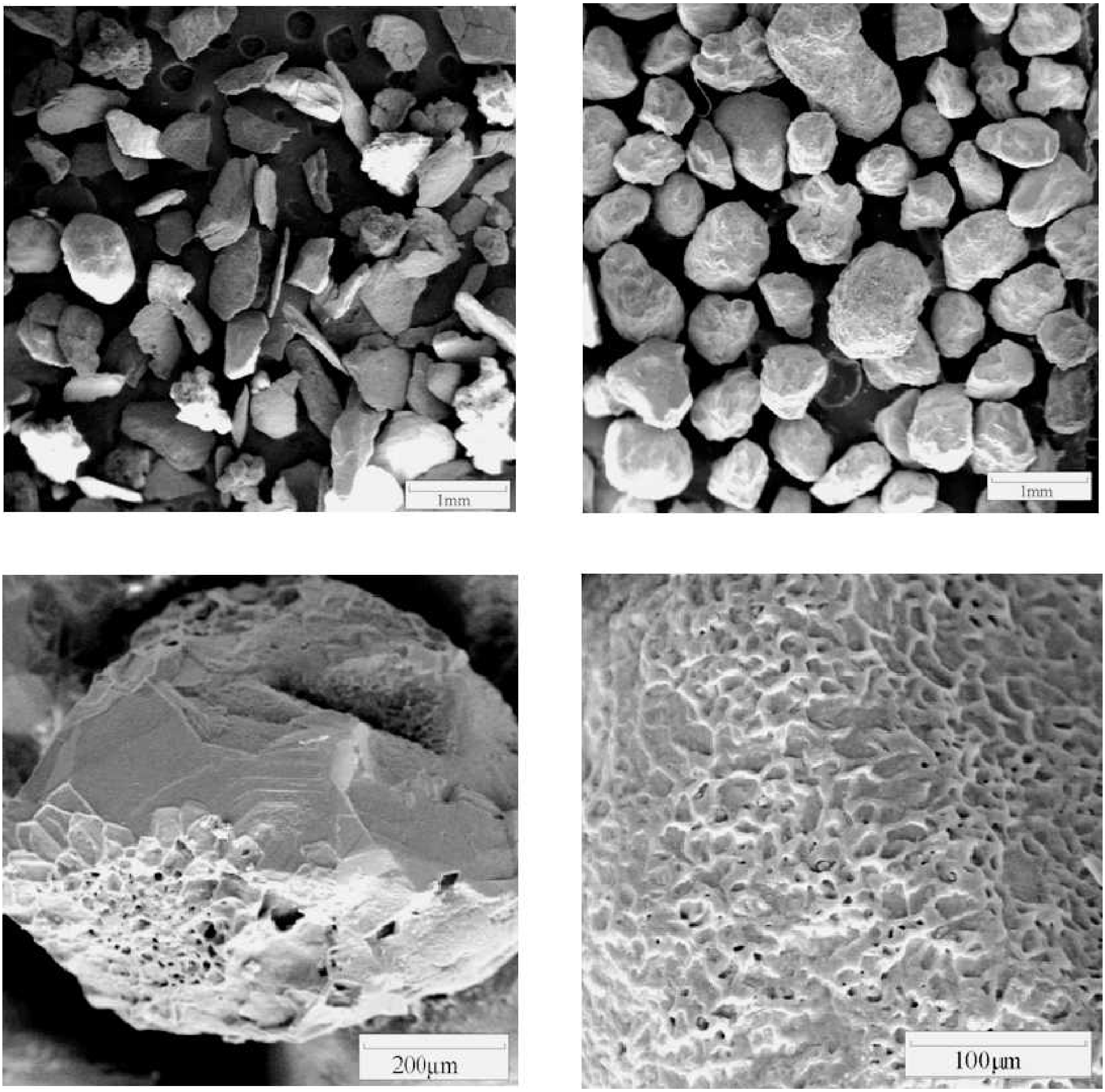

Figure 12. Surface of quartz grains. Top left – mixture of quartz and angular grains from Bed 3 in Section 1; top right – quartz from modern soil; bottom left – a detail of quartz corrosion from Bed 15 in Section 1; bottom right – a detail of newly-formed quartz precipitates from Bed 2 in Section 2A.

These deposits reveal an opaque/non-opaque mineral ratio 1:3 while other sediments studied contain a higher proportion of opaque minerals. Higher concentrations of garnet were also determined in the basal sand from Bed 14 in Section 1. Staurolite dominates in sediments with lower garnet content, including the bedrock sandstone (Table 1).

Flowstone Dating

Radiometric dating of the flowstone bed by $^{230}Th/^{234}U$ method reveals that the age of three dated samples exceeds 350 ka (limit of the dating method). However, the flowstone age higher than 1.2 Ma cannot be eliminated based on $^{234}U/^{238}U$ ratio (Table 2). During thermal demagnetization experiments magnetic moment decreased

Table 1. Heavy mineral content in modern soil, cave deposits and bedrock (values are in percent).

Cave Deposit	Garnet	Staurolite	Zircon	Rutile	Opaque/Non-Opaque Mineral Ratio
Modern Soil	72	24	2	3	1:3
Section 1 – Bed 3	80	5	15	1	1:3
Section 1 – Bed 9	4	89	5	2	1:1
Section 1 – Bed 14	3	85	7	5	1:1
Section 1 – Bed 15	45	49	3	3	8:1
Section 2 – Bed 1	35	56	2	8	1:1
Section 2 – Bed 4	7	82	9	2	1:1
Section 2 – Bed 6	9	80	7	4	1:1
Section 2A – Bed 2	50	36	10	4	1:3
Ordovician Sandstone	4	86	5	5	1:1

with increasing temperatures (Fig. 13, bottom). Directional variations of magnetic vector during the demagnetization process are expressed in the Zijderveld diagram and in the stereographic plot (Fig. 13, top). The mean paleomagnetic direction is: Declination = 18°, Inclination = 61°. Based on these paleomagnetic data, it is evident that the flowstone records normal polarity of the Earth magnetic field from the time of the carbonate deposition.

DISCUSSION OF RESULTS

Based on obtained results the sedimentary beds exposed in the studied sections were subdivided in two parts with the bottom (older) beds (beds 9–14 in Section 1, beds 4–7 in Section 2, Bed 2 in Section 2A and beds 2–4 in Section 4) and top (younger) beds (beds 1–8 in Section 1, Bed 1–3 in Section 2, Bed 1 in Section 2A, beds 1–3 in Section 3 and Bed 1 in Section 4).

The bottom beds reveal similar lithological, magnetic and heavy metal properties (except of sand in Bed 14). Basal sand deposited on the bedrock bottom shows a lower MS, similar to the bedrock sandstone. The exoscopic quartz grain characteristics are similar, too. It can therefore be proposed that the deposits filling the bottom part of cave corridors were derived from the local bedrock formed by Early Ordovician sandstones. The good roundness of quartz grains is a result of grain reworking in a high-energy Ordovician marine environment. Later, long distance redeposition of these quartz grains by Cenozoic streams can be excluded by the results of liquidizer experiment testing of the resistance of quartz grain aggregates during turbulent fluvial transport. No source of larger SiO_2-cemented aggregates (max. 2 cm long) common in beds 13 and 14 in Section 1 was found. These aggregates were cemented *in situ* during different climatic conditions allowing SiO_2 dissolution and precipitation. Sands in beds 11–13 in Section 1 and in Beds 6 and 7 in Section 2 lack prominent lamination or cross bedding (unlike the overlying sediments). It can be therefore assumed that these beds also belong to the bottom fill of cave passages.

The younger cross-bedded and laminated, mostly clayey sands in beds 8–10 (Section 1) and beds 3 and 4 (Section 2) were deposited after partial erosion of the basal deposits. The deposits reveal slightly higher MS values. The exoscopic observation shows cemented quartz grain aggregates indicating the source in the local cross-bedded sandstone (comp. Fig. 11, top right and Fig. 11, bottom right). The inner structures of these laminated sediments (small unconformities, redeposited fragments of clay, laminae partly cemented by carbonate and erosional surface of Bed 10) show a frequent alternation between local aggradation and erosion events. The sediments were deposited during heavy precipitation events, when water penetrated into the cave corridors from the surface through the swallow holes and along open cracks. The water escape structures (e.g., the fissure in beds 9–11, Section 1) were formed during the compaction of sediments. Sand grains accumulating along the fissures were later partly cemented by carbonate. Pore fluids moved during repeated liquefaction of the sediments and disturbed the primary magnetic fabric of these deposits, resulting in the tilting of the magnetic foliation to the NW (Fig. 10, bottom right). However, it is not possible to determine the flow direction

Table 2. Th/U age of the flowstone relic.

Sample Name	Sample Lab. No.	U (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	Age (ka)
BT 2	W 1302	28.2 ± 0.7	1.005 ± 0.005	1.064 ± 0.005	> 1000	> 350
BT 3	W 1301	19.8 ± 0.7	1.002 ± 0.007	1.002 ± 0.007	450 ± 40	> 350
BT 6	W 1303	11.9 ± 0.4	1.009 ± 0.008	1.083 ± 0.008	520 ± 60	> 350

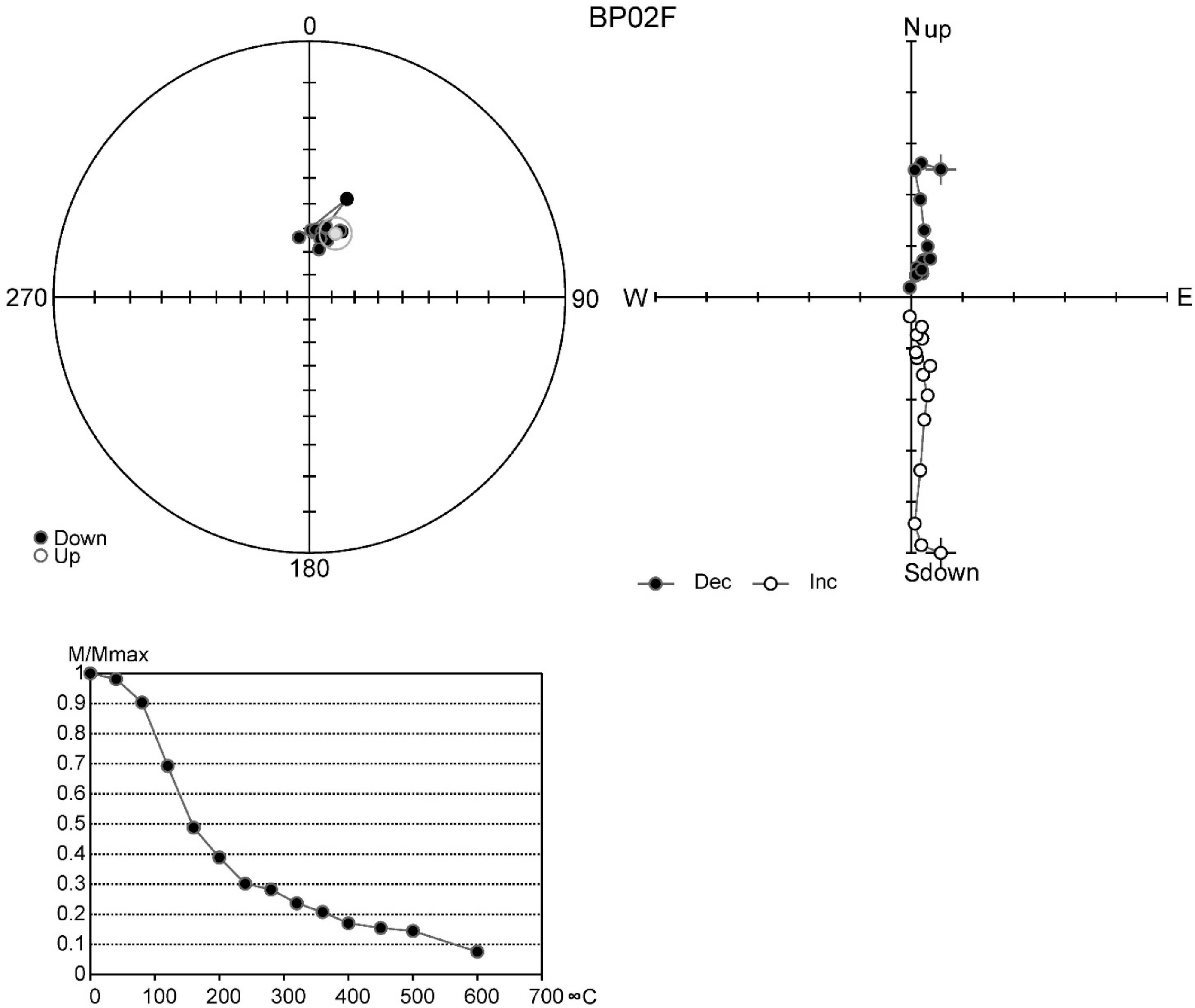

Figure 13. Thermal demagnetization of the flowstone sample BP02F. Top left – directions of magnetization vector during demagnetization process, black circles – projection of vector directions to the lower hemisphere, gray point in the circle – interpreted direction of the primary component of the magnetization vector; top right – Zijderveld diagram, black circles – projection of vector directions into horizontal plane, white circles – projection of vector directions into vertical plane; bottom left – normalized magnetization intensity values during the thermal demagnetization.

due to random dispersion of magnetic lineation directions measured in the bottom bed sediments.

Clayey sands forming the top portions of Section 1 (Beds 2–7) and Section 2 (Bed 2) reveal still higher MS values and higher garnet content, similar to the modern soil from the surface above the cave. The magnetic lineation and foliation indicate a calmer sedimentary environment with slow sediment transport directions from NW, W and SW (Fig. 10, top). Elongation of k_3 orientations in N-S direction measured in Section 3 could be a result of post-depositional deformation of the cave sediments caused by frost when the sedimentary layers filling narrow cave passage could be deflected due to volume changes. In the cave sediments with higher clay content, the MS increases together with the degree of anisotropy (Fig. 8, left). Different heavy mineral content of the sediments, compared to the bottom portions of the sections, indicates a different source of these deposits. The sediments could have been originally transported by wind to the area of Botovskaya Cave, from where they were vertically transported by precipitation waters through swallow holes and along open cracks to the cave. This assumption could be supported indirectly because angular flat mineral particles are missing in bottom cave sediments. Higher MS values of the clayey sediments correspond with the high MS of the topsoil at the cave surface. Most part of the iron present in the modern soil is the paramagnetic Fe^{3+} form (almost 80 %, identified by Mössbauer spectroscopy), which may be the result of weathering of paramagnetic minerals during pedogenic processes (e.g., Evans and Heller, 2004). The presence of superparamagnetic (SP) minerals originating during pedogenesis or taiga forest fires cannot be excluded (Thompson and Oldfield, 1986). However, results of frequency dependent magnetic susceptibility measurements, usually supporting SP mineral presence (e.g., Dearing, 1999), are not very reliable due to low MS values of the cave sediments.

MS of sand filling the karst conduit with Section 2A (Bed 2) is similarly low as in the basal sands in Section 2. Nevertheless, it differs from the latter in the high proportion of garnet (much like in Bed 14 in Section 1). The overlying clay in this section has similar properties to the youngest deposits in Sections 1 and 2 and the modern soil. However, precipitation waters flowing vertically from the surface through open fissures also transported the clay. Heavy precipitation events resulted in the erosion of the top part of the sediment in both Sections 1 and 2 and resulted in the deposition of clay-dominated sediments with chaotically arranged angular clasts of sandstones and with limestone blocks (Bed 1 in both sections).

Taiga forest fires could control the mechanism of sediment transportation from the surface above the cave to the underground passages. The topsoil retention ability is usually dramatically decreased after forest fires due to damaged vegetation. Precipitation would then percolate very fast into the cave. Evidence of a past catastrophic erosion event is preserved about 50 m west of Section 1 (Fig 2). A relic of flowstone bed is preserved on the limestone wall 1.7 m above present passage floor. The flowstone bed was originally deposited on the top of the clastic deposits, which filled the passage. The radiometric and paleomagnetic polarity dating suggests a likely age for the carbonate bed between 350 and 780 ka (i.e., older than $^{230}Th/^{234}U$ method age limit and but still within the present normal-polarity Brunhes Chron). However, we cannot entirely exclude the flowstone deposition during any older normal-polarity periods. In such case the flowstone should be older than 2.58 Ma (i.e., Matuyama-Gauss paleomagnetic boundary). We do not suppose a speleothem deposition during relatively short normal-polarity Jaramillo or Olduvai subchrons. Anyway, in the time of the flowstone deposition the artesian aquifer regime was already disrupted due to surrounding valley incision and vadose conditions dominated in the cave system. The later intensive erosion removed clastic sediments from under the flowstone bed and destroyed the entire flowstone. This erosional event had to be triggered by unusually heavy precipitation, which entered the bedrock through vertical ruptures opened both in sandstone and limestone due to differential subsidence of the massif (see below). The surrounding valleys supporting this vertical movement should be developed. Therefore, we suppose that the erosion occurred most probably during the Middle or Late Pleistocene. At that time the local surface streams were incised at a much lower position than the Botovskaya Cave. Results of this catastrophic cave flood could be the chaotic sediments deposited in Bed 1 in the Sections 1 and 2.

The morphology of the cave passages documents transverse flow under confined hydrological conditions in the artesian aquifer connected with upward solution of limestone (Klimchouk, 2000, 2003; Filippov, 2000). In the subsequent period lower parts of the passages were widened to the shape of a relatively broad channel with a flat ceiling. It should indicate a long-term dissolution, when the passages were permanently flooded with stagnant water. It is not easy to reconstruct this period in the cave system development, because this channel is completely filled with clastic cave deposits and is noticeable only in the excavated test-pits. We assume a period of relative stability and propose that the cave system was lying near the level of the ground-water table prior to the incision of the present deep valleys (Lena River) in the vicinity of the cave system. This stage should be dated to the Miocene, because the cave is located above the Pliocene river terrace level (Filippov, 2000).

Structures preserved in the clastic sediments filling the cave passages indicate deposition mostly in vadose conditions with frequent alternations of deposition and erosion. The water escape structures detected in sediments similar to silty laminae cemented by carbonate (Bed 9 in Fig. 3) support our assumption that the clastic deposition occurred in cave passages, which were not completely filled with water.

The following incision of surrounding valleys was probably triggered by a substantial Late Pliocene uplift recorded in the Lake Baikal Cenozoic sediments (Mats et al., 2000). Stability of the sedimentary massif comprising the Botovskaya Cave deteriorated as a result of this Pliocene-Pleistocene incision.

This was accompanied by gravity-induced opening of N–S joints parallel to the slope of the Garevogo Creek, where cave entrances are located, and by NE–SW opened joints parallel to the Lake Baikal rift structure indicating ongoing uplift connected with extension of the area (cf., Zorin et al., 2003). These ruptures detected at many places in the Old World of the Botovskaya Cave are now used by water seeping from the surface above the cave. These vertical pathways are also used for the underground transport of clastic sand- and clay-dominated sediments from the surface above the cave. Such a place is located east of Section 1. Sandstone blocks fallen from the ceiling are covered by light brown sands and clays (much like in Section 2A). Relicts of clayey sand are also preserved in hanging positions on rock ledges above the test-pit with Section 1. These clastic sediments do not, however, cover blocks pertaining to a younger phase of ceiling destruction. It is probable that the last falling of ceiling slabs also took place recently. Erosion caused by flowing water results, in turn, in further stability deterioration of the sandstones under- and overlying the limestone bed. Such weak points in the cave system then experience large collapse of the sandstone slabs from the ceiling and formation of chokes. Intensive water flow is also responsible for the growth of flowstone decorations at such places.

Conclusions

Three specific conclusions can be drawn from this study. First, the sections in detrital cave sediments in Botovskaya Cave (in The Old World part) evidence periodical sediment deposition. It cannot be excluded that the individual beds are separated by long hiatuses. Sediments of the cave fill are of two different types: the older, bottom sands are derived from weathered bedrock sandstones and were probably horizontally transported over a short distance. The overlying sediments dominated by clay and clay/sand were transported vertically with precipitation waters from the surface above the cave. The contrasting mineralogical and magnetic parameters of these top sediments indicate a different (more distant?) source.

Second, if the bottom sand was transported horizontally through the cave by flowing water, it must have taken place before the incision of the present deep valleys, probably in the Late Tertiary. Finer sediments should be transported by wind and deposited on the surface above the cave. From there, they were removed by precipitation waters together with weathered surface products and deposited in cave passages. These processes, most probably of Quaternary age, were lacking any direct link to the local hydrologic network.

Third, morphologies of passages in Botovskaya Cave document two stages of the cave system development: the older, characterized by confined hydrological conditions in the artesian aquifer. Passages formed during this older stage were later partly remodeled by stagnating water corrosion. This younger stage affected the cave system probably in the Tertiary, before the deep river valleys were formed.

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References

Breitenbach, S., 2004, High-resolution isotope measurements ($\delta^{18}O$ and $\delta^{13}C$) from Siberian stalagmites as potential palaeoclimatic proxies [MSc. thesis], Humboldt Universität, 72 p.

Dearing, J., 1999, Magnetic susceptibility, *in* Walden, J., Oldfield, F., and Smith, J., eds., Environmental magnetism: A practical guide, Quaternary Research Association, Technical Guide No.6, p. 35–62.

Ellwood, B.B., Petruso, K.M., Harrold, F.B., and Korkuti, M., 1996, Paleoclimate Characterization and Intra-Site Correlation Using Magnetic Susceptibility Measurements: An Example from Konispol Cave, Albania: Journal of Field Archaeology, v. 23, p. 263–271.

Ellwood, B.B., Harrold, F.B., and Benoist, S.L., 2004, Magnetic susceptibility applied as an age-depth-climate relative dating technique using sediments from Scladina Cave, a Late Pleistocene cave site in Belgium: Journal of Archaelogical Science, v. 31, no. 3, p. 283–293.

Evans, M.E., and Heller, F., 2004, Environmental Magnetism: Principles and Applications of Enviromagnetics, San Diego, Academic Press, 299 p.

Filippov, A.G., 2000, Speleogenesis of Botovskaya Cave, Eastern Siberia, Russia, *in* Klimchouk, A.B., Ford, D.C., Palmer, A.N., and Dreybrodt, W., eds., Speleogenesis, Evolution of Karst Aquifers, Huntsville, Ala., National Speleological Society, p. 282–286.

Göbel, E., and Breitenbach, S., 2003, Die Peschera Botovskaja, die längste Höhle Russlands: Mitteilungen des Verbandes der Deutschen Höhlen - und Karstforscher, v. 49, no. 2, p. 42–45.

Gorka, P., and Hercman, H., 2002, URANOTHOR v. 2.5., Delphi Code of calculation program and user guide: MS, Archive of Quaternary Geology Department, Institute of Geological Sciences, PAS, Warsaw, 65 p.

Häuselmann, P., Granger, D.E., Lauritzen, S.E., and Jeannin, P.Y., 2007, Abrupt glacial valley incision at 0.8 Ma dated from cave deposits in Switzerland: Geology, v. 35, no. 2, p. 143–146.

Ivanovich, M., and Harmon, R.S., 1992, Uranium Series Disequilibrium: Applications to Environmental Problems, Oxford, Clarendon Press, 2nd edition, 910 p.

Jelínek, V., 1981, Characterization of the magnetic fabric of rocks Tectonophysics, v. 79, T63–T67

Kadlec, J., Hercman, H., Beneš, V., Šroubek, P., Diehl, J.F., and Granger, D., 2001, Cenozoic history of the Moravian Karst (northern segment): Cave sediments and karst morphology: Acta Musei Moraviae, Scientiae Geologiae, v. 85, p. 111–161.

Klimchouk, A., 2000, Speleogenesis under deep-seated and confined settings, *in* Klimchouk, A.B., Ford, D.C., Palmer, A.N., and Dreybrodt, W., eds., Speleogenesis, Evolution of Karst Aquifers, Huntsville, Ala., National Speleological Society, p. 244–260.

Klimchouk, A., 2003, Conceptualisation of speleogenesis in multi-storey artesian systems: a model of transverse speleogenesis, http://www.speleogenesis.info/archive/publication.php?PubID=24&Type=publication&keyword=Klimchouk

Mats, V.D., Khlystov, O.M., De Batist, M., Ceramicola, S., Lomonosova, T.K., and Klimansky, K., 2000, Evolution of the Academician Ridge Accommodation Zone in the central part of the Baikal Rift, from high-resolution reflection seismic profiling and geological field investigations: International Journal of Earth Science, v. 89, p. 229–250.

Nagata, T., 1961, Rock Magnetitism, Tokyo, Maruzen, 2nd edition, 350 p.

Sroubek, P., Diehl, J.F., Kadlec, J., and Valoch, K., 2001, A Late Pleistocene paleoclimatic reconstruction based on mineral magnetic properties of the entrance facies sediments of Kulna Cave, Czech Republic: Geophysical Journal International, v. 147, no. 2, p. 247–262.

Sroubek, P., Diehl, J.F., and Kadlec, J., 2007, Historical climatic record from flood sediments deposited in the interior of Spirálka Cave, Czech Republic: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 251, p. 547–562.

Thompson, R., and Oldfield, F., eds., 1986, Environmental Magnetism, Allen and Unwin, London, 227 p.

Zorin, Y.A., Turutanova, E.Kh., Mordvinovaa, V.V., Kozhevnikova, V.M., Yanovskayab, T.B., and Treussovc, A.V., 2003, The Baikal rift zone: the effect of mantle plumes on older structure: Tectonophysics, v. 371, p. 153–173.

M.C. Osborne and C.N. Jass – The relationship of mineralogical data to paleontological questions: A case study from Cathedral Cave, White Pine County, Nevada. *Journal of Cave and Karst Studies,* v. 70, no. 3, p. 156–162.

THE RELATIONSHIP OF MINERALOGICAL DATA TO PALEONTOLOGICAL QUESTIONS: A CASE STUDY FROM CATHEDRAL CAVE, WHITE PINE COUNTY, NEVADA

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Abstract This study describes the mineralogy of sediment samples taken from a paleontological excavation in Cathedral Cave in eastern Nevada. Sediment samples were composed mostly of calcite and gypsum, and a few samples contained minor amounts of quartz and halite. A discrete cemented layer was present throughout portions of the excavated area. The primary mineral constituents of the cemented layer were nitratine (i.e., nitratite and soda niter) and halite, although a sample near the top of the layer was composed of Mg-calcite. Spherical pockets of powdery white gypsum were found intermittently at lower depths. The deposition of the nitratine and the gypsum pockets is likely the result of a leached guano layer. However, the presence of soluble nitratine and soluble halite may be a proxy for very arid conditions at the age of deposition. Mineralogical data can provide an independent source for addressing questions related to a variety of topics (e.g., paleoenvironments and depositional context), and we suggest that paleontologists who conduct excavations in caves may want to incorporate mineralogical analyses as part of their research program.

INTRODUCTION

Paleontological studies of fossiliferous cave deposits are common, and in most of these research projects, attempts are made to identify changes in features of the excavated sedimentary sequences (e.g., Barnosky et al., 2004). Those changes (e.g., grain-size, color, etc.) are often interpreted as distinct stratigraphic and/or chronologic layers. However, few of these types of studies incorporate detailed observations relating to mineralogical changes through the excavated stratigraphic sequences.

Chemical and mineralogical inputs into cave systems can be distinct from surface settings (Gillieson, 1996). As a result, data concerning these inputs may improve understanding of the unique depositional context of fossils collected from a particular cave setting and can potentially provide an independent source of data for other types of research questions (e.g., paleoenvironmental questions). The primary objective of this research project was to examine the mineralogy of an excavated section of Cathedral Cave, Nevada in order to understand better the depositional context of fossils excavated from the site. In this paper we describe the mineralogical content of excavated sediments from Cathedral Cave based on transmitted polarized light microscopy of thin-sections, X-ray diffraction (XRD), and scanning electron microscope (SEM) examination. We report a rare mineralogical record for the state of Nevada and discuss possible causes for some of the unique mineralogical characteristics observed. Finally, we offer suggestions for improving similar types of studies.

SITE DESCRIPTION

Cathedral Cave is located in the northern Snake Range in eastern White Pine County, Nevada within the east-central portion of the hydrographic Great Basin (sensu Grayson, 1993; Fig. 1). The cave entrance is situated on a north-facing slope within middle Cambrian rocks that crop out at the mouth of Smith Creek Canyon. Middle Cambrian formations in the Snake Range include (from oldest to youngest) the Pole Canyon Limestone, Lincoln Peak Formation, and Johns Walsh Limestone (Hose and Blake, 1976). Cathedral Cave is situated within one of these formations, but presently it is not known which.

The cave has two north-facing entrances and only three major rooms (Fig. 1). The paleontological excavations that provided the samples for this project were carried out in Room 2 by a joint team from The University of Texas at Austin and Northern Arizona University in June 2003. Age estimates for the excavated materials are currently being revised, but likely pre-date the terminal Pleistocene (Jass, 2005).

EXCAVATION METHODS

Sediments excavated from Cathedral Cave were collected using standard paleontological techniques. Horizon-

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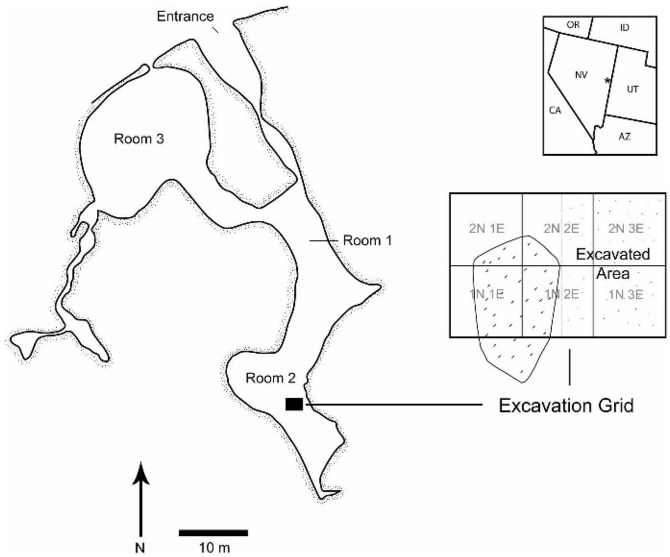

Figure 1. Map of Cathedral Cave showing geographic locations (inset) and the area included in the 2003 excavation. Sediment samples for this study come from the area demarcated in 1N 2E, 2N 2E, 1N 3E, and 2N 3E.

tal control was maintained by devising a 1 m × 1 m grid system. Vertical control was maintained by excavating in arbitrary 5-cm intervals except in instances where natural sedimentary breaks were evident (e.g. grain size, color, cemented versus non-cemented). In such cases, natural sedimentary levels were collected as distinct samples. The majority of excavated sediments were dry-screened on site using nested 6.35 mm and 0.7 mm mesh box screens in order to reduce excess matrix.

Site Stratigraphy and Sample Selection

Sediments removed during the excavation at Cathedral Cave consisted primarily of an amalgamation of vertebrate bone and unconsolidated silty clay sediments. Grain-size for the majority of sediments (excluding bone) was estimated to be fine or smaller and no notable changes in grain-size were observed through the excavated sequence. Minor color variations were noted (see Fig. 2), but were not deemed significant enough to warrant the excavation of distinct layers. Minor color differences observed in cross-section were not readily evident in plan view as the excavation proceeded.

During the excavation, three discrete sedimentary features were observed. A layer of cemented matrix and bone was encountered in four of the excavation grids between depths of 42 centimeters below datum (cmbd) and 57 cmbd (Fig. 2). The upper and lower boundaries of this level were easily identified as the excavation proceeded and the level was collected as a discrete sample. This layer was not horizontally continuous throughout the entire excavated area and did not extend into the northernmost portions of excavation. Sediments below the cemented

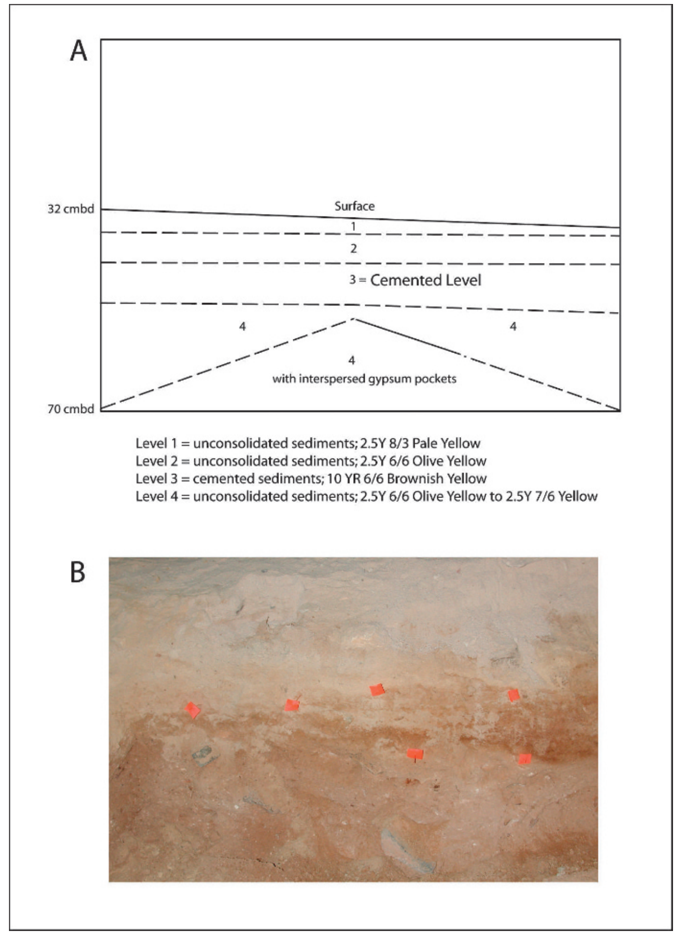

Figure 2. Sedimentary features discussed in text. A. Generalized cross-section from the north wall of excavation square 1N3E indicating overall sedimentary character of deposit. Color changes are noted using descriptions from a Munsell color chart. B. Photograph of the south wall of the excavation showing the cemented level. The top and bottom of the cemented level is bracketed by orange tape.

layer were similar to those occurring above the cemented layer in that they were composed primarily of a homogenous, unconsolidated matrix. A second observable stratigraphic feature was the presence of discrete pockets of fine-grained, spherical, powder-like, white sediments that occurred sporadically throughout the excavation at 53 cmbd and below (Fig. 2). These pockets occurred below the cemented layer. Finally, several collected bones were encrusted with mineral deposits. These occurred above, within, and below 5 cm of the cemented level.

Samples of the spherical white sediments, samples of bones with encrusting minerals, and some samples from the cemented level were collected separately on site and were used in the analyses presented here. Other samples from the top of the cemented level or within the cemented level were subjected to the dry-screening process but remained consolidated. Samples of unconsolidated sediments were selected from those materials that were dry-screened during fieldwork at the site. A complete summary of samples and their provenience is presented in Appendix 1.

LABORATORY METHODS

Light microscopy of thin-sections, X-Ray diffraction (XRD) analysis, and scanning electron microscope (SEM) examination were used to identify minerals in excavated sediments from Cathedral Cave. A total of 14 thin sections were impregnated with blue epoxy and cut to 30 µm thickness. Two thin sections from the cemented level were made two months after the other sections were prepared. Special care was taken to prepare these two sections, because XRD data suggested these samples contained nitratine and/or halite. These minerals are both highly soluble, so these thin sections were cut using a dry saw (Nesse, 2000).

In our XRD analyses, we used a Siemens D500 diffractometer fitted with a Cu X-ray tube. Samples were ground to a fine powder and scanned from 5° to 65° 2θ. Operating conditions for the tube were 45 kV accelerating voltage at 30 milliamps. XRD data were collected using the automation controller 'DataScan' by MDI, Inc. XRD patterns were analyzed using the matching routines of JADE 6+ by MDI, Inc., and using the 'Minerals 2003 ICDD' database.

SEM analyses were conducted using a model JEOL T330A at an accelerating voltage of 20 kV. Samples were gold coated using the Denton Desk II Gold Sputter Coater. Gold was sputtered at 50 millitorr in a vacuum at 45 milliamps for 30 seconds. All samples except for the bones exhibiting evidence of secondary mineral deposition were gold coated for an additional 20 seconds at 50 millitorr in order to obtain better control of sample charging.

RESULTS AND DISCUSSION

SEDIMENTS ABOVE CEMENTED LEVEL

Light microscopy

Light microscopy of the two thin-sections made from above the cemented level showed the samples to be composed mostly of angular to sub-angular particles of unidentified grains. Bone was recognizable in both thin sections. Angular calcite grains were evident and commonly contained micro-fractures. These micro-fractures may be artifacts of thin-section preparation. Some conical grains evident in thin-section are likely derived from speleothems.

In both thin-sections, many grains were coated with unidentified clay-sized particles. The texture of these grains may be the result of precipitation of microcrystalline materials on the grains after deposition but before excavation. Alternatively, clay-sized particles may have accumulated around the edges of the grains as they were being agitated during the dry-screening. Another explanation for the coating of grains is that during transportation of the sediments (in plastic Ziploc bags) from the field to the laboratory there was an increase in humidity within the bags that resulted in the accumulation of mud around these grains.

XRD analysis

XRD-analyses from sediments from above the cemented layer confirmed the presence of calcite. One sample shows a peak consistent with aragonite (35–40 cmbd). In two samples, XRD-analysis showed pronounced peaks consistent with halite. Thin sections from these levels were made using water, so it is possible that any evident halite grains were dissolved away during preparation. These same samples also showed peaks consistent with quartz, but quartz was not identified in thin section. Quartz may be a constituent of the microcrystalline materials observed throughout the thin section.

SEM analysis

SEM-analyses of sediments above the cemented level were uninformative. No distinct mineralogical structures were noted.

TOP OF CEMENTED LEVEL

The cemented level was first encountered between 40–45 cmbd. Numerous samples were taken from sediment bags at this horizon. Because the mineralogy of the excavated section becomes unique at this horizon, we draw a distinction between the top of the cemented level and the cemented level. One of our samples from 40–45 cmbd was loosely-cemented and broke easily in hand sample. This sample was distinct from more well-cemented materials at lower depths in the cemented level. Other sediments from the top of the cemented level at 40–45 cmbd were unconsolidated and loose.

Light microscopy

The loosely-cemented sample from 40–45 cmbd had particles of bone that were observable by the naked eye and in thin section. The color and texture of that sample resembled bat guano, so there was focus towards discerning phosphate minerals. The index of refraction of material from that sample was less than 1.5 (phosphate minerals have indices of refraction larger than 1.5), so it is certain that phosphate minerals were not dominant constituents. Phosphate may be present, but amorphous.

XRD analysis

XRD-analyses of the loosely-cemented sample from 40–45 cmbd showed it to be dominated by Mg-calcite. Comparisons of the XRD pattern from this sample to huntite, a common magnesium-rich carbonate ($CaMg_3(CO_3)_4$) known to occur as an evaporite in caves (Hill and Forti, 1997), were inconclusive.

XRD-analysis of a sample of unconsolidated sediments from 40–45 cmbd showed peaks consistent with nitratine, halite, calcite, and gyspum. Nitratine ($NaNO_3$), also called nitratite (Hutchinson, 1950) and soda niter (Gaines et al., 1997), is isostructural with calcite (Hill and Forti, 1997), and exhibits many similar optical properties to calcite (such as high birefringence and rhombohedral cleavage).

SEM analysis

No SEM-analyses of sediments from the top of the cemented level were conducted.

Cemented Level

Light microscopy

Thin section analyses of the stratigraphically lower, cemented-level samples showed the dominant phase occurring as porous or spongy bladed aggregate. These samples were well-cemented as compared to the samples from the top of the cemented level (40–45 cmbd). A predominance of nitratine in XRD analyses suggests that nitratine is most likely the cementing mineral. Calcite and nitratine are essentially indistinguishable in light microscopy.

XRD analysis

Three XRD-analyses of samples taken from cemented level were dominated by nitratine. Smaller amounts of calcite, gypsum, and bone also were present. Two bone samples exhibiting secondary mineral deposition were taken from the cemented level and analyzed using XRD. XRD-analysis also showed distinct peaks indicative of nitratine with smaller amounts of halite.

Three additional tests were performed to confirm the presence of nitratine in Cathedral Cave. Comparisons of XRD data with nitratine from The University of Texas mineral collection (Figs. 3a and 3b), dissolution and re-precipitation of the mineral, and a taste-test following Gaines et al. (1997) supported the identification of nitratine. No other nitrate mineral was identified in this research. Calcium nitrate ($Ca(NO_3)_2$) is conspicuously absent, despite the availability of calcium in a carbonate setting. This may be due to the greater sensitivity to relative humidity of ($Ca(NO_3)_2$) (Hill, 1981).

SEM analysis

SEM-analyses of sediments in the cemented level were uninformative. No distinct mineralogical structures were noted.

Sediments Below the Cemented Level (excluding discrete, white sediment pockets)

Light Microscopy

Analyses of the sediments below the cemented level (70–75 cmbd and 100–105 cmbd) showed many similarities to sediments above the cemented level. Both samples contain angular calcite grains with micro-fractures, and some grains are coated with clay-sized particles. Angular calcite grains with micro-fractures also are present as isolated particles. Grains composed of a mixture of material also contain smaller particles of calcite. Gypsum occurs as colorless, fine-grained material between larger particles. Bone is also present in these samples.

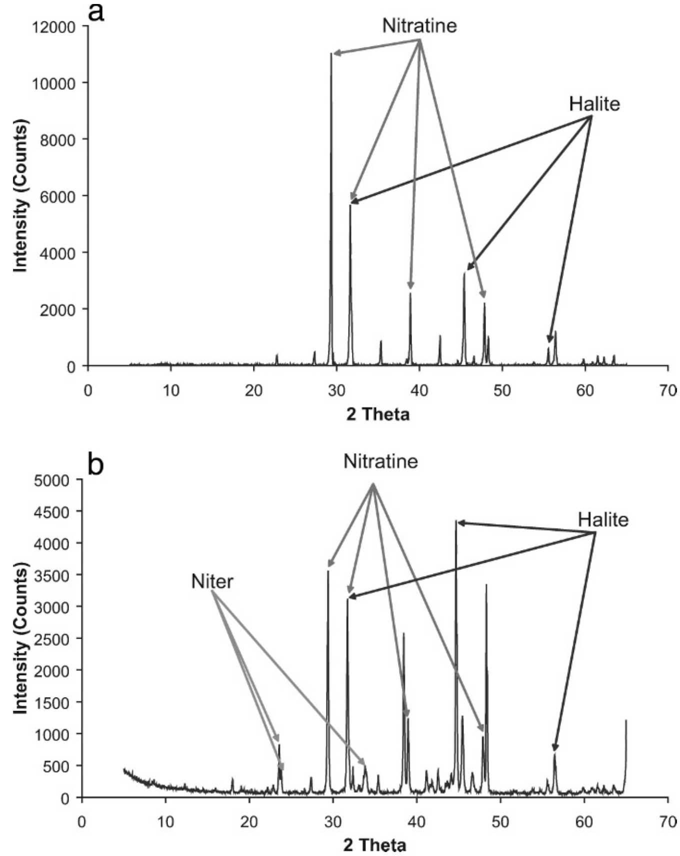

Figure 3. X-ray diffraction (XRD) data. Patterns were generated using Cu K-α radiation. (a) Example of XRD pattern from the cemented level showing the presence of nitratine (peaks marked) (b) XRD pattern of nitratine from the University of Texas collection (peaks marked).

XRD analysis

The presence of calcite was demonstrated using XRD-analyses in all five samples taken from below the cemented level. Two of the samples show peaks consistent with quartz (70–75 cmbd and 100–105 cmbd), two samples show peaks consistent with dolomite (60–65 cmbd and 87–102 cmbd), and one sample showed peaks consistent with aragonite (87–102 cmbd). Again, microcrystalline particles were present throughout the thin section and quartz may be a constituent of that material.

SEM Analysis

SEM-analyses of sediments below the cemented level were uninformative. No distinct mineralogical structures were noted.

White Sediment Pockets Below Cemented Level

Light microscopy and XRD-analysis of the powdery, white sediment showed it to be predominantly composed of gypsum with some calcite. Energy Dispersion Spectrometry (EDS) analyses on the SEM confirmed the presence of calcium and sulfur. The grains of gypsum did not show any preferred orientation, and grain size did not vary within individual samples or between samples. Smaller detrital materials were scattered throughout the sample, including small fragments of calcite, bone and particles consisting of a mixture of material.

NITRATINE IN CATHEDRAL CAVE

The presence of nitratine in Cathedral Cave provides an additional record of that rare mineral for the state of Nevada. Only four other occurrences of nitratine in Nevada are reported (Castor and Ferdock, 2004). Those records come from Churchill, Elko, Pershing, and Washoe Counties, making ours the first report of nitratine from White Pine County. With the possible exception of the Pershing County record, all of the earlier occurrences were associated with niter, and none have been reported since 1941 (Gianella 1941; not seen, cited in Castor and Ferdok, 2004).

In most cases, the source for the nitrate ion is biological (Hill and Forti, 1997). Nitratine is known to occur as a derivation of bat and woodrat urine (Hill and Forti, 1997), and fossils of these animals occur throughout the excavated section at Cathedral Cave. Those organisms likely played a crucial role with regard to chemical inputs into the cave. If the origin of the nitrate ion at Cathedral Cave is biological, then it is plausible to speculate that other nitrate minerals should be present in the sediments as well. However, that is not the case, and the absence of other nitrate minerals (e.g., $Ca(NO_3)_2$) would seem to indicate either a sampling bias and/or a unique enrichment of sodium in the cemented level. Because the XRD data supports the identification of nitratine ($NaNO_3$), we prefer the latter explanation.

Other potential sources of sodium at Cathedral Cave include other biological origins (non-urine) and dissolution processes. Woodrats are avid collectors of vegetation detritus within a local setting (Betancourt et al., 1990). Saltbush (*Atriplex* sp.) occurs in the vicinity of Cathedral Cave today and did so in the past as well (Thompson, 1979). Species of *Atriplex* are halophilic and will concentrate salts in their leaves in response to salt-stress (Bajii et al., 1998). Detrital material from saltbush enriched in sodium and brought into the cave by woodrats constitutes a potential source of sodium into the cave. Presently, woodrat middens from Cathedral Cave have not been analyzed, but saltbush is known from woodrat middens collected at other localities in Smith Creek Canyon and the Great Basin (Thompson, 1979).

Another possible source of sodium is related to dissolution processes within local bedrock. The source of sodium may be derived from the dissolution of a halide bed. We found no literature references to sulfate or halide beds in the Pole Canyon Limestone, Lincoln Peak Formation, or Johns Wash Limestone. However, sodium that is not bonded with chlorine can exist in significant quantities in marine carbonates (Land and Hoops, 1973).

It is impossible to state accurately the extent of nitratine in Cathedral Cave. The cemented level constituted a 15 cm interval in a 1 m × 1 m grid, so each of the samples can fall anywhere within a 150,000 cm^3 spacing. The occurrence of nitratine was confirmed in two grids. Nevertheless, in all analyses of the cemented level (excluding analyses from the top of the cemented level), nitratine was the dominant constituent. Given the sensitivity of nitratine with respect to relative humidity, its occurrence at Cathedral Cave is potentially informative with regards to paleoenvironmental conditions within the cave.

Nitratine is hygroscopic and deliquescent, and is only stable within a particular range of humidity (Hill, 1981). According to Hill, if relative humidity and temperature exceed a critical value, nitratine "will dissolve and seep into the surrounding sediment or bedrock" (Hill, 1981, p. 131). The instability of nitratine in humid environments calls the timing of the deposition of the nitratine in the cemented level in Cathedral Cave into question.

Several lines of evidence suggest that the nitratine was deposited subsequent to the deposition of other sediments in this horizon. This interpretation is supported by the relatively shallow depth of the nitratine occurrence, and the occurrence of the gypsum pockets that are commonly associated with guano soils (Hill and Forti, 1997). Under this scenario, a likely source for the nitrate and sulfate ions would be bat guano. Similar to deposits of desert caliche, nitrates and sulfates could have been leached from a guano deposit on the cave floor and carried down to some depth where they then re-precipitated at the level encountered during the excavation. The necessary chemical constituents could have entered the system at any post-depositional point relative to non-cementing sediments in this horizon. Although we found no reports of caliche-like layers in cave soils, caliche-like nitrate soils are widely reported from the Atacama Desert in Chile (e.g., Böhlke et al., 1997). This interpretation of the cemented layer would constitute a unique contribution to the science of cave mineralogy.

However, an alternative interpretation is that the deposition and crystallization of nitratine was synchronous with the surrounding sediments and fossils at the level that the nitratine was encountered during the excavation. This suggests a period of low relative humidity that was less than the critical value where nitratine becomes unstable. We assume that low relative humidity in the cave would be associated with arid conditions surrounding Cathedral Cave. Given that the sediments above and below the cemented level lack nitratine, applying a paleoenvironmental explanation for the occurrence or lack of nitratine is enticing. This is particularly so, because one of the primary goals of the paleontological project at Cathedral Cave relates to understanding mammalian response to environmental change prior to the terminal Pleistocene.

Without additional sedimentological or independent support for either hypothesis, it is not possible to resolve the exact timing of nitratine deposition. Our inability to resolve the timing of nitratine deposition highlights the need for future researchers to consider additional excavation and sampling procedures.

Suggestions for Future Studies

Because this project was conceived post-excavation, there are several issues and challenges that may improve future studies. The sample sizes and choices were limited to sediments that had not been subjected to a post-excavation, wet-screening process. The on-site, dry-screening of unconsolidated sediment samples prevents any type of quantitative analysis of mineral content and likely contributed to false textures (e.g., clay-sized coatings on grains). Another issue that arose as this project developed was the inability to reconstruct detailed, three-dimensional relationships between samples. Many of the samples for this research were selected from 5 cm levels referenced to 1 m × 1 m excavation square meaning that each sample selected can fall anywhere within a 50,000 cm^3 spacing (5 cm × 100 cm × 100 cm). In the context of paleontological studies, excavating in 5 cm intervals is a rigorous protocol. However, for studies that seek to reconstruct paleoenvironmental conditions based on sediment stratigraphy, a much smaller interval would be more informative.

Incorporation of more detailed observations regarding the depositional context (e.g., mineralogy of sediments) of fossils in caves may provide independent and novel data regarding a variety of paleontologically-related questions (e.g., paleoenvironmental, paleohydrology). Near-constant temperatures, varying levels of relative humidity, and isolation from surface weathering are all factors that combine to make cave mineralogy and stratigraphy distinct. In future studies, detailed descriptions of the distribution of soluble elements in the section could help provide insight into the amount of water that has passed through the system.

In the case of Cathedral Cave, the synchronicity of nitratine deposition with vertebrate fossils may have important implications for how Pleistocene mammals interacted with their environment. Independent of the paleontological interpretations, improved understanding of the stratigraphy of cave floor sediments potentially allows for improved interpretations of regional paleoclimatology and paleohydrology.

For future paleontological projects that want to incorporate detailed aspects of sediment stratigraphy, we propose taking small core samples prior to (or in conjunction with) the excavation proceedings. Oriented core samples could be useful for generating cross-sections and chemical/mineralogical distribution graphs. Bedrock samples should also be collected for mineralogical comparisons with excavated sediment sequences. Additionally, temperature and relative humidity measurements of present-day cave conditions would provide a framework for identifying potential element sources in the context of mineral stability regimes. Explaining the occurrence of minerals (or lack thereof) throughout an excavated sequence may help address a variety of research questions and potentially lead to new ones.

Conclusions

Multiple methods of analysis indicate some interesting mineralogical occurrences and anomalies in an excavated, paleontological sequence from Cathedral Cave. The presence of nitratine as a cement throughout a discretely excavated level represents only the fifth known record of this arid-climate indicator from the state of Nevada. While the cemented level may preserve a caliche-like deposit leached from guano, the presence of nitratine highlights the potential of detailed, mineralogical studies for providing independent environmental data for paleontological research. Although this project did not follow an ideal methodological path to completion, it serves to illustrate the potential gain from such projects.

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Literature Cited

Bajii, M., Kinet, J.M., and Lutts, S., 1998, Salt stress effects on roots and leaves of *Atriplex halimus* L. and their corresponding callus cultures: Plant Science, v. 137, p. 131–142.

Barnosky, A.D., Bell, C.J., Raynolds, R.G., and Taylor, L.H., 2004, The Pleistocene fossils of Porcupine Cave, Colorado: Spatial distribution and taphonomic overview, *in* Barnosky, A.D., ed., Biodiversity response to climate change in the Middle Pleistocene: The Porcupine Cave fauna from Colorado, Berkeley, University of California Press, p. 6–26.

Betancourt, J.L., Van Devender, T.R., and Martin, P.S., eds., 1990, Packrat Middens:The Last 40,000 Years of Biotic Change, Tucson, Arizona, The University of Arizona Press, 467 p.

Böhlke, J.K., Ericksen, G.E., and Revesz, K., 1997, Stable isotope evidence for an atmospheric origin of desert nitrate deposits in northern Chile and southern California, U.S.A.: Chemical Geology, v. 136, p. 135–152.

Castor, S.B., and Ferdock, G.C., 2004, Minerals of Nevada, Reno, Nevada, University of Nevada Press, 512 p.

Gaines, R.V., Skinner, H.C.W., Foord, E.E., Mason, B., and Rosenzweig, A., 1997, Dana's New Mineralogy. 8th ed., New York, John Wiley & Sons, Inc., 1819 p.

Gianella, V.P., 1941, Nevada's Common Minerals, Carson City, Nevada, State Printing Office, 110 p.

Gillieson, D., 1996, Caves: Processes, Development, and Management, Oxford, Blackwell Publishers, 324 p.

Grayson, D.K., 1993, The Desert's Past: A Natural Prehistory of the Great Basin, Washington, D.C., Smithsonian Institution Press, 356 p.

Hill, C., 1981, Mineralogy of cave nitrates: National Speleological Society Bulletin, v. 43, p. 127–132.

Hill, C., and Forti, P., 1997, Cave Minerals of the World 2nd Ed., Huntsville, Alabama, National Speleological Society Inc., 463 p.

Hose, R.K., and Blake, Jr., M.C., 1976, Geology and mineral resources of White Pine County, Nevada. Part 1: Geology: Nevada Bureau of Mines and Geology Bulletin, v. 85, p. 1–32.

Hutchinson, G.E., 1950, Survey of contemporary knowledge of biogeochemistry: Bulletin of the American Museum of Natural History, v. 96, p. 393–402.

Jass, C.N., 2005, A re-evaluation of the age assignment of Cathedral Cave, Nevada: Journal of Vertebrate Paleontology, v. 25, no. (supplement to number 3), 74A p.

Land, L.S., and Hoops, G.K., 1973, Sodium in carbonate sediments and rocks: A possible index to the salinity of diagenetic solutions: Journal of Sedimentary Petrology, v. 43, p. 614–617.

Nesse, W.D., 2000, Introduction to Mineralogy, New York, Oxford University Press, 442 p.

Thompson, R.S., 1979, Late Pleistocene and Holocene packrat middens from Smith Creek Canyon, White Pine County, Nevada, *in* Tuohy, D.R., and Rendall, D.L., eds., The archaeology of Smith Creek Canyon, eastern Nevada, Carson City, Nevada State, Museum Anthropological Papers 17, p. 363–380.

APPENDIX 1.

Summary of sediment samples utilized in this study by material, level, and grid. 'Bulk sediment' represents a sample of loose, unconsolidated matrix irrespective of color. 'White sediment' represents discrete samples of white colored sediments found in isolated pockets below 53 cmbd. 'Bone' samples represent isolated elements that were encrusted with secondary mineral deposition. The type of collection method listed separates those samples collected in the field versus those collected in the lab from dry-screened sediments. TS = Thin Section, XRD = X-ray diffraction analysis, SEM = Scanning Electron Microscopy. If the sample number for a given level exceeds one, the actual number of samples is indicated in parentheses.

Material	Sample Level	Sample Grid	Type	Analysis(es)
Bulk Sediment	25–30 cmbd	1N3E	lab	TS, XRD, SEM
Bulk Sediment	35–40 cmbd	2N3E	lab	TS, XRD, SEM
Bulk Sediment	35–40 cmbd	2N3E	lab	XRD
Bulk Sediment	40–45 cmbd (cemented)	1N3E	field	TS (2), XRD, SEM
Bulk Sediment	40–45 cmbd (not cemented)	2N3E	lab	XRD (2)
Bulk Sediment	45–60 cmbd (not cemented)	2N 2-3E	field	XRD
Bulk Sediment	Cemented	1N3E	field	TS, XRD (2)
Bulk Sediment	Cemented	2N3E	field	TS, XRD, SEM
Bulk Sediment	60–65 cmbd	1N 2E	lab	XRD
Bulk Sediment	60–65 cmbd	1N 3E	lab	XRD
Bulk Sediment	70–75 cmbd	2N3E	lab	TS, XRD, SEM
Bulk Sediment	100–105 cmbd	2N3E	lab	TS, XRD, SEM
Bulk Sediment	87–102 cmbd	2-3E 2N-1N	lab	XRD
White Sediment	65–70 cmbd	1N3E	lab	TS (2)
White Sediment	65–70 cmbd	2N3E	field	TS (2), XRD, SEM
Bone	Varies	Varies	field	TS (2), XRD (2), SEM

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A REVIEW OF THE BIOSPELEOLOGY OF MEGHALAYA, INDIA

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Abstract This paper reviews the current state of knowledge of the biospeleology of the northeast Indian hill state Meghalaya. Since the early 1990s the Meghalayan Adventurers Association (based in Shillong), in partnership with European speleologists, has conducted a series of projects with the objective of mapping and documenting caves. To date over 320 km of cave passage have been mapped and much more remains to be discovered. The quantity and length of caves in Meghalaya exceeds that of any other known karst region of India. An exhaustive search of historical records yielded one highly detailed biological survey of a single cave in the west of the state and a few records of opportunistic specimen collection from caves at other locations. This data is supplemented by a review of numerous biological observations made during the Meghalayan Adventurers Association cave mapping program. Taxa with pronounced troglomorphic characteristics appear to be relatively common in the Jaintia Hills region of eastern Meghalaya and rare elsewhere in the state. In contrast, taxa with partial troglomorphy are widespread throughout Meghalaya. There is a range of taxa which occur regularly within caves and should be considered as significant components of the cave ecosystem regardless of troglomorphy. In some cases there is evidence of reproductive activity and opportunity for feeding which indicates that a proportion of the population complete their lifecycle within the caves and can be regarded as troglophiles. Sources of nutrition are primarily composed of flood borne debris, although dense colonies of bats (or cave-nesting swiftlets at some sites) can also contribute. The composition of cavernicole communities is not constant throughout the region and varies due to environmental and geographic factors. A major expansion of the limestone extraction industry is underway in the Jaintia Hills and elsewhere in Meghalaya. This will inevitably cause significant destruction and perturbation of cavernicole habitat. It would be prudent to implement formal studies to document the biospeleology of the region before significant loss or damage occurs.

Introduction

Meghalaya is situated in the far northeast of India on the northern border of Bangladesh (Figs. 1 and 2). Over most of the state the topography is that of a hilly plateau which reaches altitudes of over 1000 m. The plateau is bounded to the north and to the west by the river plains of the Bramaputra and to the south by the plains of Bangladesh. Along the southern and eastern margins of the plateau there is a band of limestone interstratified with sandstone beds. This band is discontinuous due to divisions caused by differential tectonic uplift, associated faulting and deep concordant river valleys that run southwards off the plateau to the plains of Bangladesh. The limestone band extends from west to east along the southern boundary of the state and is approximately 200 km long and 30 km wide. It runs from the West Garo Hills in the west through the West Khasi Hills, East Khasi Hills and into the Jaintia Hills in the east. During the monsoonal months of May to October the region experiences some of the world's highest recorded rainfall, while during the rest of the year, the climate is mild and dry.

Until relatively recent times only a handful of the Meghalayan caves had been formally documented. The first systematic program to explore, map and catalogue the Meghalayan caves was initiated in 1992 by the Meghalayan Adventures Association. The program subsequently expanded and partnerships were formed with speleologists from several European countries and the USA. The program is ongoing, and to date, over 320 kilometers of cave passage have been mapped and over a thousand cave entrances have been documented. It is thought that this accounts for only a small proportion of the caves that remain to be discovered in the state (Brooks and Brown, 2008). It is undisputable that the quantity and length of caves in Meghalaya far exceed that of any other known karst region of India.

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Figure 1. Location of Meghalaya showing approximate distribution of limestone.

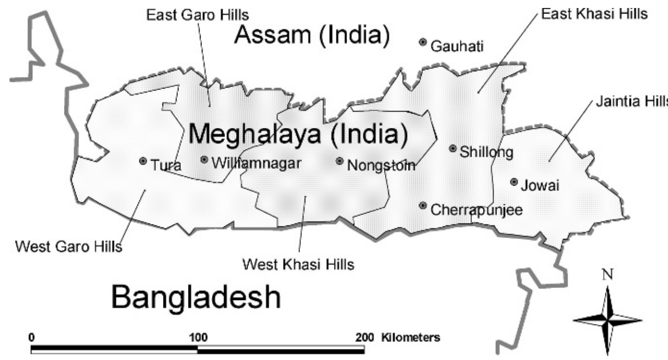


Figure 2. Outline map of Meghalaya showing main towns and boundaries of hill regions.

PRE-EXISTING LITERATURE

The coverage of existing published literature on the biota of Meghalayan caves is sparse. By far the most thorough of the studies was made in February 1922 by Kemp, Chopra and Hodgart of the Zoological Survey of India. They spent three weeks conducting a comprehensive survey of the fauna of Siju Cave in the West Garo Hills. The survey covered areas from the entrance to a point 1200 m within the cave and topography is described. The habitats and distribution of species within the cave are reported, and abundance, behavioural and ecological notes are given for selected species. The findings of this study were subsequently published in a series of papers (Andrewes, 1924; Annandale and Chopra, 1924; Blair, 1924; Brunetti, 1924; Cameron, 1924; Carpenter, 1924; Chopard, 1924; Chopra, 1924; Edwards, 1924; Fage, 1924; Fletcher, 1924; Fleutiaux, 1924; Gravely, 1924; Hora, 1924; Kemp, 1924a; Kemp, 1924b; Kemp and China, 1924; Kemp and Chopra, 1924; Lamb, 1924; Meyrick, 1924; Ochs, 1925; Patton, 1924; Roewer, 1924; Rohwer, 1924; Silvestri, 1924; Stephenson, 1924; Wheeler, 1924).

The Siju survey recorded the presence of 102 taxa within the cave. The presence of 16 of these taxa was judged to be accidental and a further 53 were restricted to the threshold zone. Of the remaining 33 taxa only four species were thought to show troglomorphic traits. These included a terrestrial gastropod (*Opeas cavernicola*), two species of terrestrial isopod (*Philoscia dobakholi* and *Cubaris cavernosus*) and an aquatic decapod (*Macrobrachium cavernicola*). The troglomorphy was not pronounced and consisted of a variable degree of reduction in eye size and pigmentation as related to comparable epigean species.

A number of other published records also relate to the biological communities of Siju Cave. There is early literature describing a species of reduviid bug from Siju Cave (Paiva, 1919) and this species was subsequently re-recorded during the 1922 survey. In 1971 Dr Yazdani collected fish from the stream issuing from the entrance of Siju Cave. Specimens collected at an unspecified distance within the cave were identified as *Schistura multifasciata* (Pillai and Yazdani, 1977) and it was suggested that these corresponded to the nemacheiline loach reported by Hora (1924). However, Hora's material has also been identified as *Schistura beavani* (Hora 1935) and described as *Schistura sijuensis* (Menon, 1987). There is clearly some uncertainty regarding the identity of the *Schistura* species reported from Siju Cave (Kottelat et al., 2007) but it can be stated that the specimens showed no significant troglomorphy and that there is insufficient information to establish their status as cavernicoles. A more recent survey of Siju Cave (Sinha, 1999) was primarily aimed at documenting the bat fauna but also includes some records of other organisms found in the vicinity of the cave entrance.

The majority of the remaining literature consists of taxonomic descriptions of cavernicoles with little contextual information. Several records relate to caves in the Cherrapunji area of the East Khasi Hills. Collinge (1916) described two species of cavernicolous isopods from the area. These were *Burmoniscus kempi* (name revised to *Rennelloscia kempi* (Vandel, 1972), now accepted under original name [Schotte et al., 1995]), collected from Mawsmai Cave by S.W. Kemp and *Cubaris cavernosus* collected from unspecified caves by R. Friel. Both taxa show some degree of troglomorphy including reduced eye size and depigmentation. The cavernicolous orthopteran *Eutachycines brevifrons brevifrons* (*Diestrammena brevifrons*) was described by Chopard (1919) also based on material collected from Mawsmai Cave. The species does not show marked troglomorphy. In 1947 Lindberg collected

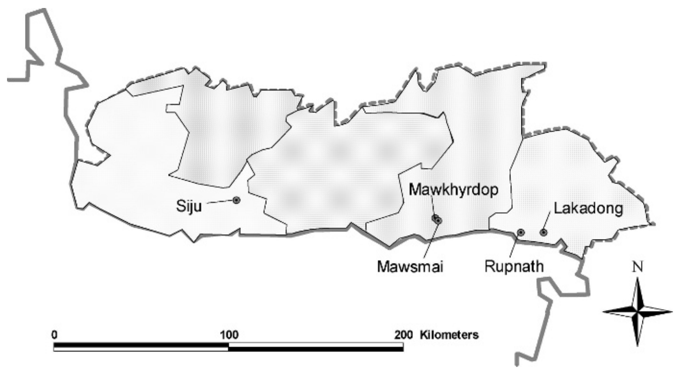


Figure 3. Locations of Meghalayan caves covered by previous biospeleological literature.

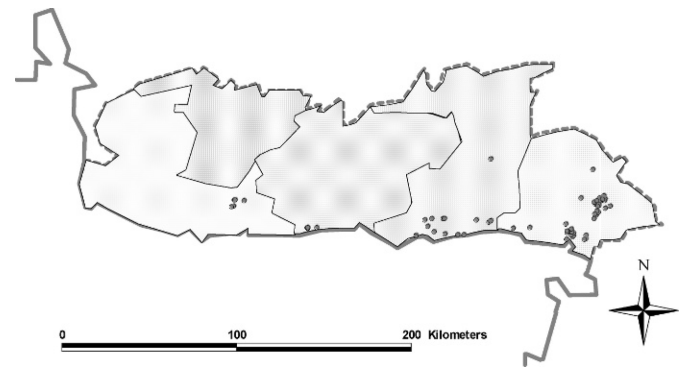


Figure 4. Locations of caves represented in database.

biological material from a cave near Cherrapunji. This was named as Mawsmai in the subsequent publications but from the description given it is thought that the actual location was Mawkhyrdop Cave (Gebauer, 2003, p. 73). Lindberg's work yielded records of the isopods *Burmoniscus kempi* and *Cubaris cavernosus* (Lindberg, 1960), the slightly troglomorphic shrimp *Macrobrachium cavernicola* (Lindberg, 1960), a cavernicolous millipede, *Assamodesmus lindbergi* (Manfredi, 1954), and also unspecified Hydras, oligochaetes, insect larvae and cosmopolitan cyclopoid and harpacticoid copepod species (Lindberg, 1949).

There are records relating to two caves in the Jaintia Hills. Two cavernicolous orthopterans were described from material collected in 1921 by R. Friel from Lakadong Cave (Chopard, 1924). These were *Eutachycines brevifrons frieli* (originally *Diestrammena brevifrons frieli*) which does not show marked troglomorphy, and *Eutachycines caecus* (originally *Diestrammena caeca*) which is strongly troglomorphic being both depigmented and anopthalmous.

A troglomorphic dictyopteran, *Typhloblatta caeca* (previously *Spelaeoblatta caeca*), was described from Rupnath Cave (Krem Jognindra) in the Jaintia Hills (Chopard, 1921). The species is totally depigmented, anopthalmous and is clearly a troglobite. The cavernicolous orthopteran *Eutachycines brevifrons frieli* has also been recorded from Rupnath Cave (Chopard, 1921). The specimens were collected by R. Friel and W. Ballantine.

In summary, the literature covers one cave in the West Garo Hills, two caves in the East Khasi Hills and two caves in the Jaintia Hills (Fig. 3). It is notable that the relatively rigorous examinations of Siju Cave (West Garo) and caves near Cherrapunji (East Khasi) yielded no species with well developed troglomorphy, whereas the opportunistic collecting from the two caves in the Jaintia Hills yielded two species with strongly developed troglomorphy.

Recent Data

The cave mapping program that has been ongoing since 1992 has yielded numerous additional records of biological observations made within caves. These records have been collated into a database and plotted using GIS software to assess trends in the geographic distribution of cavernicoles within Meghalaya. The database currently includes in excess of 1000 records representing ~90 distinct taxa and 80 separate caves (Fig. 4).

Coverage is discontinuous and reflects the distribution of cave mapping effort. There is a concentration of records in the Jaintia Hills and sparse coverage in the western parts of the state. The quality of records is also variable and some represent broadly defined taxa (e.g., crickets) which are of little value in determining geographic trends. Most records refer only to relatively large taxa. Small inconspicuous fauna such as copepods, nematodes and mites are known to occur but are under-represented in the data. It is probable that a sampling program targeted at the smaller taxa would yield interesting new discoveries.

For the majority of caves, biological records were made as incidental observations during the course of cave mapping. Targeted biological surveys have been conducted at six caves (Fig. 5). In these caves species abundances were estimated at defined locations, and meat baits were used to attract scavenging fauna. The survey locations within the caves were selected to represent different environmental conditions and different degrees of remoteness from the

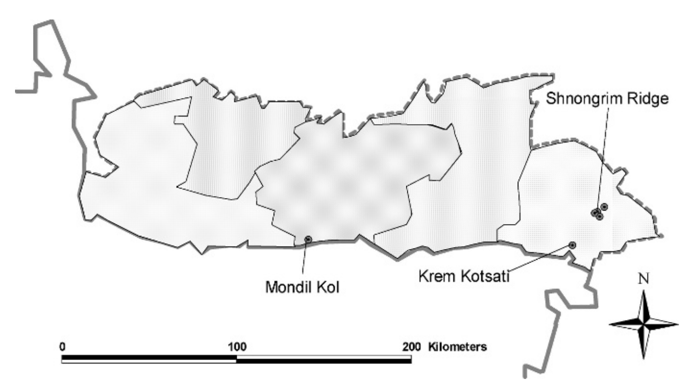


Figure 5. Locations of caves where targeted biological surveys were conducted.

Table 1. Taxa exhibiting pronounced troglomorphy.

Taxonomic group	Provisional name in database	Probable identity	Troglomorphy	Number of caves
Arachnida - Spider	Oonopidae sp.	unknown	Depigmented & anopthalmous.	1
Arachnida - Opiliones	Opiliones sp. 1	Assamidae indet.	Depigmented & anopthalmous.	4
Arachnida - Opiliones	Opiliones sp. 2	Assamidae indet.	Depigmented & anopthalmous.	1
Insecta - Orthoptera	Rhaphidophoridae sp. 2	*Eutachycines caecus*	Depigmented & anopthalmous.	10
Insecta - Dictyoptera	Blattoidea sp. 1	*Typhloblatta caeca*	Depigmented & anopthalmous.	12
Teleostei	*Nemachilus* sp. 1	*Schistura papulifera*	Depigmented & anopthalmous.	16

surface. Four of these caves are within a relatively small area on the Shnongrim Ridge of the Jaintia Hills. A fifth (Krem Kotsati) is in a lower altitude area near the village of Lumshnong and the sixth (Mondil Kol) is in the West Khasi Hills.

Data Overview — Troglomorphic Taxa

A review of the data indicates that Meghalayan cavernicolous taxa exhibit varying degrees of troglomorphy. Taxa with pronounced troglomorphy occur most frequently in the Jaintia Hills in the eastern part of the state while taxa with partial troglomorphy tend to have a broader distribution.

We have categorised degree of troglomorphy based on pigmentation and degree of eye reduction. Taxa categorised as displaying pronounced troglomorphy are shown in Table 1. These taxa are totally depigmented and anopthalmous with the exception of *Schistura papulifera* where tiny vestigial eyes are present in juveniles. Taxa categorised as displaying partial troglomorphy are shown in Table 2. These taxa exhibit varying degrees of depigmentation and reduction of eye size. None are both totally depigmented and anopthalmous. The anopthalmia of *Assamodesmus lindbergi* is not necessarily a troglomorphic trait as it is a member of the polydesmida all of which are anopthalmous.

Taxa with pronounced troglomorphy have been recorded in 20 caves in the Jaintia Hills, and more than half of these caves had multiple troglomorphic taxa (Fig. 6). The only records outside of the Jaintia Hills are of dictyopterans and opiliones in two caves in the West Khasi Hills.

Taxa with partial troglomorphy have been recorded from caves throughout the state (Fig. 7). There is a greater frequency of records from the caves of the Jaintia Hills, but this may be due to uneven survey effort rather than a true trend in the distribution in the fauna.

Data Overview — Characteristic Cavernicoles

A number of taxa occur within caves with sufficient frequency and abundance to be considered ecologically important cavernicoles regardless of troglomorphy.

Arachnida (Spiders)

Large, conspicuous spiders of the genus *Heteropoda* are among the most commonly recorded of the Meghalayan cave fauna (Fig. 8). They are often abundant and tend to be most common on passage walls and ceilings near cave entrances, but can also occur much deeper within the caves. At least two species of *Heteropoda* are present. *H. robusta* (Fage, 1924) predominates in the western part of the state (Garo and West Khasi Hills) while *H. fischeri* (Jager, 2005) appears to be more widespread, particularly in the eastern part of the state (Jaintia Hills).

In Siju in 1922, *H. robusta* was abundant and seen to be reproducing, but they were not seen feeding (Fage, 1924;

Table 2. Taxa exhibiting partial troglomorphy.

Taxonomic group	Provisional name in database	Probable identity	Troglomorphy	Number of caves
Gastropoda	*Opeas* sp.	*Opeas cavernicola*	Eyes reduced.	3
Arachnida - Pseudoscorpiones	Pseudoscorpiones Sp. 1	unknown	Pigmented & anopthalmous.	1
Arachnida - Spider	*Amauropelma* sp.	unknown	Pigmented & anopthalmous.	3
Crustacea - Decapoda	Caridea sp. 1	*Macrobrachium cavernicola*	Depigmented & eyes reduced.	22
Crustacea - Isopoda	*Cubaris cavernosus*?	*Cubaris cavernosus*	Depigmented & eyes reduced.	11
Crustacea - Isopoda	*Philoscia* sp.	*Philoscia dobakholi*	Depigmented & eyes reduced.	13
Crustacea - Isopoda	Not recorded	*Burmoniscus kempi*	Depigmented & eyes reduced.	2
Myriapoda - Diplopoda	Not recorded	*Assamodesmus lindbergi*	Depigmented & anopthalmous.	1
Insecta - Coleoptera	Trechinae sp 1	unknown	Pigmented & eyes reduced.	3

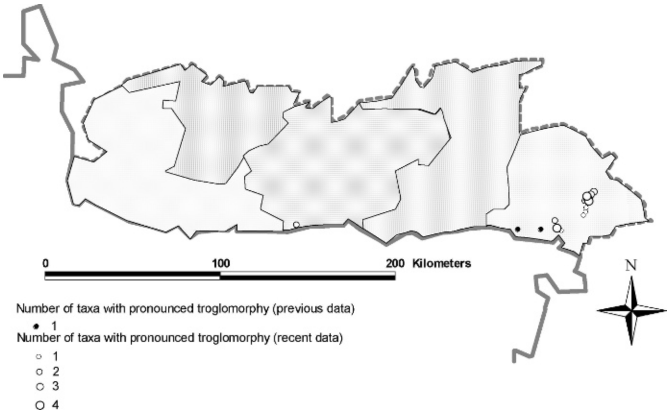


Figure 6. Distribution of caves where taxa with pronounced troglomorphy have been recorded.

Kemp and Chopra, 1924). We have records of *H. robusta* carrying egg sacks in caves in the West Khasi Hills and a record of what appears to be *H. fischeri* carrying egg sacks in a cave in the East Khasi Hills. We also have records of *H. fischeri* feeding on the brown Rhaphidophorid cave crickets in a cave in the Jaintia Hills.

Brachyura (Crabs)

The freshwater crab *Maydelliathelphusa falcidigitis* (formerly *Paratelphusa (Barytelphusa) falcidigitis)* was found to be common in Siju in 1922 (Kemp, 1924b) and was present deep into the cave (730 m). The species was also common in the surface stream outside of the cave and the author considered it to be "a mere straggler into subterranean waters" (accidental trogloxene). We have found similar crabs to be widespread and a distinctive component of the cave fauna (Fig. 9). They are often present deep into the caves and can be abundant in some wet gravelly passages where crab burrows may occur at densities of several burrows per 10 m^2.

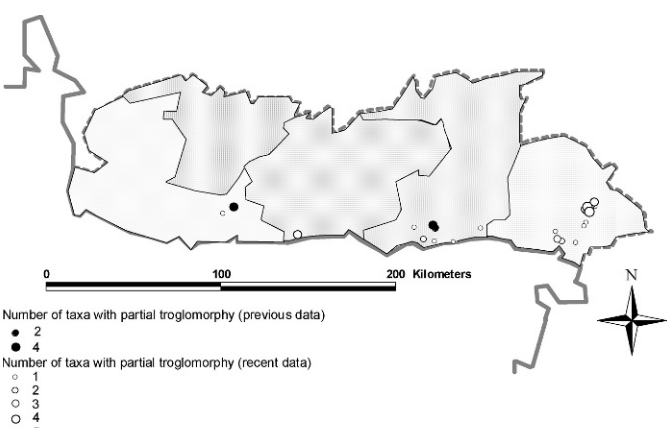


Figure 7. Distribution of caves where taxa with partial troglomorphy have been recorded.

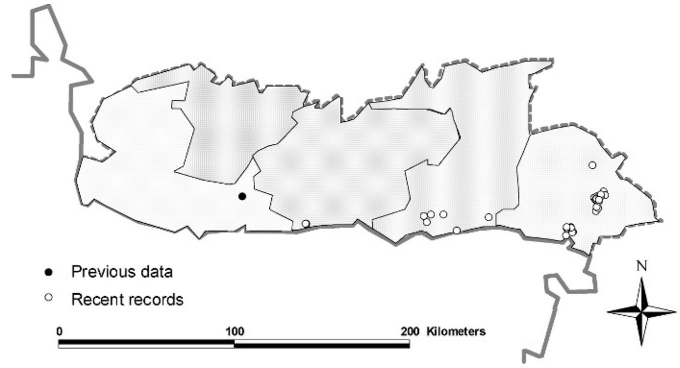


Figure 8. Distribution of *Heteropoda* spp. (43 caves).

In view of their abundance, frequency of occurrence, and deep distribution within the caves, we believe that these crabs should be considered to be troglophiles. In the dry season (November to April) there is very little surface water in the Shnongrim area and the streams feeding the caves on the ridge are totally dry. Consequently it is improbable that the abundant subterranean population of crabs exists as a result of accidental wash-in from the epigean population. In fact it is more plausible to suggest that the epigean population is replenished from the subterranean population which can survive the dry months in the subterranean pools and streams. A comparable process is known to occur in certain fish in the Dinaric karst (e.g. Mrakovčić and Mišetić, 1990).

Palaemonidae (Shrimp)

The shrimp *Macrobrachium hendersoni* and *Macrobrachium cavernicola* were recorded from Siju in 1922 (Kemp, 1924b). The population of *M. cavernicola* appeared to be reproductively active because ovigerous females and juveniles were present. *M. cavernicola* has also been reported from the East Khasi Hills (Lindberg, 1960).

We have found shrimp that approximate to the description of *M. cavernicola* to be widespread and a characteristic component of the cave fauna (Fig. 10). They are often abundant and are present wherever there is water,

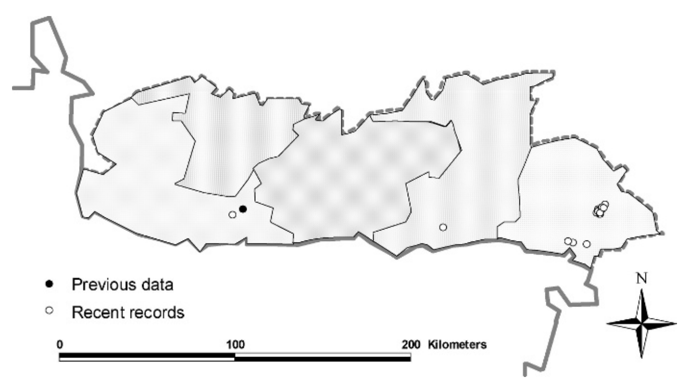


Figure 9. Distribution of *Brachyura* spp. (19 caves).

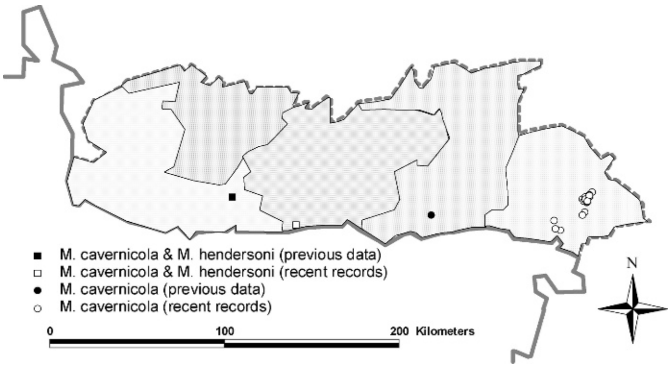


Figure 10. Distribution of *M. cavernicola* (22 caves) and *M. hendersoni* (2 caves).

including small isolated pools of standing water as well as active flowing streamways. Juveniles are frequently present and ovigerous females were noted in one of the caves in the West Khasi Hills. We have no information on the occurrence of these shrimp in surface streams but believe they should be regarded as troglophilic if not troglobitic. The only location where we have recorded shrimp that match the description of *M. hendersoni* was in the West Khasi Hills. They co-occurred with *M. cavernicola* but were immediately distinguishable due to their dark colouration and larger eyes.

ISOPODA (WOODLICE)

Four isopods (*Porcellio assamensis*, *Cubaris cavernosus*, *Philoscia dobakholi*, *Burmoniscus kempi*) have been recorded within Meghalayan caves (Collinge, 1916; Chopra, 1924; Lindberg, 1960). We have recorded isopods which are a close match to *Cubaris cavernosus* and to *Philoscia dobakholi*. Both appear to be widespread and are characteristic members of the cave fauna (Figs. 11 and 12). Both taxa can become abundant in certain environments. *Cubaris* sp. is much more strongly attracted to meat bait than *Philoscia* sp. and has been found to occur in high abundance in areas below bat roosts. *Cubaris* sp. also appears to have a greater degree of environmental tolerance to desiccation than *Philoscia* sp. and can occur in relatively dry passage. *Philoscia* sp. is typically abundant in wet areas particularly where there are deposits of decomposing vegetation. Small depigmented isopods which appear to match neither of these species have been noted in various caves in the Jaintia and Khasi Hills. Further study is likely to document additional species of cavernicolous isopods.

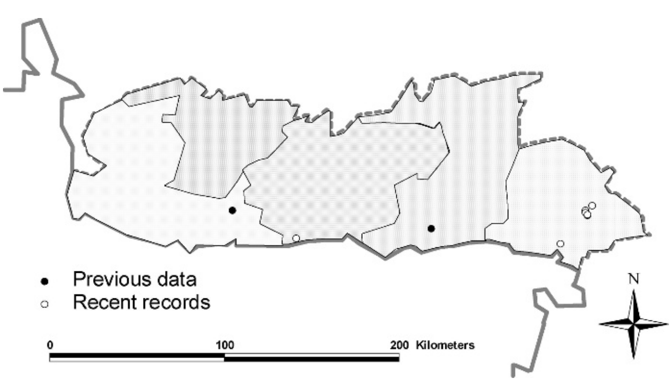


Figure 11. Distribution of *Cubaris* sp. (10 caves).

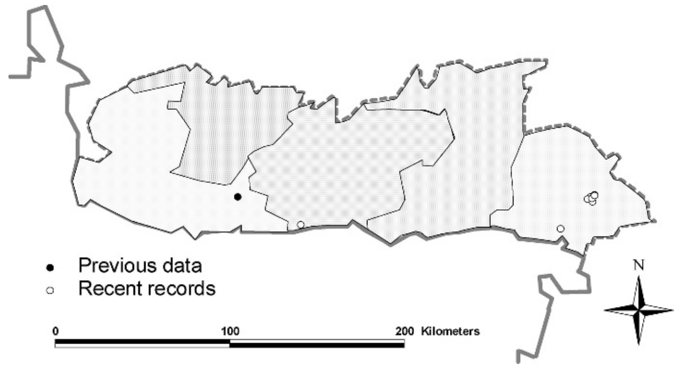


Figure 12. Distribution of *Philoscia* sp. (9 caves).

DIPLOPODA (MILLIPEDES)

The millipede *Trachyiulus mimus* was recorded from Siju in 1922 (Silvestri, 1924). It was found throughout the cave and the author comments that there is no evidence of troglomorphy and considers that it is a "recent inhabitant of the cave".

We have found that *Trachyiulus* is widespread, often abundant and is a characteristic member of the Meghalayan cave fauna (Fig. 13). It is normally found throughout the caves from the threshold area to deep within the cave. It can occur in both wet and dry areas but tends to be more abundant in drier areas away from flood prone active streamways. *Trachyiulus* is strongly attracted to meat bait and large numbers have been observed feeding on dead bats, snakes, insects and on guano and faeces. *Trachyiulus* should certainly be regarded as a troglophile and is undoubtedly an important component of the Meghalayan cave fauna.

ORTHOPTERA (CRICKETS)

Orthoptera are frequently encountered and often abundant in the Meghalayan caves. Three distinct main taxa are represented in the database. Rhaphidophoridae sp. 1 approximates to the published description of *Eutachycines brevifrons*. It is a characteristic member of the cave fauna in the Jaintia Hills (Fig. 14a) and is not markedly troglomorphic. It tends to be most abundant on walls and ceilings within a few hundred metres of cave entrances but can also occur in significant numbers much deeper within the caves. It is strongly attracted to meat bait. It appears tolerant of desiccating conditions and occurs in strongly draughting dry passage where few other

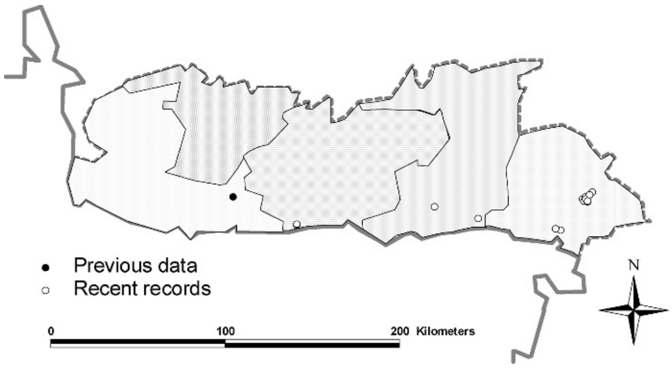


Figure 13. Distribution of *Trachyiulus* sp. (17 caves).

taxa are present. Rhaphidophoridae sp. 2 approximates to the published description of *Eutachycines caecus* and is also a characteristic member of the cave fauna in the Jaintia Hills (Fig. 14b). Size and morphology are similar to Rhaphidophoridae sp. 1 but it is totally depigmented and anopthalmous. It can occur in significant numbers and is particularly common below bat roosts. It tends to be absent from areas close to cave entrances and strongly draughting passages. Both of these taxa can be regarded as significant components of the cave ecosystem in the Jaintia Hills and often co-occur in the same location. They were notably absent from caves in the West Khasi Hills where a third orthopteran of a similar size predominated (Fig. 14c). This taxon (Orthoptera sp. 3) approximates to the published description of *Kempiola longipes* and is not markedly troglomorphic. It was common on rock walls and ceilings in both wet and dry passages and was present throughout the caves including the entrances and inner reaches.

Dictyoptera (Cockroaches)

Troglomorphic dictyopterans have been recorded in 11 caves in the Jaintia Hills (Fig. 15) and approximate to the published description of *Typhloblatta caeca* (Chopard, 1921). There is also a single unverified record of the taxon from a cave in the West Khasi Hills. They generally occur in low numbers but are occasionally common. They are found deep within the caves in both wet and dry passages but appear to be more common in areas that are not flood prone.

Coleoptera (Beetles)

A range of coleopterans have been recorded in the caves but in most cases the level of discrimination between different taxa is too low for their distribution to be examined. Two exceptions are a partially troglomorphic Trechinae and a species of Cholevidae.

Trechinae sp 1 has a strongly pigmented cuticle and vestigial eyes. It has been recorded in low abundances from three separate caves on the Shnongrim Ridge of the Jaintia Hills. It does occur near entrances but is more frequently found deeper in the caves in both wet and dry cave passages.

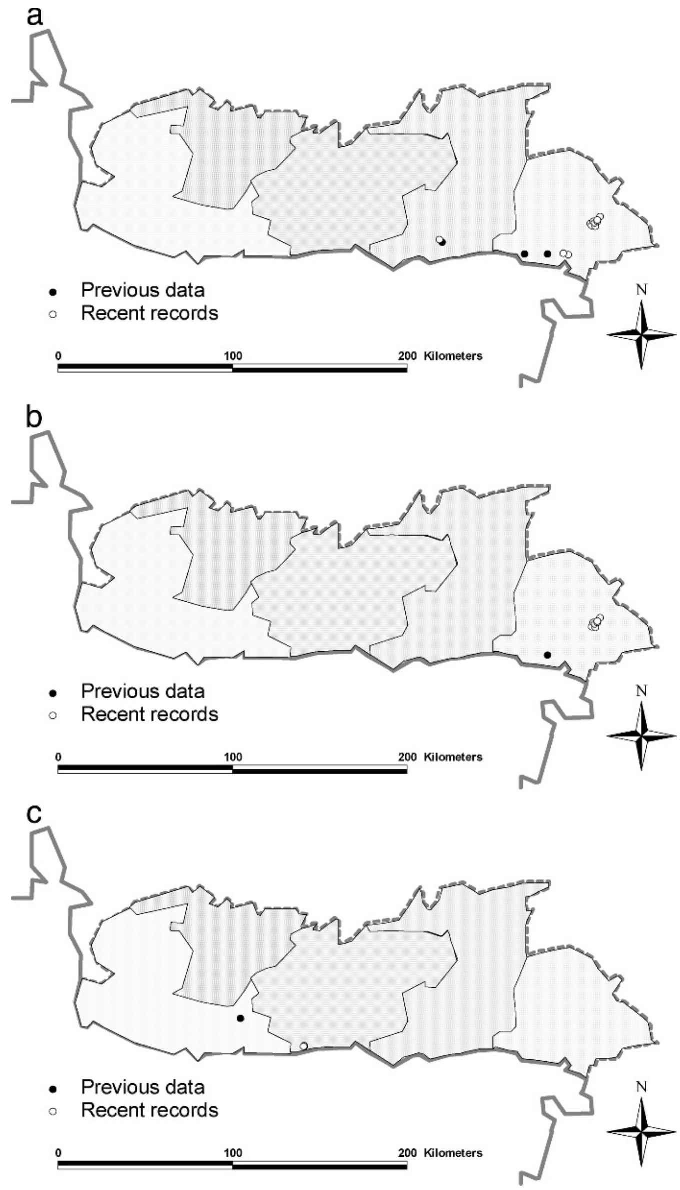


Figure 14a. Distribution of Rhaphidophoridae sp. 1 / *Eutachycines brevifrons* (20 caves).

Figure 14b. Distribution of Rhaphidophoridae sp. 2 / *Eutachycines caecus* (10 caves).

Figure 14c. Distribution of Orthoptera sp. 3 / *Kempiola longipes* (4 caves).

Cholevidae sp 1 is not troglomorphic but has been recorded in locally high abundances deep within three caves on the Shnongrim Ridge of the Jaintia Hills and in one cave near Rongdangi in the West Khasi Hills (Fig. 16). They occur in both wet and dry areas of the caves and are particularly abundant near bat colonies. They have been observed in flight and are strongly attracted to meat bait. It is likely that they represent a sustainable population of troglophiles and feed on the carcasses of dead bats.

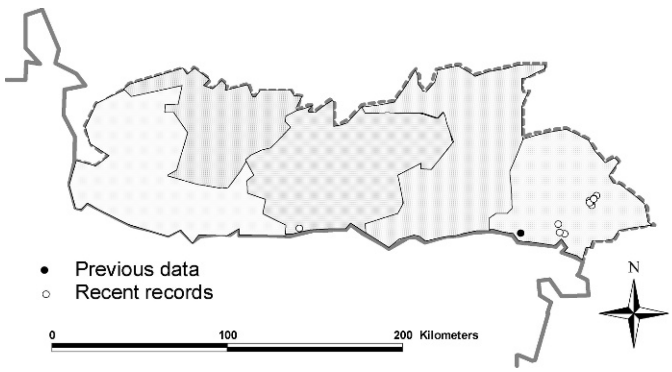


Figure 15. Distribution of troglomorphic dictyopterans (13 caves).

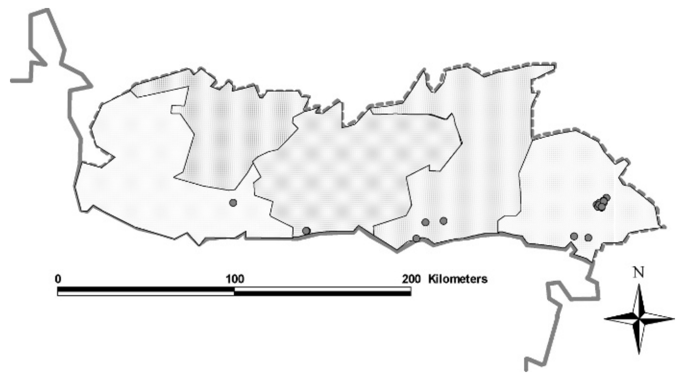


Figure 17. Distribution of Mycetophilidae larvae (19 caves).

DIPTERA (FLIES)

We have records of two significant (disregarding records of single individuals) dipteran taxa. Larval mycetophilidae are commonly recorded in the caves (Fig. 17) and build webs of delicate draperies of vertical sticky strands with the larva living on the upper supporting strand of the web. The webs are suspended from ceilings or overhanging rock and can occur close to entrances and also deep within the caves. The webs are often abundant particularly in passages that carry a substantial air flow.

Conicera kempi was originally described from Siju Cave (Brunetti, 1924). We have records of this species from five additional caves (Fig. 18). They occurred throughout the caves and were sometimes common near bat roosts. They were attracted to meat bait on which they laid eggs and larvae developed. It is probable that these represent a sustainable population of troglophiles. Other species of the family Phoridae also occurred in some of the caves where *Conicera kempi* was present. These were also attracted to meat bait but their distribution tended to be restricted to the areas near cave entrances.

PISCES (FISH)

We have frequent records of unidentified fish within caves, with three taxa occurring on a regular basis. *Schistura papulifera* (Kottelat et al., 2007) is depigmented and has vestigial eyes. It tends to occur in gravelly pools of still water deep within the caves and is often abundant (Fig. 19). *Glyptothorax* sp. is darkly pigmented with small eyes. It is often abundant and can occur deep within the caves both in pools of standing water and in fast flowing streamways (Fig. 20). Large pale carp with well developed eyes (Cyprinidae spp.) are often common and can occur deep within the caves, generally in large pools of standing water (Fig. 21).

The frequency of records, distribution and abundance of both *Glyptothorax* sp. and Cyprinidae spp. would indicate that they are a significant component of aquatic ecosystems within the caves, and it is probable that they exert an influence on the aquatic invertebrate community through predation. In view of this, it is justifiable to regard them as troglophiles. Although their presence in the caves may be attributable to accidental wash-in from surface rivers, this clearly occurs with sufficient frequency to make them regularly occurring and ecologically important components of the cave fauna.

DATA OVERVIEW — COMMUNITY VARIATION

The subjective impressions of the authors suggest that there are distinct differences in the faunal composition of

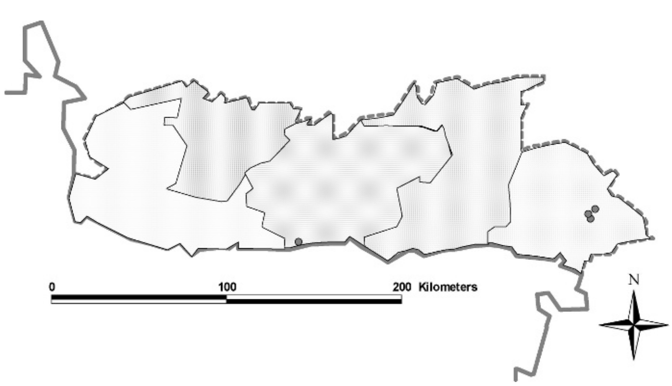


Figure 16. Distribution of Cholevidae sp 1 (4 caves).

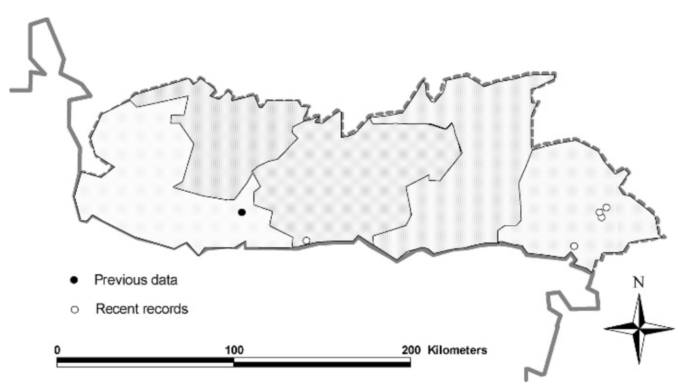


Figure 18. Distribution of *Conicera kempi* (6 caves).

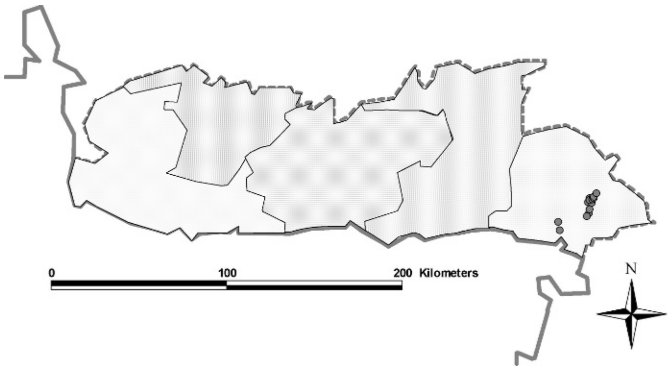


Figure 19. Distribution of *Schistura papulifera* (16 caves).

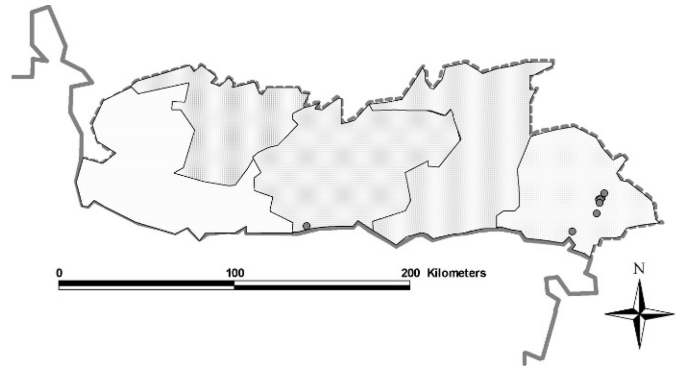


Figure 21. Distribution of Cyprinidae spp. (8 caves).

the Meghalayan caves depending on geographic region and perhaps also on altitude. Attempts to submit the data to an objective analysis are hampered by unbalanced survey effort and inconsistencies in the estimates of faunal abundance between different caves.

Sixteen caves were selected for a comparison of faunal composition. The criteria for selection were that a minimum of ten distinct taxa had been recorded in each cave. Multidimensional scaling analysis (MDS) was performed on species presence within the caves and the results are shown graphically in Fig. 22. It is not possible to assess the significance level of apparent differences in faunal composition due to lack of adequate replication of specific categories of cave.

The plot indicates twelve caves are relatively similar in faunal composition. Eleven of these are from the Shnongrim Ridge in the Jaintia Hills. These all located within a relatively small area (~3 km by ~8 km) at an altitude of about 1000 m to 1100 m above sea level. The twelfth (Synrang Pamiang) is situated some 25 km south west of the Shnongrim Ridge at a somewhat lower altitude of ~800 m. Nevertheless, the faunal composition appears to be broadly similar to the caves of the Shnongrim Ridge.

Two caves (Mondil Kol and Rong Kol) are separate from this main group. These are located in the West Khasi Hills some 150 km west of the main group and are at a considerably lower altitude of ~100 m above sea level. The MDS plot indicates that the faunal composition of these caves is distinct from that of the Shnongrim Ridge caves thus supporting the subjective impressions of the authors. The most obvious differences in the West Khasi Hills fauna are fewer troglomorphic taxa, the presence of *Macrobranchium hendersoni* in addition to *M. cavernicola* and different species of the dominant orthopterans.

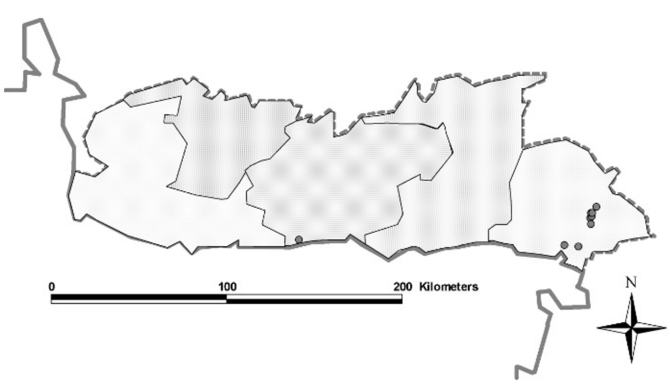


Figure 20. Distribution of *Glyptothorax* sp. (9 caves).

Two outliers remain. Krem Pyrda is located at the foot of the Shnongrim Ridge. We attribute its distinct faunal composition to its small size (length ~250 m as opposed to >1 km in the case of the other caves) and its shallow nature (much of the cave is within a few meters of the overlying surface). Krem Kotsati is located near Synrang Pamiang and its situation contrasts with that of the Shnongrim Ridge caves in a number of ways. The altitude is lower (~650 m ASL), surrounding land is densely vegetated and the cave carries a substantial stream which is likely to flood severely during the rainy season.

With current data it is not possible to establish if the differences between Jaintia and West Khasi cave faunal composition represent geographical distribution trends or if it is a consequence of environmental differences. The West Khasi caves are at much lower altitude than the Shnongrim Ridge caves. The main biological significance of this is that lower altitude caves are likely to be subject to a much greater volume of flood water during the rainy season. There is clear visible evidence of this in some of the West Khasi caves, with substantial tree trunks wedged in cave ceilings many meters above the dry season water level. By contrast, the Shnongrim Ridge caves have a more limited catchment area and watercourses within the caves tend to be steeper with more vertical sections. Consequently they are likely to receive smaller volumes of floodwater with a more rapid transit time through the cave, thus increasing the potential for survival of fauna intolerant of immersion. Other factors may also be significant. The West Khasi caves are at a higher temperature and are in a more densely forested area than the Shnongrim Ridge caves. These factors are likely to result in differences in the composition and abundance of potential colonizing fauna.

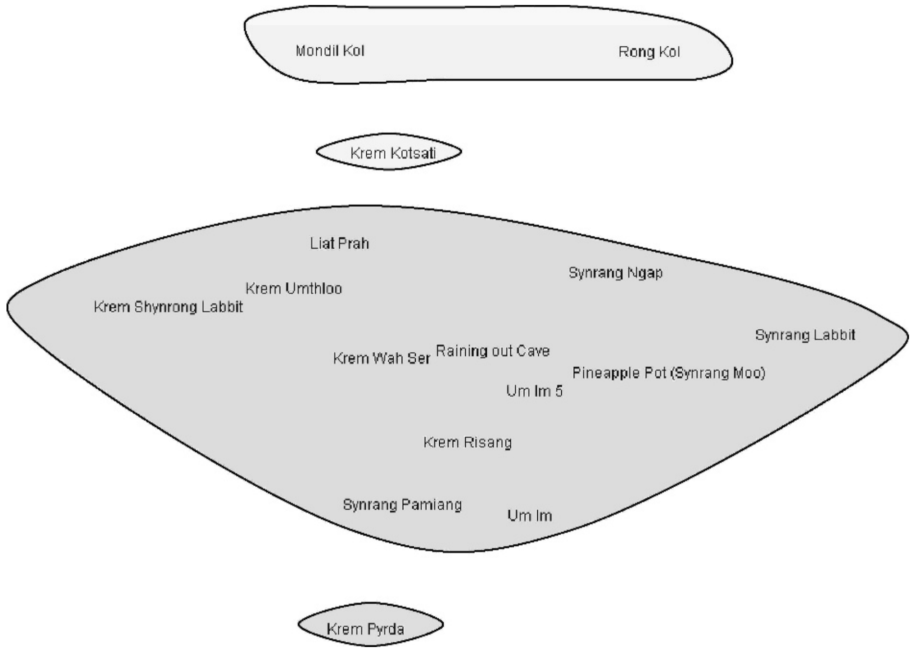


Figure 22. MDS plot illustrating similarities in species composition for 16 caves.

DATA OVERVIEW — OTHER TAXA

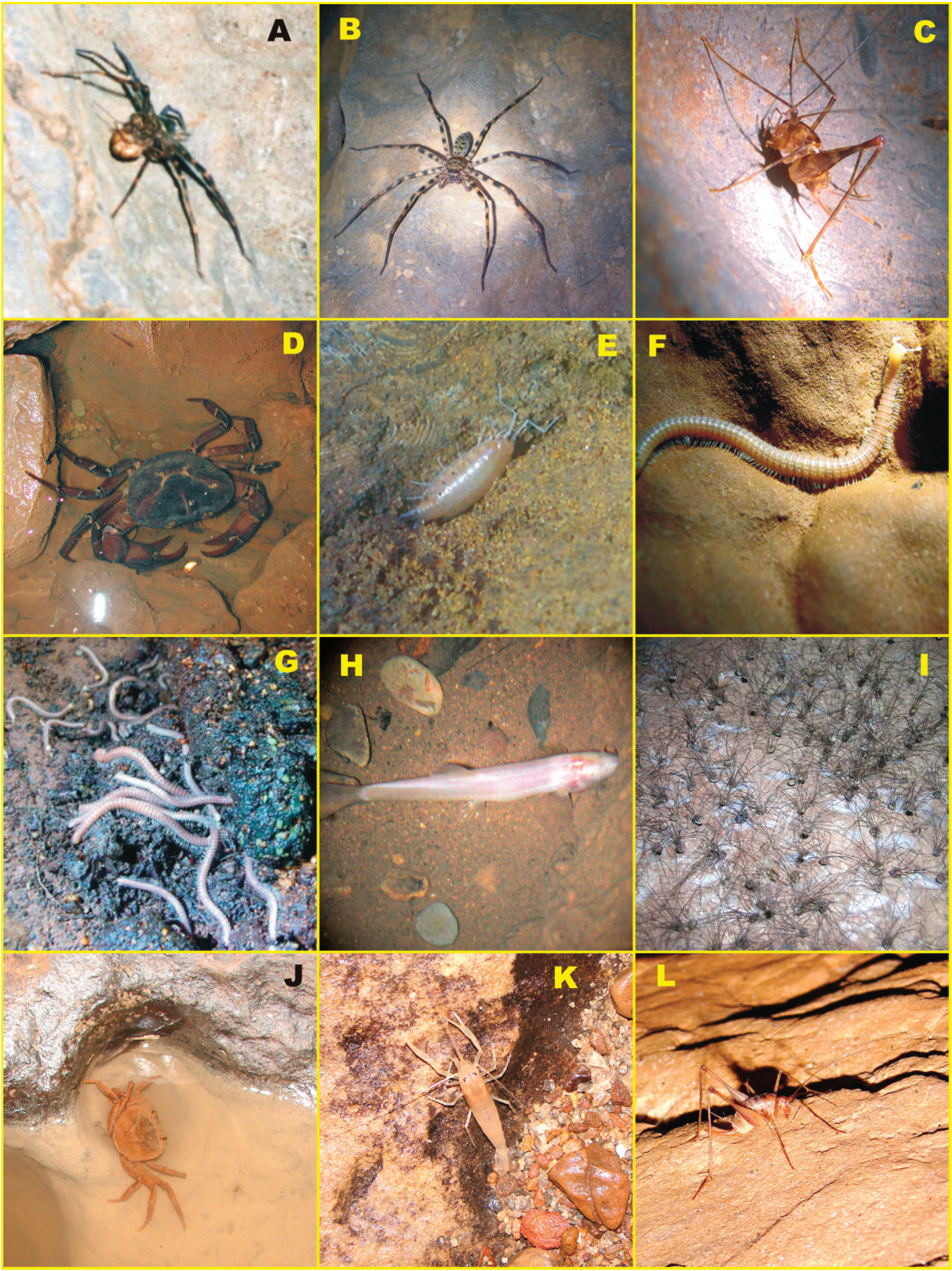
A range of other taxa have been recorded less frequently, but occur at sites deep within the caves and are possibly troglophilic. Aquatic gastropods (*Paludomus* spp.) occur occasionally (four caves), with numerous individuals found in pools or streamways. Oligochaete faecal casts are a common sight in damp fine sand or mud, particularly in areas close to deposits of decomposing vegetation. Their presence may be attributable to accidental wash-in, but the high proportion of organic detritus in the streamway sediments will provide a locally abundant food source and it is highly probable that persistent reproducing populations are maintained within the caves. These oligochaetes undoubtedly play an important role in breaking down vegetation deposited in the caves by floods and so form a significant component of the cave ecosystem functioning. A variety of spider species occur in the caves, including those of the genus *Pholcus* which are frequently encountered (seven caves) on webs built between boulders and suspended on rock walls. A large distinctive orange coloured variety of opiliones are frequently (seven caves) encountered deep within Jaintia caves. A large distinctive chilopod of the genus *Scolopendra* has been recorded in three caves in close proximity to standing water. In one of these cases the centipede was observed moving rapidly around on a submerged rock surface within a pool of standing water, once disturbed it left the pool and moved with equal facility over the exposed rock surfaces giving the appearance of being semi aquatic. Scutigeromorpha have also been recorded from three caves occurring as single individuals on rock walls deep within the caves. Collembola have been recorded in significant numbers within several caves and some appear to be anopthalmous. It is probable that a more thorough examination of the collembolan fauna will reveal troglobitic species.

Certain taxa appear to be primarily associated with cave entrances and might be regarded as characteristic threshold fauna. Examples include large planarians (four caves), black opiliones forming dense aggregations (six caves), scorpions (three caves) and geckos (Gekkonidae spp.) (four caves).

Meghalaya has a diverse and abundant bat fauna (Thabah, pers. comm.) and a full consideration of the group is beyond the scope of this paper. The main reason for this is that many of the published records are derived from data collected by mist net surveys on the surface. It is highly probable that many of these recorded bat species utilize caves as roost sites, but there is often no direct evidence that this is the case. Our records indicate that bats are present in the majority of caves throughout the state and at some locations there are dense colonies of many hundreds of individuals.

→

Figure 23. Representative photographs of Meghalayan cave biota. (A - *Heteropoda* sp. feeding on cave cricket (Krem Um Lawan 2002); B - *Heteropoda* sp. (Krem Wah Ser 2005); C - Rhaphidophoridae sp. 1. (Krem Wah Ser 2005); D - Crab (Krem Krang Maw 2003); E - *Philoscia* sp. (Krem Wah Ser 2005); F - *Trachyiulus* sp. (Krem Umthloo 2005); G - *Trachyiulus* sp.



feeding on faecal matter (Krem Umthloo 2005); H - Schistura papulifera. (Krem Krang Maw 2003); I - Black Opiliones at cave entrance (Krem Wah Tylliang 2004); J - Crab (Krem Mawkhyrdop/Mawmluh 2007); K – ***Macrobranchium*** **sp. (Krem Mawkhyrdop/Mawmluh 2007); L – Rhaphidophoridae indet (Krem Mawkhyrdop/Mawmluh 2007)).**

These colonies may be associated with extensive guano deposits which support abundant populations of invertebrates. However, many cave systems are subject to seasonal flooding which can prevent the accumulation of significant quantities of guano. Despite the lack of accumulated guano at such sites, the abundance of many invertebrate taxa was significantly higher in the vicinity of bat colonies than in other areas of the caves. The fauna associated with guano deposits in the West Khasi caves was distinct in composition from comparable sites in the Jaintia Hills. It included abundant moth (Tineidae) larvae and ants (Formicidae), as well as snails that appear identical to the figured specimens of *Opeas cavernicola* var. *vamana* recorded in Siju Cave (Annandale and Chopra, 1924). None of these taxa have been documented within the caves of the Jaintia Hills.

We have recorded swiftlets (assumed to be *Collocalia brevirostris*) within three caves on the Shnongrim ridge of the Jaintia Hills. We are unaware of published records of birds inhabiting Meghalayan caves, but colonies of swiftlets (*Collocalia brevirostris*) are known from caves in Uttaranchal (formerly Uttar Pradesh), Northern India (Glennie, 1944; Glennie, 1969). In the Jaintia Hills, the birds were particularly abundant at a cave that consisted of vertical shafts and high rifts. At this site we recorded over forty birds on the rock walls and innumerable others entered the cave at nightfall. They were found deep in the cave in total darkness and their echolocation clicks were clearly audible. At the base of the cave and on ledges higher in the rift we found deposits of guano and nest debris with an abundant associated population of invertebrates.

Frogs (Anura spp.) are frequently recorded within caves (11 caves) in the vicinity of streamways and pools, with tadpole larvae sometimes occurring as well as adults. Although the abundant invertebrate fauna within the caves may allow individual frogs to sustain themselves for a considerable period, the low abundance of frogs is unlikely to allow for reproduction and establishment of a breeding population within the caves. Snakes (Ophida spp.) have been recorded within six caves occurring as isolated individuals sometimes deep within the caves. It is unlikely that snakes would find sufficient suitable prey species to sustain themselves within the caves and some of the individuals encountered appeared emaciated. In most cases these snakes should be regarded as accidental trogloxenes. However, on the Lum Iawpaw Plateau in the West Khasi Hills there are shallow sandstone caves where numerous snakes were recorded. At this location it is possible that the snakes use the caves as hibernacula or refuges during the dry season.

A range of mammalian skulls and bones has been recorded in various caves. The species include mongoose, Assamese macaque, Nilgai, Temminck's golden cat, Asian black bear, human and various domestic animals. Most of these are likely to have been present through accidental falls down entrance shafts or by carcasses being washed into the caves. There are reports of bears using cave entrances as dens in some parts of the state, but we have no direct evidence of this. Rats are known to frequent areas well beyond cave entrances and living individuals, nest material and skulls have been recorded. The only other mammalian species to show a significant association with caves are porcupine. Evidence of porcupine presence has been reported from four caves in the Jaintia Hills. This includes evidence of long term regular use with rock walls and cave floors highly polished by the passage of porcupines. It is well known that Indian crested porcupines (*Hystrix indica*) use natural caves as dens (e.g., Alkon, 1999).

Discussion

Previously published data has conveyed the general impression that Meghalaya is of limited biospeleological interest with most species present in caves only as accidental trogloxenes and with just a few species displaying minor troglomorphic traits. This impression is erroneous and has arisen because the only detailed and best known biospeleological survey was conducted in Siju Cave in the western part of the state. Records presented in this paper, together with a detailed examination of published literature on Meghalayan cave fauna, indicate that taxa with pronounced troglomorphy are widespread and commonly occurring in the caves of the Jaintia Hills in the eastern part of the state but rare or absent elsewhere. Additionally, there is a range of partially troglomorphic taxa which occur regularly in caves throughout the state and a range of non-troglomorphic taxa which are regularly reported in abundance from different caves. Where such taxa are frequently recorded, abundant and present deep within cave systems there is a high probability that they should be regarded as true components of the cave ecosystem or characteristic cavernicoles for the area. This conclusion is supported if feeding activity or the presence of a source of nutrition can be identified within the cave or if there is evidence of reproduction within the cave.

Many of the recorded taxa meet these criteria, with larval or juvenile forms present and an abundance of potential sources of nutrition. The seasonal floods produced by monsoonal rain are likely to provide the primary source of nutrition by washing in vegetation and organically rich detritus and by redistributing deposits of bat guano within the caves. Fungal growth can occur on flood debris and tall etiolated seedlings are not uncommon on sand banks deep within caves. Such features provide living vegetation to supplement the nutrition source provided by the dead vegetation. The presence of dense colonies of bats (and swiftlets at some sites) provides a rich source of nutrition through guano, organic detritus and carcasses. These areas support significantly higher abundances of fauna than other areas of the caves.

The monsoonal floods are likely to impose a pronounced seasonality on the cavernicoles but due to access difficulties we have yet to visit the area during the wet season. In many areas there is very little water on the surface during the dry season. There is a distinct possibility that the caves act as a seasonal refuge for some aquatic and hygrophilic taxa that recolonise the epigean environment when monsoonal rains create humid conditions and replenish aquatic habitats on the surface.

In terms of communities, we have found that within a given area there is a high degree of similarity in the composition of the cavernicoles within different caves and the communities of caves in widely separated areas (e.g., West Khasi and Jaintia Hills) are distinctly different in composition. However, environmental factors (e.g., altitude, flood regime, etc.) also differ in the separate areas and currently it is not possible to establish if the difference in communities is due to differences in the geographic distribution of cavernicole species or to differences in prevailing environmental conditions.

Trends in community composition within cave systems remain unclear. We have noted significantly increased abundance of invertebrates in association with bat roosts. We found strongly drafting passages tended to support a community of low species diversity and abundance and attribute this to the desiccating effect of the draft. The distribution of certain taxa appears to be linked to factors such as distance from the entrance, presence of water or probable frequency of flooding. Where tentative conclusions on distribution can be reached, they have been referred to in the text relating to the taxon in question.

Rapid ongoing industrial development within Meghalaya is creating a new urgency to conduct research on the biospeleology of the region with a view to assessing conservation status (Biswas, 2007). Progressive and widespread deforestation has taken place across the state over the years resulting in what has been called a colossal loss of biodiversity in the entire region (Ramakantha et al., 2003). This deforestation has potential to alter subterranean ecosystems through altered run-off rates for rainfall and altered inputs of flood debris and nutrients. In recent years a major development of the limestone extraction industry has been implemented throughout Meghalaya. This is clearly a matter of concern as direct destruction of cavernicole habitat is inevitable and pollution of subterranean watercourses with industrial effluent is probable. It is of particular concern that significant levels of industrial development are occurring in the Jaintia Hills, which appears to be the region of greatest potential biospeleological interest within Meghalaya. We consider that it would be prudent to implement a program of formal biospeleological surveys within the region to document subterranean communities which are likely to become radically altered or eradicated over the next few decades.

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References

Alkon, P.U., 1999, Microhabitat to landscape impacts: crested porcupine digs in the Negev Desert highlands: Journal of Arid Environments, v. 41, p. 183–202.

Andrewes, H.E., 1924, Coleoptera of the Siju cave, Garo Hills, Assam I Carabidae: Records of the Indian Museum, v. 26, p. 115–117.

Annandale, N., and Chopra, B., 1924, Molluscs of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 33–40.

Biswas, J., 2007, Towards the Verge of Extinction? The Biodiversity of the Krem Mawmluh Cave Ecosystem: Abstracts, NSS 2007 National Convention, Marengo, Indiana, www.nss2007.com/abstracts.pdf (accessed Aug 27, 2008), p. 82.

Blair, K.G., 1924, Coleoptera of the Siju cave, Garo Hills, Assam IV Histeridae, Hydrophilidae, Erotylidae, Lathridiidae, Tenebrionidae and Hylophilidae: Records of the Indian Museum, v. 26, p. 120–122.

Brooks, S., and Brown, M., 2008, Meghalaya, caving in the abode of the clouds — 2008: The Grampian Speleological Group bulletin, v. 3, p. 24–25.

Brunetti, E., 1924, Diptera of the Siju cave, Garo Hills, Assam I Tipulidae, Tabanidae, Anthomyidae, Acalyptrate Muscidae and Phoridae: Records of the Indian Museum, v. 26, p. 99–106.

Cameron, M., 1924, Coleoptera of the Siju cave, Garo Hills, Assam II New species of Staphylinidae: Records of the Indian Museum, v. 26, p. 118–119.

Carpenter, G.H., 1924, Collembola of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 285–289.

Chopard, L., 1919, Zoological results of a tour in the far east, Les orthopteres cavernicoles de Birmanie et de la Peninsule Malaise: Memoires of the Asiatic Society of Bengal, v. 6, p. 339–396.

Chopard, L., 1921, On some cavernicolous dermaptera and orthoptera from Assam: Records of the Indian Museum, v. 22, p. 511–527.

Chopard, L., 1924, On some cavernicolous orthoptera and dermaptera from Assam and Burma: Records of the Indian Museum, v. 26, p. 81–92.

Chopra, B., 1924, Isopoda of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 49–59.

Collinge, W.E., 1916, Contributions to a knowledge of the terrestrial isopoda of India: Records of the Indian Museum, v. 12, p. 115–128.

Edwards, F.W., 1924, Diptera of the Siju cave, Garo Hills, Assam II Chironomidae: Records of the Indian Museum, v. 26, p. 107–108.

Fage, L., 1924, Araneids from the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 63–67.

Fletcher, T.B., 1924, Lepidoptera of the Siju cave, Garo Hills, Assam I Pyralidae: Records of the Indian Museum, v. 26, p. 113.

Fleutiaux, E., 1924, Coleoptera of the Siju cave, Garo Hills, Assam III Elateridae: Records of the Indian Museum, v. 26, p. 119.

Gebauer, H.D., 2003, South Asia cave registry, Gebauer, Schwäbisch Gmünd, Germany, 223 p.

Glennie, E.A., 1944, Note on the nesting of the Himalayan Swiftlet (*Collocalia fuciphaga*): Journal of the Bombay Natural History Society. Bombay, v. 44, p. 593–597.

Glennie, E.A., 1969, Cave fauna in northern India: Transactions Cave Research Group of Great Britain, v. 11, p. 107–110.

Gravely, F.H., 1924, Tartarides from the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 61–62.

Hora, S.L., 1924, Fish of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 27–31.

Hora, S.L., 1935, Notes on fishes in the Indian Museum. XXIV. Loaches of the genus Nemachilus from eastern Himalayas, with the description of a new species from Burma and Siam: Records of the Indian Museum, v. 37, p. 49–67.

Jager, P., 2005, New large-sized cave-dwelling *Heteropoda* species from Asia, with notes on their relationships (Areneae: Sparassidae: Heteropodinae): Revue Suisse de Zoologie, v. 112, p. 87–114.

Kemp, S., 1924a, Part II. Notes on the mammals of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 23–25.

Kemp, S., 1924b, Crustacea Decapoda of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 41–49.

Kemp, S., and China, W.E., 1924, Rhynchota of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 93–97.

Kemp, S., and Chopra, B., 1924, The Siju cave, Garo Hills, Assam. Part I: Records of the Indian Museum, v. 26, p. 3–22.

Kottelat, M., Harries, D.R., and Proudlove, G.S., 2007, *Schistura papulifera*, a new species of cave loach from Meghalaya, India (Teleostei: Balitoridae): Zootaxa, v. 1393, p. 35–44.

Lamb, C.G., 1924, Diptera of the Siju cave, Garo Hills, Assam III Dolichopodidae: Records of the Indian Museum, v. 26, p. 108–112.

Lindberg, K., 1949, Observations au sujet des quelques grottes asiatiques, et listes des Cyclopides (crustacés copépodes) recueillis dans ces grottes: Annales de speleologie spelunka 3. series, v. 4, p. 35–45.

Lindberg, K., 1960, Revue des recherches biospéléogiques en asie moyenne et dans le sud du continent asiatique: Rassegna Speleologica Italiana, v. 12, p. 43–50.

Manfredi, P., 1954, Un nouveau Polydesmien cavernicole de l' Assam (Inde): Notes Biospéologiques, v. 9, p. 141–144.

Menon, A.G.K., 1987, The fauna of India and the adjacent countries: Madras, Amra Press, 259 p.

Meyrick, E., 1924, Lepidoptera of the Siju cave, Garo Hills, Assam II Tineidae: Records of the Indian Museum, v. 26, p. 114.

Mrakovčić, M., and Mišetić, S., 1990, Status, distribution and conservation of the salmonid, *Salmothymus obtusirostris* (Heckel) and the cyprinid, *Aulopyge hugeli* (Heckel) in Yugoslavia: Journal of Fish Biology, v. 37(A), p. 241–242.

Ochs, G., 1925, Descriptions of new asiatic Gyrinidae: Records of the Indian Museum, v. 27, p. 193–204.

Paiva, C.A., 1919, Rhynchota from the Garo Hills, Assam: Records of the Indian Museum, v. 16, p. 349–377.

Patton, W.S., 1924, Diptera of the Siju cave, Garo Hills, Assam IV Nycteribiidae: Records of the Indian Museum, v. 26 p. 112.

Pillai, R.S., and Yazdani, G.M., 1977, Ichthyo-fauna of Garo Hills, Meghalaya (India): Records of the Zoological Survey of India, v. 72, p. 1–22.

Ramakantha, V., Gupta, A.K., and Kumar, A., 2003, Biodiversity of northeast India an overview, *in* Gupta, A.K., Kumar, A., and Ramakantha, V., eds., ENVIS Bulletin: Wildlife and Protected Areas, Conservation of Rainforests in India, v. 1, no. 1, chapter 1.

Roewer, C.F., 1924, Opiliones aus der Siju-hohle in den Garo-Hills im Assam: Records of the Indian Museum, v. 26, p. 69–70.

Rohwer, S.A., 1924, Hymenoptera of the Siju cave, Garo Hills, Assam II Description of a new Braconid: Records of the Indian Museum, v. 26, p. 124–125.

Schotte, M., Kensley, B.F., and Shilling, S., 1995, World list of Marine, Freshwater and Terrestrial Crustacea Isopoda, National Museum of Natural History Smithsonian Institution: Washington D.C., USA. http://invertebrates.si.edu/isopod/ [accessed May 2, 2008].

Silvestri, F., 1924, Myriapoda from the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 71–79.

Sinha, Y.P., 1999, Bats of the Siju Cave, South Garo Hills District, Meghalaya, India: taxonomy and bionomics: Records of the zoological Survey of India, v. 97, p. 101–122.

Stephenson, J., 1924, Oligochaeta of the Siju cave, Garo Hills, Assam: Records of the Indian Museum, v. 26, p. 127–135.

Vandel, A., 1972, Sur une espece d'isopode terrestre et cavernicole recueillie dans une grotte de l'Assam: Annales de Speleologie, v. 27, p. 543–546.

Wheeler, W.M., 1924, Hymenoptera of the Siju cave, Garo Hills, Assam I *Triglyphothrix striatidens* Emery as a cave ant: Records of the Indian Museum, v. 26, p. 123–124.

SELECTED ABSTRACTS FROM THE 2008 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION LAKE CITY, FLORIDA

Archaeology

Under the Edge of this World: A Preliminary Investigation of Deep Cave Exploration on the Eastern Highland Rim Escarpment, Tennessee

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As part of a larger project focusing on the prehistoric use of Tennessee caves, the author investigated the spatial, chronological, and environmental contexts of several deep cave sites located on the western escarpment of the Eastern Highland physiographic province, an area where little previous cave archaeology research has been conducted. Initial work involves documenting the human presence and discerning site function. Cultural features at four caves were observed, photographed, and their locations noted in relationship to cartographic information from existing (or new, specifically created) maps of the caves. Environmental factors both inside and outside the caves were examined, including entrance setting, geologic attributes, and the presence of culturally important resources such as gypsum. Results show a continuity of deep cave exploration over a long time span in the area, ranging from the Late Archaic to the Protohistoric period. Despite the presence of mineral resources, and suitability for other uses, preliminary research reveals only early exploration, not extractive, ceremonial, or other interactions. This confirms previous work suggesting exploration-only was the most common of all prehistoric cave usages in the Mid-South. A close examination of contexts as well as content provides the best framework for determining site function for caves.

Biology

Composition of Bacterial Mats in El Malpais National Monument, NM: Comparison and Contrasts with Bacterial Communities in Hawai'i Lava Tubes

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Cave bacterial mats cover walls of lava tubes around the world, including in New Mexico, yet little is known about their composition and role in the ecosystem. To address these issues, we undertook a study of the different colored bacterial mats in Pahoehoe, Four Windows and Roots Galore Caves, in El Malpais National Monument (ELMA), located to the southwest of Grants, NM. Previous studies in Four Windows Cave in ELMA, have revealed the presence of many members of the *Actinobacteria*, the group that produces many of the antibiotics in use today. To determine the composition of bacterial mats found in these three caves, and how they overlap with each other, we sampled bacterial communities found in the twilight and dark zones of each cave. DNA was extracted and purified, the 16S rRNA gene was amplified using PCR, cloned, and approximately 1400 bases were sequenced from clone libraries. Closest relatives were found using Ribosomal Database Project II and BLAST and a phylogenetic tree was constructed using PAUP. Comparison of Pahoehoe bacterial sequences with BLAST revealed that some were most closely related to *Actinobacteria*, while other grouped with *Alphaproteobacteria*, and *Gammaproteobacteria*. Some overlap was found between clones from Four Windows, Pahoehoe and Roots Galore Caves, particularly within the *Actinobacteria*. There is less diversity in yellow bacterial mats than white bacterial mats, and this can be observed in the New Mexican and Hawaiian lava tubes. Our studies are shedding light on the nature of these communities and their possible roles in the ecosystem.

Discovering New Diversity in Hawaiian Lava Tube Microbial Mats

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Bacterial mats cover walls and ceilings of lava tubes around the world, yet little is known about their composition and role in the ecosystem or what controls their diversity. To address these issues, we ask: 1) What bacterial species are found in the mats? 2) Does diversity vary with respect to the different ages of lava flow? 3) Does species composition differ between differently colored mats? and, 4) What is the amount of organic carbon present in the drip water entering the cave system that can fuel heterotrophic growth? Samples were collected from microbial mats in eight different lava tubes found on the Big Island of Hawaii. Sampled mats ranged in color including yellow, white, pink, tan, and what appears to be an organic ooze. Samples were aseptically collected from each cave, and DNA was extracted and then purified. The 16S rRNA gene was amplified using PCR (~1365 bp), cloned, and then later sequenced. From this, closest relatives were found using the Ribosomal Database Project II and BLAST databases, and a phylogenetic tree was constructed using PAUP. *Actinobacteria* were found to dominate in most microbial mats, but not all. Other closest relatives were found to be *Cyanobacteria*, *Acidobacteria*, *Bacteroidetes*, *OP11*, *Chloroflexi*, and all divisions of the *Proteobacteria*. From our results we see a trend of less diversity in the yellow colored mats then in the white, while the greatest diversity was found in the organic ooze. Our studies show a great deal of novel diversity in these striking mats.

To Eat or Not to Eat: A Thermodynamic Model of Free and Calcite-bound Organic matter Respiration by Karst Microbes

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In the subsurface, heterotrophic microbes require organic matter (most likely from the surface) both as a carbon source and as an electron acceptor to be used during respiration. While the utilization of free simple organic molecules is most likely energetically favorable, molecules that are sorbed to mineral surfaces must first be desorbed making their utilization less energetically favorable. The goal of this study was to calculate the energy yield of the utilization of simple, organic molecules of varying concentrations (free versus bound citric acid and benzoic acid) and then model the environmental conditions that constrain their use in karst vadose zone-like systems. We assemble organic compound/O_2/CO_2 stability fields that make it possible to predict the conditions under which substrates can or cannot be used. Our results suggest that under certain conditions likely to be found in the subsurface, the utilization of compounds such as benzoic acid that are more strongly bound to calcite is energetically unfavorable and, thus, cannot be utilized as a source of organic C to cave-dwelling microbes. These results have implications for

the possible role of microbes in calcite dissolution/precipitation in the subsurface.

Leg Loss as a Measure of Fitness in Cave Crickets (*Hadenoecus subterraneus*) in Mammoth Cave National Park, Kentucky

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Hadenoecus subterraneus is a keystone species in central Kentucky caves, leaving the cave to forage on nights when conditions of temperature and humidity are favorable, and returning to the cave for a daytime refuge. Invertebrates are preyed upon by a wide range of animals and have developed defenses, including autotomy, or voluntary loss of a limb. Our study was done to determine if missing limbs affected the fitness of cave crickets. We used a visual census to record frequency of missing legs by gender among adult cave crickets at eight different cave locations in Mammoth Cave National Park. We expected males to be missing legs more frequently than females because they must leave the refuge of the cave to forage more frequently than females, but males and females were missing legs in equal frequency. The hind leg is missing significantly more commonly than other limbs (78% Hind vs. 7% Middle vs. 13% Front), probably because crickets attempt to jump away from threats, making the larger hind limb closest to the predator. The frequency of crickets with missing limbs varied by location from a low of 6.2% of the sampled population, to a high of 28%. Two crickets out of 1077 were missing more than one limb. In general, crickets from caves that have higher levels of reproduction (source populations) had the lowest frequency of missing limbs, while crickets from populations that are not replacing themselves (sink populations) had the highest frequency of leg loss. Our results suggest that loss of limbs reduces fitness in cave crickets.

Cave/Karst Conservation, Management, and Restoration

NSS Karst Partnership Forum: Collaborations for Karst Protection

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What happens in local communities when land development encounters karst? Proactive communities find strategies to resolve karst issues as development occurs. In 2006, the NSS Conservation Committee initiated an outreach effort to educate land use planners, local planning officials, and developers about the importance of cave and karst conservation in the scope of local ecological systems. The NSS Karst Partnership Forum is achieving the goals outlined in its 2006 strategic plan. Forum members attended the American Planning Association National Conference in Las Vegas, April 2008. Forum Partners collaborated in creating a museum quality karst-outreach exhibit booth targeting solutions for planners and developers. The NSS Karst Partnership Forum also sponsored an accredited session on Development Solutions in Karst Regions. Forum Partners that financially sponsored and participated in the successful week-long karst outreach event include: Conservation Division of the NSS, National Cave and Karst Research Institute, National Speleological Foundation, Texas Cave Conservancy, and Virginia Tech's "Growing Communities on Karst". Eight NSS members from around the nation networked directly with the national planning community. Planners seeking information and answers for karst regions facing development pressure joined the NSS Karst Partnership Forum. The Forum is compiling a list of target communities in karst regions; networking communities with cavers, grottos, and scientists; designing a series of development conferences for karst regions; recruiting developers to network and assist; and developing a Web presence through the Karst Information Portal to provide karst ordinances from around the world. The NSS Karst Partnership Forum is positioned to promote cave and karst protection across the nation through collaborations with developers and community planners.

Conservation Easements for Karst Protection and Cave Conservation in Virginia

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A conservation easement is a legal agreement negotiated between a landowner and a government agency, a land trust, or other qualified conservation organization for protecting conservation values including caves and other karst resources. Conservation easements limit rights to subdivide or develop a particular piece of land. Conservation easements are permanent and appurtenant; deeds of easement restrict both current and future landowners. Conservation easements can ensure environmental protection of a property beyond the tenure of one landowner. Virginia landowners who donate conservation easements may realize substantial economic benefit from transferable state tax credits. Prior to making any decision to donate a conservation easement, landowners should consult an attorney and/or accountant having expertise in conservation easements. Conservation easements ought to require landowners to adopt best management practices to protect conservation values. Deeds of easement may specify practices including fencing livestock from losing/sinking streams, sinkhole dump cleanouts, and establishing fenced vegetated buffers around streams, springs, sinkholes, and caves. Virginia Outdoors Foundation (VOF) holds most of the 588,549 acres of conservation easements in Virginia. Approximately 2.6% of Virginia caves are located on properties protected by conservation easements held by VOF or The Nature Conservancy. The Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program reviews proposed VOF conservation easements for biological significance and for presence of caves and other karst resources. The DCR Natural Heritage Karst Program assesses resources and makes recommendations to VOF, to other land trusts, and to individuals on ways to better protect groundwater and manage cave and karst resources.

Surveying the Historic Signatures of Carlsbad Caverns National Park

Lois Man and Dale Pate
Carlsbad Caverns National Park

Since the initial discovery and exploration of Carlsbad Caverns in the late 1800s, visitors to the cave have documented their passing by leaving signatures and other inscriptions. Some of these signatures were left by important early explorers like Jim White and Ray V. Davis; others belonged to the guano miners. Many more, however, belonged to local residents and visitors from far away. The dates included with many of these signatures give important clues to the progress of early visitation and the areas most frequently visited. The National Park Service began an inventory of these signatures in 1983, but the process of recording them was not refined at the time and the project did not continue, other than occasional notations made by survey teams mapping in the cave. Beginning in 2007, the park resumed collecting historic signature data in a much more systematic way. This presentation will show historic photographs from the early days of Carlsbad Caverns exploration, and will describe the methods being used by teams collecting data about the signatures. The historic signature survey is intended to help preserve and record yet another aspect of the fascinating history of Carlsbad Caverns National Park.

The Virginia DCR Karst Program Overview

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Established in 1994 by the Virginia Department of Conservation and Recreation Division of Natural Heritage, the Karst Program works to protect biological and hydrological resources of Virginia's karst areas. Most program funding comes from EPA Section 319 Clean Water Act grants. Recently, a growing percentage of funding has come from other sources: Natural Heritage Program funds, grants from NGOs such as the Cave Conservancy of the Virginias and the Nature Conservancy, and contracts with government agencies and private companies. The karst program utilizes a three pronged approach - education and outreach, technical assistance, and data development. Education and outreach efforts target agency staff and local government officials through professional development workshops. Each year, dozens of educators attend workshops and facilitator trainings and learn to use the Project Underground Curriculum to teach about karst. Karst education staff fills leadership roles in the state-wide environmental education community, ensuring that karst issues are a priority. The karst program provides on-call expertise to localities, agencies, and citizen stakeholders. Every year, staff screens hundreds of projects, ranging from highway construction to conservation easements, for potential impacts to karst, and provides guidance on avoidance or minimization of impacts and conservation of karst resources. Staff assists Natural Heritage Program stewards in management and monitoring of the caves and karst of the Virginia Natural Area Preserve System. Data development efforts focus on karst resource inventories, hydrological studies, and biological and water quality monitoring. Many data development activities are initiated through technical assistance to fill in data gaps.

Geology and Geography Session

Structural and Facies Control of Hypogenic Karst Development in the Guadalupe Mountains, New Mexico

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Cave development in the Guadalupe Mountains was controlled by fracture zones, faults, and structures associated with Permian and Tertiary tectonics. Local passage character can be affected by changes in facies and lithology. The overall pattern of cave development shows strong linear trends that are correlative to linear features seen in aerial photographs and geologic maps. These features are consistent with broader structural trends in the Guadalupe Mountains and reflect fracturing, faulting, and folding during uplift. Some anticlinal features reflect deposition of Permian sediments across syndepositional faults. Many of these syndepositional faults can be observed in the caves and exhibit a strong influence on both overall passage trends and on passage character. There are large breccia zones associated with syndepositional faults. In these areas, cave passages typically change from large, linear trunk passages to complex three-dimensional mazes of smaller passages. Forereef deposits, paleokarst, and paleochannels through the reef can also be preserved as breccia zones and have a similar effect on passage character. While overall speleogenesis crossed formational boundaries, lithology had some influence on passage character. The backreef units contain more rectilinear maze-type passages than the underlying reef and forereef units, probably reflecting more tightly-spaced fracturing and greater porosity. Large trunk passage development is prevalent in the Capitan formation, especially along the reef/forereef transition. Other facies changes exhibit significant, but more localized controls on passage character. Variations in reef facies, cementation, and dolomitization may also exhibit some localized influence on passage character.

Crystal Nucleation, Crystal Growth, and the Concept of Speleothem Ontogeny

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Speleothem ontogeny has been introduced as a concept for using the form and interrelationships of mineral grains in speleothems as a means of deducing growth environment. To this end, there is a large body of existing literature on the growth of crystals that can be applied to the speleothem problem. Calcite, the most common mineral in speleothems, is peculiar in that the activation energy for two dimensional nucleation and thus growth of large single crystals is almost the same as the activation energy for three-dimensional nucleation and thus the growth of polycrystals. Calcite is thus highly sensitive to minor impurities that may poison growth in certain crystallographic directions or may poison growth altogether. Growth may also be modified by epitaxy on templates, of which humic substances are a possibility. Observations with the atomic force microscope have revealed the atomic scale mechanisms of calcite growth and thus provide an explanation for the growth behavior observed at the macro-scale. Aragonite is much less sensitive to impurities than calcite and grows easily at high supersaturation. However, growth is rapid in preferred crystallographic directions, resulting in both fiber and dendrite growth. Gypsum, also, has preferred fast growth directions resulting in fibrous growth habits. The smallest fibers (angel hair) appear to be the result of whisker growth along a single screw dislocation. Gypsum needles grow as re-entrant twins, a mechanism widely studied by the semiconductor industry as the growth mode of silicon ribbons. Much of the information needed to understand speleothem ontogeny already exists.

Interregional Comparison of Karst Disturbance: West-Central Florida and Southeast Italy

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The karst disturbance index (KDI) consists of 30 environmental indicators contained within the five broad categories: geomorphology, hydrology, atmosphere, biota, and cultural. The purpose of this research is to apply the KDI to two distinct karst areas, West Florida, and Apulia, Italy. Through its application, the utility of the index can be validated and other important comparisons can be made, such as differences in the karst legislation implemented in each region and effect of time exposure to human occupation in each karst terrain. Humans have impacted the karst of southeast Italy for thousands of years compared to decades in west-central Florida. However, west-central Florida is more populated than southeast Italy establishing differences in the scale of human occupation between the two studied areas. These two differences allowed for the determination of whether length of human occupation or population density is most influential in the anthropogenic destruction of karst terrains. Similarly, Italian karst is more diverse than the karst found in west-central Florida, aiding in the evaluation of the applicability of each KDI indicator through the application of the index in distinctly different karst terrains. Overall, major impacts for southeast Italy include quarrying, stone clearing, and the dumping of refuse into caves, while west-central Florida karst suffers most from the infilling of sinkholes, soil compaction, changes in the water table, and vegetation removal.

Coastal Caves in Bahamian Eolianites: Origin as Flank Margin Caves, Sea Caves, and Tafoni Caves

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Bahamian Quaternary eolianites in coastal settings contain breached flank margin caves, sea caves and tafoni caves. Flank margin caves are dissolutional features formed by water mixing internally within the subsurface, as sealed chambers, whereas sea caves and tafoni caves form by nondissolutional processes acting from the outside inward. These three cave types, while similar in outcrop appearance, can be differentiated by application of two measures: area to perimeter ratio, and maximum cave-width to entrance-width ratio. Flank margin caves and sea caves are tied to sea-level position, and are good paleo sea-level indicators, whereas tafoni caves form at random elevations on exposed cliffs. Based on their size, shape and configuration, flank margin caves carry information on paleo fresh-water lens conditions. Sea caves have been classified in the literature based on the nature of lithological or structural differences (e.g. faults and intrusions), but sea cave distributions in the relatively uniform Quaternary eolianites of the Bahamas implicate off-shore focusing of wave energy as an additional factor. Subaerial erosion progressively removes sea caves, then breaches flank margin caves, allowing denudation rates to be determined. Tafoni caves form wherever Quaternary eolianites are cliffed to present an unweathered surface lacking a calcrete crust. Tafoni development in eolianites is caused by wetting/drying cycles and wind, as no halite or gypsum were found within tafoni. Tafoni develop quickly, growing to meters in size in Holocene dunes and tens of centimeters in size in road cuts, buildings and quarries.

Environmental Ramifications of not Recognizing the Subjacent Karst Collapse Sinkholes Developed on the Edges of the Cumberland Plateau Escarpment in Tennessee

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A narrow, flat area called the Hartselle Bench exists approximately half way up the steep Cumberland Escarpment in Tennessee. It is underlain by the resistant, Mississippian-aged Hartselle Sandstone. Most of the state's deep pits occur in the underlying Monteagle Limestone due to cave roof collapse up into the Hartselle. The Hartselle varies in thickness from 20 to 60 feet, but erosion has caused many areas of the Hartselle Bench to have less than 20 feet of sandstone. In many areas, broad, shallow sinkholes occur, that are not recognizable from the 20 foot topographic contours. As a result, state regulators can make bad decisions permitting waste disposal sites not understanding subjacent karst phenomena. In one incident, the author became involved at a site where chicken processing grease was being disposed of in a broad, shallow sinkhole on the Hartselle Sandstone. The grease was emerging from a nearby, underlying Monteagle cave spring with a grease-laden cave trending toward the sinkhole. The site had been permitted based on its porous sandstone soils and underlying bedrock type. Topographic maps did not depict the sinkhole. Housing developments are increasingly occurring on the Hartselle Bench due to the scenic views of the Highland Rim plateau surface below and ease of obtaining a septic tank permit on the sandy soils. There is a need to educate the regulatory community about the pollution potential of waste disposal on thin areas of Hartselle sandstone and develop regulatory statutes to require a special "karst investigation" before permitting sites.

Influxes of Matrix Permeability on Conduit Flow in Eogenetic Karst

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In the eogenetic Upper Floridan Aquifer (UFA), high intergranular porosity (20–40%) and matrix permeability ($10^{-12}-10^{-14}$ m^2) may contribute to the aquifer's hydraulic diffusivity (transmissivity/storativity), flow paths, and mass transport. To assess the exchange of water between intergranular and conduit porosity in the UFA, we conducted two quantitative dye traces during high and low flow conditions in the lower portion of the Santa Fe River Sink-Rise system in north-central Florida. For each tracer test we injected 18.14 kg (40 lbs) of 20% Rhodamine WT solution (3.63 kg active ingredient) into a karst window called Sweetwater Lake, which connects to a first magnitude spring, the River Rise, via a single conduit previously mapped by cave divers. Fluorescence of river water and river stage were monitored continuously until fluorescence returned to background values. In addition to river water, ground water was monitored from wells located 30 to ~890 m from the conduit. The high flow test had breakthrough of dye occurring 13 hours and 58 minutes following dye injection, a peak concentration of 6.97 ppb, and average flow velocity of 0.038 m/s. The low flow test had breakthrough of dye occurring 54 hours and 34 minutes following dye injection, a peak concentration of 4.87 ppb, and average flow velocity of 0.0077 m/s. High fluorescence was detected in three wells during the high flow test, suggesting conduit water may have been lost to the matrix, but no fluorescence was detected in the wells during the low flow test.

Influence of the Hydrogeological Setting on Englacial Conduit Morphology

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Glaciological ideas about the character and evolution of englacial drainage systems (glacier "caves") have been deeply influenced by the theoretical model developed by Shreve (1972). This model is based on three main assumptions: (1) englacial drainage is in steady state; (2) englacial water will flow along the steepest hydraulic gradient within the glacier; and (3) pressure head equals the pressure of the surrounding ice minus a small component due to melting of the walls. The Shreve model has been widely adopted as a fundamental component of englacial drainage theory. There is no evidence, however, that the model provides a realistic picture of actual glacier drainage systems. Observed englacial drainages show no discernable tendency to follow theoretical potential gradients and generally do not behave as predicted by the model. Conduit surveys from nine expeditions between 2005 and 2008 to glaciers that bracket the full range of common glacier thermal and structural regimes indicate that conduits do not form as predicted by the Shreve model. Englacial conduit morphologies are intimately linked to the orientation of a glacier's principle stresses or the presence of pre-existing lines of high hydraulic conductivity. If a sufficient supply of water is available, hydrofracturing forms vertical conduits in zones of longitudinal extension and subhorizontal conduits where longitudinal stresses are compressive. On unfractured glacier surfaces, subhorizontal conduits with migrating nickpoints form by cut-and-closure provided channel incision is significantly faster than surface lowering. Conduits can also form along permeable debris-filled crevasse traces that connect supraglacial lake basins of different potential.

Flank Margin Cave Development in Eolianites: the Influence of Terra Rossa Paleosols

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Eolian calcarenites, in island settings (Bahamas) and continental settings (southern Australia), contain flank margin caves. These eolianite sequences consist of dunes deposited during sea-level highstands separated by terra rossa paleosols developed during sea-level lowstands. The role of these paleosols in cave development has been confusing. As surface outcrops, the paleosols form a catchment that can collect meteoric water and deliver it to pit caves. In the subsurface, the paleosols have been ignored in some localities, with cave passages developing through the paleosol as if it were ordinary limestone. In other localities, the paleosol has acted as an aquiclude, distorting the shape of the fresh-water lens with a consequent impact on the nature of the cave passages below. One such distortion is a pinching out of flank margin caves both above and below a given paleosol. Another distortion is the ramping of the lens upwards along a paleosol inclined as it follows the side of an older dune ridge, creating passages at elevations higher than expected, as well as passages with a significant linear extent, as at Hatchet Bay Cave, Eleuthera. At scattered locations in the Bahamas, caves that look like flank margin caves are found at elevations above any known past sea-level highstand, from

20 m at Osprey Cave on Crooked Island, up to 55 m at St Francis Grotto (Big Cave) on Cat Island. These caves may be perched on a paleosol, and so reflect development more as a banana hole cave than as a flank margin cave.

Speleothem Paleoclimatology of the Last Deglaciation for Two Caves in Yucatan, Mexico

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Speleothems were sampled from Cueva Columnas and Cueva Oxpehol in Yucatan, Mexico. Samples from Columnas and Oxpehol have basal ages placing the initial growth of the stalagmites in the last glacial period (U/Th basal ages range from 21,089 to 30,816 years). Oxygen and carbon isotopes were measured on calcite samples drilled every 0.5 mm along the growth axis of these speleothems. Oxygen and carbon isotope values from stalagmites decrease along the speleothem growth axis. These results are consistent with recent findings in sediment cores from Lake Peten Itza in Guatemala and expected changes in oxygen and carbon isotope values across the Pleistocene/Holocene (P/H) boundary. Previous pollen studies on lake cores indicated a cooling of 6 to 8 °C during the Pleistocene in the Maya lowlands, which would have increased the $\delta^{18}O$ of speleothem calcite. Furthermore, the Maya lowlands were drier during the Pleistocene, which should also have been expressed by an increase in the of speleothem calcite owing to an increase in the $\delta^{18}O$ of rainfall (i.e., the amount effect). During the glacial period, the abundance of dry-adapted C_4 vegetation was greater than today and transitioned to an increased abundance of C_3 vegetation at the start of the moister Holocene. The decrease in the carbon isotopic values across the P/H boundary is consistent with such a vegetation shift above the cave. Other current work includes a detailed investigation correlating rainwater and cave drip water $\delta^{18}O$ ratios to precipitation amount in the Yucatan Peninsula.

A Comparison Between Glacial and Mid-Holocene Climate in Florida using Speleothem Stable Isotopes: Evidence of Heinrich Event 2

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A stalagmite collected from BRC Cave in west-central Florida was deposited from 29 ky to 21 ky BP, encompassing Heinrich Event 2 (H2), and from 5 ky to 4 ky BP, during the mid-Holocene. The timing of H2 in our record is ~24 ky BP, which is temporally similar to its timing in other areas worldwide. However, the oxygen and carbon isotope values indicate the climate in Florida was warm and wet, rather than cool and dry like many other regions, with more precipitation and a shift from savannah to forest during this period. One possible cause is shutdown of the North Atlantic Conveyor Belt due to increased glacial meltwater input, thereby preventing heat transfer by the Gulf Stream from the subtropics/tropics to the northerly latitudes. This mechanism would allow for an increase in convective thunderstorm activity due to higher evaporation rates. In contrast to the H2 event, the mid-Holocene speleothem oxygen isotopes show a ~2‰ shift, indicating higher precipitation amounts than the glacial period. Additionally, the carbon isotopes show a ~3‰ shift towards more negative values, indicating more heavily forested conditions during that time. The speleothem isotopes during the mid-Holocene reflect a warmer and wetter environment than the end of the glacial period. The preliminary data support the possibility of atmospheric teleconnections between the tropics/subtropics and northerly latitudes playing a major role in controlling climate change in Florida. Possible causes include changes in the migration pattern of the Intertropical Convergence Zone and the influence of El Nino on Florida's winter precipitation.

Characterization of Airflow Using Simple Temperature-Humidity Loggers, Carlsbad Caverns National Park, New Mexico

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The characterization of airflow from caves and blowholes is important for broad resource understanding, determining cave potential, and evaluating the effects of gating or other passage modifications. The hypogenic caves of the Guadalupe Mountains are vertically complex and some have tremendous volumes. These caves can exhibit barometric or chimney-effect airflow or combinations of the two. Detailed, extensive airflow studies can be labor and cost prohibitive. The park has experimented with using simple temperature-humidity loggers located inside cave entrances to provide general characterization of airflow. Loggers were placed inside cave entrances out of the direct influence of minor changes in surface weather. A baseline pressure logger was kept in the park headquarters area to monitor changes more closely than available at the nearest weather station. Readings of temperature, humidity, and pressure were logged every two hours. The data from Lechuguilla Cave and a smaller, partially-explored backcountry cave show that these loggers can detect changes in airflow caused by both major and minor changes in surface conditions. As shown in previous studies, the data show that airflow in Lechuguilla Cave is primarily controlled by changes in barometric pressure. The data from the backcountry cave shows that the airflow is primarily due to chimney effects, controlled by fluctuations in surface temperature, especially seasonal changes in average daily temperature. The results of this preliminary study show that simple temperature-humidity loggers can be used to characterize the controls on airflow. This type of characterization can be done inexpensively with minimal labor and equipment.

Thermal Imaging and Temperature Analysis of Parks Ranch Cave, New Mexico

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The main entrance to Parks Ranch Cave, NM was imaged over a 24 hour period using a long wave infrared camera. Temperature, humidity and barometric pressure measurements were taken inside and the cave and out during the same period. Wall temperature measurements were taken at the entrance of the cave and tens of meters inside. During the January, 2008 measuring period, the cave entrance had a pronounced outflow of warm, moist air in the upper half of the passage. The lower half had cold, dry air flowing in. This pattern probably continues for a significant period of time, as evidenced by a layer of dark green algae coating the passage wall that is in full (but indirect) daylight, coinciding with the level of out-flowing humid cave air. The out-flowing air moves at less than 0.5 m/s, however the effect of the airflow extends well beyond the dripline. When the air temperature falls below freezing, frost accumulates on the headwall several meters above the entrance as the humid cave air drops below the dewpoint. Parks Ranch has 18 known entrances to the system. A second entrance lies immediately below the main one, but does not show same strong, differential airflow. Much work remains to be done to understand the airflow in this complex cave system.

Metrics of Cave Complexity with Application to Mapped Tennessee Caves

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Mazes in caves may occur due to frequent loop connections in a single level, to overlay of multiple levels, to vertical solution in domepit complexes, or to combinations of factors. Cave mazes pose difficulties for the explorer, representational dilemmas for the cartographer, and, at times, interpretational challenges for the karst researcher. The common generalization of cave patterns as single conduit, branchwork, network, etc. are useful as general descriptive terms, but fail to allow numeric specification of the degree of mazelike character or to permit comparisons of distinct maze sections within a single cave. This paper introduces passage spacing and complexity metrics based on equivalent values to those of similar-dimensioned hypothetical square maze caves with square loop components. A cave intricacy descriptor, invariant under scale changes, is also posed. These metrics are illustrated using a selection of mapped Tennessee caves of varying lengths and degrees of mazelike character. Adaptations of these metrics to examination of complexity variations within more complex caves are presented with a few examples. Tennessee has more than 9000 caves recorded by the Tennessee Cave Survey (TCS), of which approximately 1500 have been mapped. Mapped caves span nine physiographic provinces (as defined by the TCS) in limestones ranging from Cambrian to Mississippian in age. Relationships of cave complexity to physical variables such as geologic formation and physiographic province are tentatively explored for the non-random subset of approximately 500 caves for which complexity data have been compiled, with emphasis on caves over one kilometer in length.

INTERNATIONAL EXPLORATION

FIRST U.S. AND NSS CAVING EXPEDITION TO ARMENIA, THE SOUTH CAUCASUS

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The first U.S./NSS caving expedition to Armenia took place August 2007, with a team of 5 California cavers. Four significant caves within the Vayots Dzor province were explored. Mozrovi Cave: A cave (1,554 m. elevation) with 700 meters of passage. Notable for its large main chamber, its wonderful multicolored speleothems - stalactites, stalagmites, flowstone, draperies, helictites, crystalline spars, bacon, and moon milk – and passages containing pristine coral formations. Arjeri Cave: The largest of Armenia's caves (1,676 m elevation) with approximately 4 kilometers of passage – a world-class cave. The team encountered colorful speleothems – stalactites, stalagmites, flowstone, columns (large and small), draperies, bacon, coral, moon milk. The quantity (and size) of such calcite formations throughout this relatively pristine cave were remarkable. A bat colony resides in the cave. Karmir Cave: This is the smallest of the caves (2,134 m elevation) with red cave mineralization throughout much of the passages. Mageli Cave: The cave (1,219 m elevation) has approximately 2 km of known passage, and is in conglomerate, as opposed to classical karst, with high, narrow booming passages, crawls, climbs, and squeezes. The amazing 3.7 meter long, slotted venturi squeeze with high velocity wind is noteworthy. The cave is also home to a large bat colony. The team also visited the magnificent cave monastery of Geghard, and the cave church of Jerovank. Natural or man-made, caves have played a significant role in the history of Armenia and the Armenians.

THE QUINTANA ROO SPELEOLOGICAL SURVEY: RECENT EXPLORATIONS IN DRY AND UNDERWATER CAVES IN QUINTANA ROO, MEXICO

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The Quintana Roo Speleological Survey supports conservation, safe exploration and confirmed survey documentation of the caves in Quintana Roo, Mexico. The present study area incorporates 8500 square kilometers (km) in eastern Quintana Roo. Over 44 km of cave survey is reported for the preceding year. Our area of interest contains 169 independent underwater caves (729 km of surveyed passage), and 22 independent dry caves (12.3 km of surveyed passage). Over 200 collaborators have contributed raw survey data to the database, establishing one of the largest archives of underwater survey data in the world. Current investigations of underwater caves south of the town of Tulum continue to support an aerial geomagnetic survey of the fresh water aquifer. Explorations in Sistemas Alomo, Toh Ha, and Dos Pisos reinforce a southern origin for the local aquifer. Explorations north of Tulum in Sistema Actun Hu and caves inland from the town of Chemuyil support this component for the aquifer. Dry cave exploration under a Pleistocene ridge common to the area is producing exciting results. Sistema Tixik K'una is progressing south along a large fracture towards another dry cave. In the northern area, a connection between Tixik K'una and two terminal sumps in Sistema Xunaan Ha (a sizeable underwater cave) is imminent. Exploration in both areas of the dry cave continues.

CAVES AND NON-CAVES OF FAIS ISLAND, FEDERATED STATES OF MICRONESIA

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Fais Island, Yap State, Federated States of Micronesia, is an uplifted carbonate atoll 1.2 km wide and 2.9 km long with a maximum elevation of 28 m, located 220 km east of the island of Yap in the Western Pacific. Field reconnaissance for water resources in 2005 located a variety of features that had been identified as karst features by earlier workers. However, the feature called a "cenote" was actually a well dug into sand and partially lined with fitted stone, and the "unroofed stream caves" were actually spur and groove depositional reef structures, fossilized by tectonic uplift into the subaerial environment. The only true dissolutional caves were a number of flank margin caves found only on headlands around the perimeter of the island. These headlands were preferential flow paths for the fresh-water lens, and thus controlled cave development. The flank margin caves were all of small to modest size, with only one, Ngatarocoroc Cave, having a true dark zone. But the caves are located in spectacular settings, and some can only be reached at low tide during calm conditions. Cave interiors show many fossils in the wall rock, and some caves, as at Yicimal Point, show evidence of fossil marine infill. The caves did not show evidence of cultural or religious use, but Ngatatapurowag Cave was used by Japanese soldiers as a hideout at the end of World War II, until they were killed by U.S. soldiers sent to clear the island in September, 1945.

SOPLO DE LOS TOROS UPDATE, CAVING IN THE PURIFICACIÓN KARST

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In December 2007, work continued in Soplo de Los Toros, a recently discovered deep cave in the Purificación karst of northern Mexico. On two prior expeditions we had explored the cave to 366 meters deep with excellent prospects for continuing. This time the nature of the cave changed dramatically, becoming tight and sinuous. Three trips to the bottom managed to add only 94 meters of depth, pushing the cave to 459 meters deep. The narrow canyon continues, and will be pursued later this year. Meanwhile digging in a neighboring cave, Poza de Zorillo, opened up a series of short drops with airflow. That cave was pushed to 83 meters deep before time ran out at another drop, and may connect to Soplo next trip. With any luck Soplo will become the second-deepest cave in the Purificación area and deepest in the state of Nuevo León when we return in December 2008.

CAVE RECONNAISSANCE, CROOKED AND ACKLINS ISLANDS, BAHAMAS

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A seven-day reconnaissance trip to Crooked and Acklins Islands, Bahamas in December of 2007 built on a very short three-day visit to Crooked Island in May of 2004. The 2004 trip mapped one large and two small flank margin caves at the northwest end of Crooked Island. The 2007 trip mapped 20 caves across Crooked Island, most of small size, but some had spectacular features or were located in dramatic settings. Other caves were short, grungy holes deep in the bush. Many of the flank margin caves had unusually large and high bell holes; in some caves surface denudation had breached these bell holes to create cave ceilings with numerous perforations. One of the flank margin caves was unique as it was developed in and through a limestone blockfall and talus deposit. On Acklins Island, a single large-chamber flank margin cave was mapped during a one-day visit by ferry to assess the island's cave potential. Several large caves were reported by locals, indicating a cave-mapping trip focused on Acklins Island would yield results. The majority of caves surveyed in 2007 were flank margin caves (19), but one sea cave and one tafoni cave were mapped. The total mapped caves on both islands from both trips is 24, with 22 being flank margin caves. The last day of the trip, as always seems to be the case, we were informed of another large cave on Crooked Island in an area we had been close to, justifying a return.

Inside the Lava Dome – Expedition to Lanzarote

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Just 97 kilometers from the North African coastline, the peaceful island of Lanzarote hides its volatile past. Along this island arc are dynamic features that have revealed the earth's innermost geologic secrets for perhaps millions of years. Sudden, violent eruptions have formed virgin islands overnight. To modern cave divers, Lanzarote has more than just a fiery history. Over a quarter century ago, this, the longest submerged lava tube in the world, almost claimed the life of cave diving pioneer Sheck Exley. From its vast size, unparalleled grandeur and enduring mysteries, it is easy to see why the final submarine section of the lava tube became known as the tunnel to Atlantis. Several collapses on the lower slopes of the Monte Corona volcano provide entrances to the cave system. The tunnel is over 6 km long with an additional 1.6 km under the sea and about 2 km open to the public. We accessed many wild portions of the cave with basic dry caving and sump diving techniques. Diving in Atlantida Tunnel is only possible through rare scientific permits, but it is not because of the challenges of entry. In fact, after walking through a show cave complete with a swimming pool, restaurants and concert hall, we arrived at our dive site. Carrying our gear, we paraded past tourists standing at the bar, and weaved between diners and sightseers and climbed over a railing in the restaurant to get to the water. In 2008, Dr. Tom Iliffe, Terrence Tysall, Jim Rozzi and Jill Heinerth explored the cave using closed-circuit rebreathers to add greater margins of safety while minimizing our effect on the environment that unique stygobitic cave animals depend on.

Reconnaissance of Southwest Coast of Haiti

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In 2007, in response to an invitation from tourism developers in Haiti, a small team of cavers began an initial cave and karst reconnaissance of the southern central part of the country. A number of karst features were documented and exploration/survey began in two caves located on a small limestone plateau in the Massiff de la Hotte area. The larger of the two is Grotte Marie-Jeanne and consists of a series of sizeable, well-decorated chambers developed on multiple levels which gives the cave an unusual morphology. The cave contains many entrances and skylights which show evidence of unique cave ecosystem which has not yet been fully identified or studied. The other cave in the area shows evidence of pre-historical and historical human usage of the cave and surrounding landscapes making it an important part of the cultural and ethnic history of the area and of the island. One significant karst spring was documented though its relationship to the other known caves in the area is not yet known.

Exploration of Caguanes National Park, Cuba

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In November 2007, a team of US cavers with a team from the Comité Espeleológico de Sancti Spíritus, Sociedad Espeleológica de Cuba traveled to Caguanes National Park on the north coast of Cuba. Many of the caves in the area had been mined for guano up to the 1950s and most had been documented by the famous Cuban naturalist Antonio Nuñez Jímenez fifty years ago. The goal of this expedition was to survey all of the known caves and tie them together using surface surveys and limited global positioning data into a GIS project. Correctly determining the spatial relationships and morphology of the caves was used to determine their speleogenesis and identify additional cave potential. More than 11 kilometers of passages were mapped in seven main caves. Some smaller, coastal caves were also located and mapped. The caves appear to be primarily flank-margin-type caves though the timing and specific hydrologic mechanism of speleogenesis is unclear. The caves are large and well-decorated and are host to several colonies of bats, including the rare butterfly bat. Several interesting microbial colonies were observed and documented and some very well-preserved vertebrate paleontological remains were found.

Wulong, China 2008

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In 2008, a series of international expeditions by the Hong Meigui Cave Exploration Society explored the karst and caves of northern Wulong County in Chongqing,China. The teams surveyed over 20 kilometers and identified numerous new karst features, caves, and springs in the Tongzi, Huolu, and Houping areas. Highlights include Gan Dong (Dry Cave), a 2,213 m-long stream cave, and Shang Hetaowan Dong (Upper Walnut Bend Cave) which was extended to 8,489 m long and 471 m deep with only one short pitch, making it the 6th deepest in China. Over 2 km were mapped in Quankou Dong (Spring Mouth Cave), extending it to 3,561 m long and 114 m deep, including sections of impressive air flow. Exploration also continued in the core zone of the Wulong Karst World Natural Heritage site, where San Wang Dong was extended to 34,767 m long, 293 m deep and Er Wang Dong to 26,021 m long, 241 m deep.

Four Years Under the Ice: Glacier Caving on Mt. Everest, in the High Artic, and in Alaska 2005–2008

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Increasing temperatures in glaciated areas are increasing melt rates and most glaciers are now losing mass and/or retreating. On the Greenland Ice Sheet (GrIS), increased melting has accelerated outlet glacier velocities, indicating englacial conduits (glacier caves) are funneling meltwater to the bed and "lubricating" glacier motion. To understand how and where conduits might form on GrIS, we are studying glacier caves on more accessible high arctic glaciers in Svalbard, Norway (78°N), that are analogues to GrIS outlet glaciers. We have fielded three glacier caving expeditions and explored more than 10 km of englacial conduits – including Christel Höhle, which, at 2 km long, replaces Patagonia's 1,040 m-long Perito Meccanico as the world's longest englacial conduit. Other notable finds include descending through 70 meters of ice to the bed of Hans Glacier in Crystal Cave. While warming on GrIS has resulted in faster ice, increasing temperatures in the Mt Everest region of Nepal are causing debris-covered glaciers to downwaste and stagnate. Lakes form in topographic hollows on stagnant glacier surfaces which can drain catastrophically and flood Sherpa villages down-valley. We launched two expeditions to map conduits associated with lake drainage events to understand how conduits affect lake life-cycles. Caves on or near Mt

Everest were mapped at altitudes between 4,900 m and 5,300 m, making them the highest surveyed caves in the world. This research has been combined with data collected from three expeditions to the Matanuska Glacier, AK, to inform a new conceptual model of glacier hydrology based on karst processes.

Paleontology

Unique Occurrences of Fossil Marine Invertebrates from Caves Developed in the Ocala Limestone of Northern Florida

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Northern Florida caves developed in the late Eocene Ocala Limestone provide whole and partial (articulated and disarticulated) calcitic-shelled invertebrate fossil taxa thus far not found in quarries and river bottoms exposing that formation. Surface deposits typically fail to preserve well-exposed, well-preserved, multi-component invertebrate fossil skeletons because quarries and river bottoms typically undergo rapid change; either natural (e.g., erosion or sedimentation) or man-made (e.g., blasting). However, slowly eroding limestones in protected cave environments have a higher probability of recovery of these types of fossils. Recently, two caves yielded well-preserved calcitic-shelled invertebrates never before reported in scientific literature. These include new species of crabs (Families: Parthenopidae, Majidae and Mithracidae), shrimps (Families: Callianassidae and Ctenochelidae), and an echinoid (sea biscuit). Although some were collected from cave walls, most were derived from cave floor sediments removed in 1-liter plastic water bottles. Fossils were collected from coarse-grained sand and fine-grained clays from Jackson Blue Springs (high flow water-filled cave) in Jackson County and fine-grained clays from Catacombs Cave (water table cave) in Marion County. Great care was taken by experienced cavers to minimize impact on the cave's floor and walls. It is hoped that with additional searching by experienced cavers other undescribed fossils, or those currently known only from disarticulated parts (e.g., sea stars, brittle stars, and sea lilies), will be discovered, carefully removed, and brought to the attention of Florida Museum of Natural History invertebrate paleontologists. Discoveries such as these are critical to our understanding of Florida's paleobiodiversity and paleoecology 35–40 million years ago.

Research & Exploration in Florida Caves

Continuous Monitoring of the Micrometeorology of a Natural Cave System: Hollow Ridge Speleoclimatology

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We are monitoring cave air, drip water and climatology at Hollow Ridge Cave to calibrate isotopic and chemical paleo-proxies in speleothems. Two monitoring stations located 50 m and 200 m within the cave and one station above the cave continuously record temperature (T), relative humidity (RH), barometric pressure (BP), drip rates (precipitation), acoustic airflow (wind) velocity, ^{222}Rn activities and CO_2 concentrations. Correlation of $^{13}CO_2$ vs. $1/CO_2$ indicates that soil gas ($\delta^{13}C = -22$ per mil) is the dominant CO_2 source in the cave. Radon-222 (20–340 dpm/L) and CO_2 (400–1500 ppm) rise and fall coherently as the cave breathes daily. Each parameter shows temporal and spatial patterns that reflect different sources – emanation from bedrock vs. soil gas and dripwater infusion. Temperature and BP drive the air exchange between atmosphere and cave under normal conditions. An unexpected flooding event once sealed the cave entrances, allowing ^{222}Rn to grow into secular equilibrium. Radon-222 peaked at 1200 dpm/L, over three-fold higher than previously measured, while CO_2 peaked at 1400 ppm, similar to peak CO_2 under normal conditions. Several methods can estimate cave air exchange rates including ^{222}Rn deficiency, CO_2 exhalation, temperature variations, and the δ^{13}C of carbon dioxide. A simple radon-deficiency model is used to estimate air exchange rates (fractional tidal air volumes) and CO_2 exhalation rates, varying from 18 to 26% of the cave volume.

A Multi-proxy Approach to Using Cave Sediment Carbon Isotopes for Late Holocene Paleoenvironmental Reconstruction in Florida

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Cave sediments collected from Jennings Cave in Marion County, Florida were analyzed using a multi-proxy approach. Fulvic acids (FAs), humic acids (HAs), bulk organic matter, and phytoliths were extracted from the sediments for carbon isotope analysis to determine periods of vegetation change caused by climatic influences during the Late Holocene (~ 3,000 years BP). Magnetic susceptibility and density analyses were also performed to compare physical sedimentary characteristics related to precipitation to the carbon isotopes. The carbon isotope record ranges from −35 to −14 per mil, exhibiting variability of ~21 per mil, within the different proxies, which indicates changes between C_3 and C_4 vegetation. Density analysis closely matches the FAs, indicating changes in the sediments during shifts in the vegetation regime. This likely indicates changes between a sub-tropical forested environment and more arid, grassy plains conditions. These changes in plant assemblages were in response to changes in available water resources, with increased temperatures and evapotranspiration leading to arid conditions and a shift toward less C_3 vegetation (increased C_4 vegetation) during the Medieval Warm Period. The cave sediment fulvic acid carbon isotope record agrees well with δ^{13}C values from a speleothem collected nearby that covers the same time period. Prolonged migration of the North Atlantic Oscillation and Intertropical Convergence Zone affects precipitation in Florida and likely caused vegetation changes during these climatic shifts.

Nuclear Magnetic Resonance Imaging of Density-dependent Fluid Exchange Between Macroporosity and Matrix in an Eogenetic Karst Aquifer

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Sequential time-step nuclear magnetic resonance images show the displacement of deuterated water (D_2O) by freshwater within two limestone samples characterized by a porous and permeable limestone matrix of peloids and ooids. These samples were selected because they have a macropore system representative of some parts of the eogenetic karst limestone of the Biscayne aquifer in southeastern Florida. The macroporosity, created by the trace fossil Ophiomorpha, is well connected and of centimeter scale. These macropores occur in broadly continuous stratiform zones that create preferential flow layers within the hydrogeologic units of the Biscayne aquifer. This arrangement of porosity is important because in coastal areas it could produce a preferential pathway for saltwater intrusion. Two experiments were conducted in which samples saturated with D_2O were placed in acrylic chambers filled with freshwater and examined with nuclear magnetic resonance imaging (NMRI). Results reveal a substantial flux of freshwater into the matrix porosity with a simultaneous loss of D_2O. Specifically, we measured rates upward of 0.001 milliliters per hour per gram of sample (mL/hr-g) in static or non-flowing conditions, and perhaps as great as 0.07 mL/hr-g when freshwater continuously flows past a sample at velocities less than those found within stressed areas of the Biscayne aquifer. These experiments illustrate how freshwater and D_2O, with different chemical properties, migrate within one type of matrix porosity found in the Biscayne aquifer. Furthermore, these experiments are a comparative exercise in the displacement of seawater by freshwater in the matrix of a coastal karst aquifer, since D_2O has a greater density than freshwater.

Biota Inventory of Peacock Springs and Blue Hole at Ichutucknee Springs, Florida

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The goal of the project is to establish baseline troglobitic population densities, and track long-term changes in the submerged cave systems of Peacock Springs, and Blue Hole at Ichutucknee Springs, by performing *in-situ* biota inventories. Biota inventories are performed on a quarterly basis, or when a significant change has occurred in the system such as a flooding event. A team of cave divers will inventory, cave crayfish (*Procambarus pallidus*), Florida cave amphipod (*Crangonyx grandimanus*), Hobbs cave amphipod (*Crangonyx hobbs*), swimming little Florida cave isopod (*Remassellus parus*), catfish, and sunfish, in specified distance intervals. This project was initiated in 2004, and data collection is still an ongoing process, but a couple of hypotheses have been generated. There is frequently an inverse relationship between concentration of catfish and other troglobitic species within a given distance, and following a flooding event it will take troglobitic species 5–6 months to rebound to preflooding levels.

A Florida Speleothem record of Variable Intensity of Teleconnections During the Late Holocene in Subtropical North America

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A stalagmite from west-central Florida was analyzed for its stable and radiogenic isotopes to determine the paleoclimate for the region over the last 1000 years. An investigation into how key ocean-atmospheric circulation patterns affect the region's climate was an important component of this study. The persistence and influence of both tropical and extra-tropical teleconnections on the hydrology of subtropical North America are little understood. We were able to reconstruct the major atmospheric-oceanic controls on the isotopic composition of the precipitation as recorded by the speleothem, controls that included the North Atlantic Oscillation (NAO) and the Pacific Decadal Oscillation (PDO). These teleconnections create decadal- to centennial-scale changes in the seasonal distribution of precipitation. An increase in the winter proportion of annual precipitation coincides with negative-phase NAO conditions and a positive-phase PDO. However, the PDO's influence appears to be weakened when it is out of phase with the El Nino Southern Oscillation (ENSO). The NAO exerts the greater decadal influence on this region's climate than the El Nino Southern Oscillation (ENSO), suggesting a greater significance of high latitude controls on subtropical North America.

A GIS-based Inventory of Terrestrial Caves in West-Central Florida: Implications for Sensitivity, Disturbance, Ownership, and Management Priority

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Active cave management, which represents any continuous action to conserve, restore, or protect a cave environment, is virtually non-existent in west-central Florida. This study focuses on developing an inventory to rank terrestrial caves in west-central Florida by management priority. A GIS-based cave inventory system, including a cave sensitivity index and cave disturbance index, were used as a tool to gain an understanding of the management priority of west-central Florida caves. The inventory was applied to 36 terrestrial caves in west-central Florida, which demonstrated a wide range of sensitivity and disturbance. The results show that by relying solely on sensitivity and disturbance scores, management priority may not be accurately determined. Further examination revealed that ownership and management status also affect management priority. Consequently, cave sensitivity, disturbance, ownership, or management status does not solely indicate management priority. Rather, the management priority of caves in west-central Florida depends on a number of complicated, interwoven factors, and the goal of management must be examined holistically. Each cave must be individually examined for its sensitivity, disturbance, resources, management, and social and physical context in order to gain an understanding of management priority. Nonetheless, the cave inventory system developed for this project was used to gain a general understanding of which caves hold management priority, based on the cave manager's objectives. In order to ensure the conservation and protection of west-central Florida terrestrial caves, support from county or state government, combined with cave inventory data, is crucial in developing sound management policy.

Spelean History

Speleological Clues: Following in the Footsteps of John and William Bartram, Eighteenth Century Botanists Extraordinaire

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The early naturalists of the United States were often descriptive of their geological surroundings. For example, well known Quaker botanist William Bartram referenced in his Travels numerous caves, springs, and other karst features of interest to the speleologist. While perusing John Bartram's 1765 diary describing his travels through the Carolinas, Georgia, and Florida, the author found a reference to a talus cave in Bladen County, North Carolina. Bartram wrote, "August 8, Walked out to Donahoos Creek to search for fossils with Billy [son William]… Sometimes ye creek would plunge down between vast rocks and not appear on ye surface for many perches unless in great cavities between ye rocks." No caves were listed for this county in the state cave survey. For that reason, in December of 2007, the author hiked the course of this remote creek to locate what the Bartrams had seen 242 years earlier. Not unexpectedly, the terrain had changed considerably. No large boulders or disappearing streams were found. Two theories are offered for the absence of Bartram's "vast rocks". They may have been quarried and used in the foundations of local houses. Also, the mouth of the creek had changed due to locks on the nearby Cape Fear River, so the boulders may be completely buried. Although Bartram's talus caves were not located, the search yielded the discovery of a new limestone solution cave along the same creek. Were it not for John Bartram's early description, chances are slim that a ridge-walk would have been considered there.

A Note on the History and Material Culture of Bellamy Cave, Tennessee

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Bellamy Cave is a large and well-known cave located in Montgomery County, Tennessee and currently managed as a biological preserve for the endangered Gray Bat. An examination of historical sources, and limited, initial investigations of the material culture on-site, allows the outlines of the history of Bellamy Cave to emerge. In the mid-to-late Mississippian period, Native Americans explored much of the cave. They also utilized it for mortuary and ceremonial purposes, as a clay mine, and perhaps as a habitation site. After Euro-American settlement, the cave was also utilized in a number of ways. The cave was an industrial space, serving as a moderate-to-large saltpeter mine in the war of 1812 era. Guano was also extracted for sale later in the nineteenth century. The cave was a cultural curiosity and social space, portrayed in the local press as a natural wonder and utilized as a place of public resort, including picnics and cave exploration. Bellamy Cave was also a hidden space, where the body of a murder victim was deposited in 1882, which upon discovery led to a sensational and significant murder trial. Finally, Bellamy Cave was part of the household or domestic economy, used for storing food and possibly liquids, and also as a water source. Thus all five categories of use in the history of American caves are represented at the site. The current study suggests that the cave will reveal even more of its past with additional research.

Rest in Pieces: A Cave Inside the Old Man of the Mountain, Franconia Notch, New Hampshire

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Sometime during the darkness of the early morning hours on May 3, 2003, the venerable Old Man of the Mountain of New Hampshire collapsed from natural causes. The Old Man, a rock bluff with the profile of a human face, was first noted in 1805 and was adopted as the official symbol of the State of New Hampshire by its legislature in 1945. It was one of the most recognized rock formations in North America and its likeness has appeared in books, posters, postcards, souvenirs, stamps, and the statehood quarter of New Hampshire. Although the demise of the Old Man was a sad event for the people of the Granite State, the memory of this iconic feature lives on. One of the most unusual and little known caves in New England existed within the rock mass comprising the Old Man's face. Like the profile, the cave has vanished, as the granitic blocks that defined its walls, floor, and roof now rest on the talus slope at base of Cannon Mountain in Franconia Notch State Park in the White Mountains. Although not visible from a distance, a small opening was noticed and sketched during a structural stability study of the Old Man formation in 1976 by Bryan K. Fowler, a New Hampshire engineering geologist. Based on this study, it is likely that the cave contributed to an overall weakness of the rock mass that eventually led to the collapse. The cave may even have had a pivotal role.

History in Grotto Newsletters

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By shelf-length, the grotto newsletters comprise the largest collection in the NSS Library. This collection contains a vital historical record of the chapters of the Society, and indirectly of the Society itself. However, the maintenance of this collection is becoming problematic. Many grottos are now publishing their newsletters online, and in some cases the Library is not receiving a paper copy to put on the shelf. An open question is whether it is desirable or practical to make a transition from shelved paper copies of the newsletters to an online collection on the Library webpage. The grottos must have a role in answering this question because copyright and public access policies differ from grotto to grotto. There is also the issue of whether back issues should be scanned and added to an online collection. A proposed solution would be for the Library webpage to provide publicly accessible sites where each grotto, using a specific password, could load its newsletters. Each grotto could also scan back issues and put them online. This potential solution leaves to each grotto the policy decisions of online publishing and access. The result would be a rich, online, historical resource for Society members and other scholars. When back issues for any grotto are scanned, another benefit would be the assurance that the content would not be lost due to deterioration of old paper copies or a catastrophe at the NSS Library.

William Karras and the Speleological Society of America

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During the 1960s the National Speleological Society, like many other organizations, was challenged by members of society who rebelled against authority, laws, and regulations. Prior to this, the caving community had consisted of unique, sophisticated individuals who supported a scientific structure for the NSS. However, it was rapidly changing into an organization with a majority of sport cavers. The younger generation wanted to have fun and generally wasn't interested in attending seminars at major hotels in Washington, DC. Most younger cavers were content with doing their own thing, but some desired to be leaders with many followers. The story of William G. Karras is an example of the internal struggles that occurred within both the NSS and the grottos. Karras led the formation of the Speleological Society of America (SSA) as an alternative organization; this was of great concern to the "bureaucrats" of the NSS due to the potential loss of revenue as well as the loss of national recognition. The effect of the publicity was to change many procedures of the NSS. Although William Karras's schism with the NSS attracted the headlines at the time, his tactics also served as a guide for others to follow.

Survey and Cartography

Survey Instruments: Digital or Manual? A Field Comparison of Relative Accuracy and Practicality of Usage

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This project served to investigate the use of digital hand-held devices compared against manual devices outside of traditional, professional surveying, in environments including caves. In recent years, the number and sophistication of hand-held surveying tools used in applications outside of professional surveying has increased. These tools have seen greatest use in construction and include laser range finders; digital inclinometers; and full-spectrum devices outputting distance, inclination, and azimuth. Specific devices include: Leica DISTO laser range finder, Shetland Attack Pony, TruPulse 200 range finder and inclinometer, and TruPulse 360 multi-function surveying tool. In the past, non-traditional surveying has been successfully conducted using survey tapes and hand-held manual survey instruments, such as Suunto liquid-filled precision compasses and inclinometers. While very cost effective, manual instruments are subject to a number of errors. These include recording blunders, instrument variability, and instrument-reader variability. Furthermore, accuracy when using manual approaches decreases as shot distances increase. Results of this work show that the above can be largely eliminated by using digital surveying devices. The most significant finding may be that errors from instrument-reader variability are nonexistent for well-aligned shots due to the deterministic nature of making measurements with digital survey devices. There are, however, two significant downsides to digital survey tools: (1) their unreliability in harsh environments, and (2) their high cost in comparison to manual precision instruments. The key conclusions of this work are that digital survey tools applied outside of professional surveying are accurate, reliable in most environments, and relatively easy to use.

U. S. Exploration

New Discoveries at Water Sinks Cave, Virginia

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A sinkhole, a mile long, receives drainage for much of the Burnsville Cove, a significant karst area that contains large cave systems in Bath County, Virginia. Prior to September 2008, a small cave was known to exist in the downstream terminus of the sinkhole. Late that month flood waters washed open a narrow fissure just inside the entrance. It was blowing a good breeze. When the fissure was widened to allow entry, a large passage was discovered extending beneath the smaller cave above. The first exploration/survey trip into the cave was unusual in that a small video camera was taped to the helmet of one of the survey team. With

183 meters of cable in tow the entire trip into virgin cave was viewed in real time on the surface. To date 3.52 kilometers of passages have been surveyed to reveal a complex multi-level maze. At the lowest level, a large stream upwelling from a deep pool, flows a hundred meters and then to another sump. This stream probably is the major portion of the sub-surface drainage of the Burnsville Cove. Nearly all of the cave's lower passages are washed clean from fast flowing flood waters. Leaves stuck to the ceiling near the entrance demonstrate the depth of flooding (50 meters). Video cameras have been placed in the cave and are remotely controlled from the surface. A subsequent video recording shows a flood event as it occurs inside the cave.

Caves and Karst of the Atlantic Coastal Ridge – Miami-Dade County, Florida

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South Florida, unlike elsewhere in the continental United States, has experienced a near continuous deposition of limestone during the past 65 million years. The most recent of these limestones are associated with periods of higher sea-level during the Pleistocene and late Pliocene. The youngest of these limestones, the Miami Limestone, developed a relatively high, but low-relief topographic feature in southeast Florida called the Atlantic Coastal Ridge approximately 125,000 years ago. Collectively these Plio-Pleistocene limestones compose the critically important Biscayne aquifer. While groundwater scientists consider the Biscayne a karst aquifer, little information exists concerning caves in south Florida. In the late 1980s and early 1990s, Alan Cressler identified and produced rough sketches of 13 Biscayne caves. Recently, we began an effort to survey these caves in cooperation with, and with permits from, the Miami-Dade County Parks and Recreation Department and Everglades National Park. To date, we have surveyed nine caves. The longest surveyed cave, Fat Sleeper Cave, presently measures nearly 95.4 meters – an incredible length considering that the average passages in the cave are armoured with so called "razor rock" and measure less than 0.3 meters high. Fat Sleeper Cave, like many of the surveyed caves in south Florida, is located along a transverse glade that nearly bisects the Atlantic Coastal Ridge. These glade-related caves are vertically restricted to a specific zone in the Miami Limestone that is dominated by cm-scale-diameter, touching-vug porosity formed when the rock was deposited and enhanced into "razor rock" by the recent formation of the cave.

Coastal Caves of Puerto Rico

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Puerto Rico's coastal caves have long been overlooked in terms of exploration and documentation. A recent inventory of coastal caves has resulted in the exploration and survey of 68 caves. Located along the northern, western and southern coastal areas of Puerto Rico, many of these caves, due to their small size and relative obscurity, had been poorly defined in the course of previous fieldwork. Prominent sea cave (littoral) development was noted in all coastal areas examined but previously undocumented examples of flank margin caves were also identified within the Quaternary eolianite and adjacent limestone exposures along the northern coast. Spatial geometric analysis of completed maps of all caves examined also revealed that the 10 flank margin caves could be graphically segregated from the 58 sea caves by comparison of cave perimeter (ranging from 12 to 333 m^2) to total cave area (ranging from 10 to 2862 m^2. This project has revealed a surprising variety and abundance of cave along these dynamic and complex Atlantic and Caribbean shorelines, and the detailed spatial analysis of the coastal cave morphology was able to determine speleogenic origin and quantify subsequent modification of these distinctive structures.

Diving in the Ichetucknee Trace

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South of Lake City, Florida, Ichetucknee Springs State Park attracts tens of thousands of visitors to swim and drift in tubes in the gin clear water. The Ichetucknee Head Spring has very special position in history. It was a resting place on the Old Indian Trail and a place of sacred significance to later visitors. The Head Spring was also a watering stop on the Old Bellamy Road, which linked St. Augustine to Tallahassee. But the secrets of the Ichetucknee have an origin in a different time and place. The water that erupts from the springs, filling the banks of the river, begins its journey far outside the boundaries of the park. Far to the north, rain falls to the earth and soaks into the ground. In some places, rain-swollen creeks like Canon Creek drain into large swallet holes that refill thirsty underground conduits. Rose Creek and McCormick Sink, 11 kilometers north of the park are two of those recharge points. Scientists have conducted dye trace experiments to determine the extent of the recharge zones for Ichetucknee. Their work has confirmed that the Ichetucknee springshed is large and extends at least twenty-four kilometers north to Alligator Lake in Lake City, and the average age of water welling up in the springs is 15 years old.

Recent Exploration at Jewel Cave

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With the completion of the Cave and Karst Management Plan in November 2007, exploration trips are now being led by several trained trip leaders, and exploration is being done throughout the cave. Previously the focus had been primarily at the periphery of the cave system. Since August 2007, nearly 4.8 km of passages were mapped. Over 1,600 meters were discovered on short, "close-in" trips, averaging 140 meters per trip. Over 2,400 meters were mapped on three overnight trips to the southeastern part of the cave. Although there were no breakthrough discoveries, this year's efforts have still resulted in a few leads that show great promise. Because of the climbing expertise among current explorers, more effort has been made to climb ceiling leads. Most of the PC Junction area has been mopped up, but there remain some leads to check, including one enticing ceiling lead. Recent rumors not withstanding, Jewel Cave remains the second-longest cave in the world, with over 228.6 km surveyed as of June 1, 2008. The current mileage is always available at www.nps.gov/jeca.

Recent Exploration in Lechuguilla Cave, New Mexico

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Since the last NSS Convention, extensive survey work has occurred in Lechuguilla Cave. Some expeditions focused on new exploration, while others were dedicated to resurvey and re-sketch so that complicated areas may be drafted onto the quadrangle maps. Work continues in all three branches of the cave. Lechuguilla has now passed the 200 kilometer mark with many promising leads to pursue. Two exciting breakthroughs in the past year have added mileage and renewed optimism that major extensions are still possible in this cave. Emerald City was discovered in the Western Branch by pushing a tight crawl. This opened into gypsum-lined trunk passage decorated with green minerals. This area continues to produce footage and features twin 60-meter domes at its end that are yet to be climbed. In the Far East, a tight belly-crawl and fissure series in the Outback was pushed to reveal the Northeast Corridor. Consisting of La Grange Hall, the Noreaster, and Northern Lights, this major trend breaks free of the Far East complex and is headed north. Northern Lights features impressive gypsum speleothems including swords, flowers, and the first major display of chandeliers in the East. The area exhibits barometric airflow and all indications are that there may be many kilometers of cave to the north towards Big Manhole. Also in the Far East, exploration continues in Coral Sea, three years after its discovery. Much resurvey work has taken place in Chandelier Maze, the Near East, and Chandelier Graveyard, as cartographers attempt to graphically depict these complicated areas.

NASA Spaceward Bound – Caving for NASA from a Hot Air Balloon or Thermographic Anomalies of Cave or Lava Tube entrances from a Raised Platform

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Thermography of cave and lava tube openings is in its infancy. NASA and cavers have come together in the study utilizing infrared thermograms to locate caves and lava tubes. Research to determine which conditions and times are the best for subterranean entrance detection by use of infrared thermography and other detection methods is ongoing. A comparison of timed thermographic images in the infrared band of cave and lava tube entrances for NASA's Spaceward Bound program have resulted in answers, as well as more questions, concerning this state of the art method of locating cave and lava tubes on Earth and possibly other planets. Timed thermographic images of Cavernas de Quitor and other caves in the Atacama Desert, Chile caves were compared with Mojave Desert Lava tubes; Pisgah and Cima, as part of an ongoing NASA project to develop protocols to locate caves and lava tubes by their thermographic images. Research methods include analysis of thermographic images taken every ten minutes over a twenty-four hour period of the Cima lava fields in the Mojave Desert of California. By utilizing a hot air balloon as an airborne platform, a study is being conducted to determine the best times and heights to obtain signatures of cave and lava tube openings. A number of factors are entered in and examined: Time of day, ambient temperature, height, dew point, distance, specific humidity, platform, as well as wind velocity and atmospheric gases. More NASA research is currently underway and cavers are starting to use building inspection infrared cameras in local areas to try to locate caves on their own.

Wind Cave Survey Project Update – 2008, Wind Cave National Park, South Dakota

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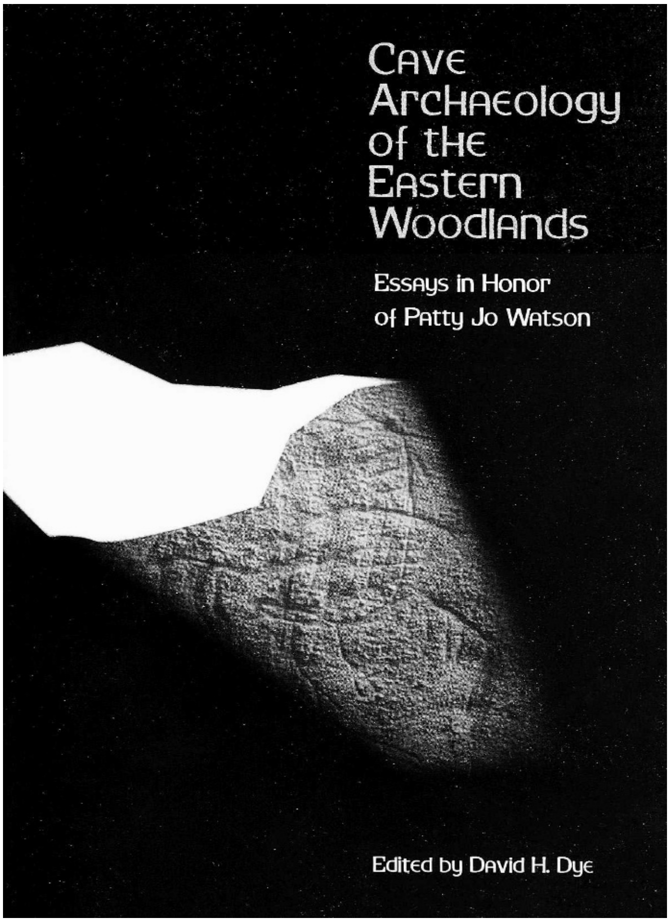
Since the 2007 NSS Convention, the Wind Cave survey project has continued to document new areas in Wind Cave. A total of 15 Wind Cave Weekends have been held since that Convention, where 5.53 kilometers were surveyed and inventoried during 47 survey trips. These trips averaged 118 meters of survey per trip and increased the official length of Wind Cave from 201.2 to 206.8 kilometers, maintaining its status as the fourth longest cave in the world. Some of the most interesting discoveries were made in the Gas Chamber area, which was pushed from the newly established Cosmos Camp in the Southern Comfort Section. This low impact camp was the first cave camp to be conducted in Wind Cave in nearly three decades. Except for the Gas Chamber area, the majority of the new survey was undertaken in the interior of the cave. Some of these discoveries included: Crumble Lane (currently at 199 meters); Chertstone Connection (currently at 551 meters); Fourteeners (417 meters); Snow Room (144 meters); and Fissure Kingdom (currently at 686 meters). In addition to the new survey, a project has been started to digitize the 36 Mylar cave quadrangle maps. To date, five quadrangles have been completely digitized. All new cave surveys are being added directly to these new digital computer maps.

BOOK REVIEW



Cave Archaeology of the Eastern Woodlands: Essays in Honor of Patty Jo Watson

David H. Dye (Ed.), 2008. Knoxville, Tenn., University of Tennessee Press, 304 p. ISBN 978-1-57233-608-7, hardcover, 6 × 9 inches, $42.95.

This collection of essays is the result of a 2004 Southeastern Archaeology Conference in honor of Dr. Patty Jo Watson and definitely does justice to the exemplary work in cave archaeology pioneered by Dr. Watson. David Dye opens the volume with a description of doing work with Dr. Watson and chronicles her diverse and highly commendable fieldwork. The chapter ends with a useful bibliography of her work. The rest of the volume is divided into two sections: Prehistoric Cave Use and Historic Cave use, with the former comprising the bulk of the volume.

The section on Prehistoric Cave Use covers a vast array of topics, many of which include interesting anecdotes about working with Dr. Watson, or the influence of her work on their own research. The first chapter (Sherwood) concerns the interpretation of burned deposits at the site of Dust Cave, Alabama. Such deposits can be difficult to interpret. This study illustrates the utility of micromorphology in discerning differences between *in situ* fireplaces, mixed burned deposits, and fireplace rakeout. The next two chapters are more historical in nature and highlight the work of Nels Nelson in the Mammoth Cave vestibule (Trader, Ward, and Switzer) and the 1978 season at Mammoth Cave (Carstens). The chapter by Carstens includes some great photos from the season. Chapter 4 (Barrier and Byrd) explores the beginning of gypsum mining at Indian Salts Cave, Kentucky, and also discusses the two forms of gypsum found in caves and two different mining methods that were utilized. Chapter 5 (Pritchard) also focuses on gypsum mining, this time at Hubbards Cave in Tennessee. Through the use of GIS to identify the location of the mining and X-ray diffraction to identify the minerals, this study documents that the prehistoric mining activities at Hubbards Cave were preceded by those at Big Bone Cave, Tennessee, and Salts and Mammoth Caves, Kentucky.

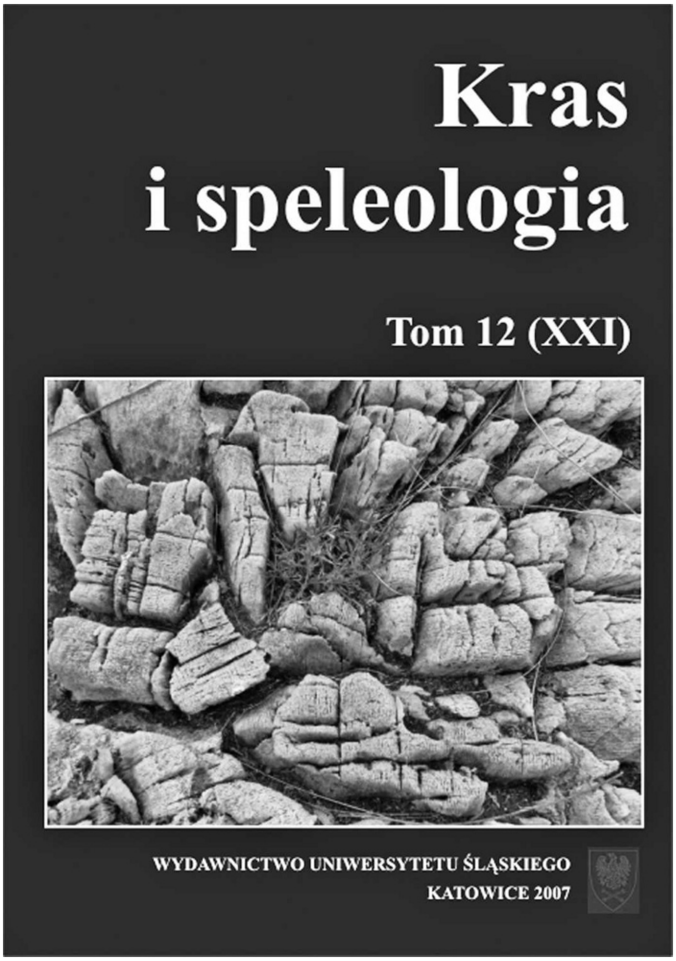
Chapters 6 and 7 address evidence of plant domesticates found in cave contexts. Gremillion examines the macrobotanical remains from Mammoth and Salts Caves, as well as sandstone rock shelters in the Cumberland Plateau region of Kentucky. In Chapter 7, Pike and Meeks present an overview of paleofecal research for eastern North America and then focus on research from Big Bone Cave. Both show the importance of these kinds of research for understanding the impact of early plant domesticates in the region. Chapter 8 continues with a focus on cave sites in Tennessee (Franklin), specifically on survey results for caves in the East Fork of Obey River Gorge, Tennessee. Presenting data from four caves, this research illustrates a broad range of cave activities, including flint mining, cave art and burial activities. A good follow-up to this chapter is presented by Douglas, Roebuck and Roebuck (Chapter 9), who reveal through work at Hubble Post Office Cave that sometimes caves were explored extensively (as indicated by cane torch remnants and torch "stoke" marks), even where no evidence of specific human activities, such as mining, is discernable.

The next three chapters focus on cave art. Chapter 10 (Simek and Cressler) gives a useful summary of production techniques, subject matter, context, and composition. The authors illustrate this with examples from three sites in Tennessee (Mud Glyph, and 7th and 11th unnamed caves) and Alabama (18th unnamed cave). In Chapter 11, Faulkner revisits the work at Mud Glyph cave and reflects on the challenges of cave art research (including the protection of these sites) and the benefits of working with members of the speleological community. The last chapter in this section, by Diaz-Granados, focuses on Picture Cave, a unique cave in Missouri with numerous pictographs. Diaz-Granados' work presents radiocarbon dates from three significant pictographs, all of which were painted around 994 radiocarbon years B.P.

The second section of the volume, Historic Cave Use, includes two chapters on saltpeter mining. The first (Chapter 13, Blankenship) provides an informative explanation of saltpeter mining operations and fills in an important gap in how the process worked; specifically, the presence of "tally marks" in Cagle Saltpetre Cave, Tennessee. These marks were used to keep track of the amount of dirt processed for saltpeter, as shown by their location near mining areas but not in processing areas. The second chapter (Chapter 14, Mickelson), also examines saltpeter mining with a focus on the hydraulic systems used. Research on the Mammoth Cave saltpeter mining operation reveals that the hydraulic system used in the cave was a suction-lift system, and this knowledge can be used to estimate productivity rates for the mining operations.

The volume closes with an Afterword by Simek, who discusses future directions for cave archaeology. He contends that the future trajectory should include more multidisciplinary approaches in research, expanding the information on historical cave use, and integrating cave archaeology into a broader understanding of regional resource use. I couldn't agree more with Simek's assessment, and the essays in this volume particularly illustrate significant advances in multidisciplinary cave research. However, I think the last two objectives deserve further attention. In particular, it is telling that this volume includes only two chapters on historic activities in caves. It is clear that more work needs to be done in this area. I also think that integrating cave archaeology in a more regional perspective is important. For example, I have noticed that symposia at regional and national meetings tend to be very specific (i.e., they focus on caves, or a particular region, but not both). Cave researchers may want to include more regional, non-cave sites in their symposia, edited volumes and articles for a broader perspective. In sum, this volume is a tremendous testament to the legacy of Patty Jo Watson. The sheer expanse of topics covered, from micromorphology to gypsum mining, to Mississippian cave art and on to historic saltpeter mining, clearly illustrate the impact of Dr. Watson's research on cave archaeology. While I found each of the essays incredibly informative and thought-provoking, I particularly enjoyed the photographs and anecdotes from people who have worked with and learned from Dr. Watson. Her work has been an inspiration to many.

Reviewed by Renee B. Walker, Associate Professor, Department of Anthropology, State University of New York, Oneonta, NY 13820-4015 (walkerr@oneonta.edu).



Kras i Speleologia, 2007
Issue 12(XXI)

Cave and Karst Science of the British Cave Research Association
Volume 32(1), 2005

Acta Carsologica of the Karst Research Institute ZRC SAZU
Volume 34(2), 2005

International Journal of Speleology
Volume 35(2), 2006

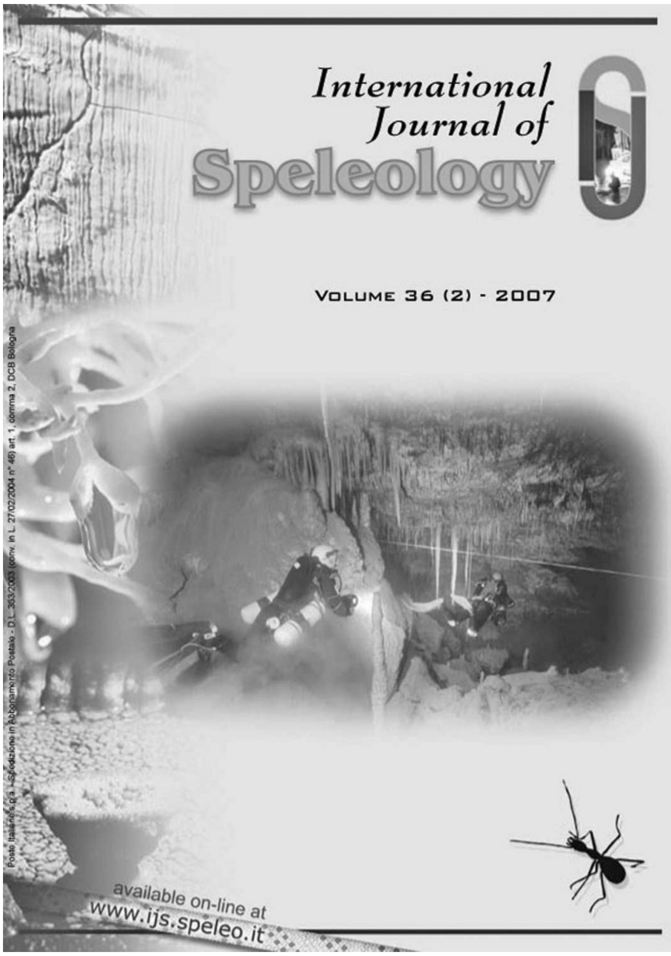
Die Höhle of the Verbandes Österreichischer Höhlenforscher & Verbandes der Deutschen Höhlen- und Karstforscher E.V.
Volume 56(1-4), 2005

Helictite - Journal of Australasian Speleological Research
Volume 39(2), 2006

Journal of Cave and Karst Studies of the National Speleological Society
Volume 68(2), 2006

Karstologia of the Fédération Française de Spéléologie and the Association Française de Karstologie
Volume 47, 2005

Speleogenesis and Evolution of Karst Aquifers – Online Scientific Journal
2006, vol. 4, issue 1



International Journal of Speleology, 2007 Issue 36(2)

Eogenetic karst, glacioeustatic cave pools and anchialine environments on Mallorca Island: a discussion of coastal speleogenesis. Ginés A., and Ginés J., 57–67.

Speleothems as indicators of wet and dry periods. Fairchild, I.J., and McMillan E.A., 69–74.

Climatic differences and similarities between Indian and East Asian Monsoon regions of China over the last millennium: a perspective based mainly on stalagmite records. Tan M., 75–81.

The polygenetic caves of Cuatro Ciénegas (Coahuila, Mexico): Morphology and speleogenesis. Piccini L., Forti P., Giulivo I., and Mecchia M., 83–92.

The impact of host rock geochemistry on bacterial community structure in oligotrophic cave environments. Barton, H.A., Taylor, N.M., Kreate, M.P., Springer, A.C., Oehrle, S.A., and Bertog J.L., 93–104.

A Taxonomic Survey of Lamp Flora (Algae and Cyanobacteria) in Electrically Lit Passages within Mammoth Cave National Park, Kentucky. Smith, T., and Olson, R., 36(2).

Book reviews

Jo De Waele
Karst Hydrogeology and Geomorphology
(Ford D.C. & Williams P., John Wiley & Sons Ltd., Chichester, UK, 562 pages, 2007 - paperback ISBN 978-0-470-84997-2).

Jo De Waele
Archives of Climate Change in Karst.
(Bogdan P. Onac, Tudor Tămaş, Silviu Constantin and Aurel Perşoiu (Eds.), Karst Waters Institute Special Publication 10, 246 pages, 2006 – ISBN 978-0- 9640258-9-2)

Malcolm Field
Perspectives on Karst Geomorphology, Hydrology, and Geochemistry - A Tribute to Derek C. Ford and William B. White.
(Russell S. Harmon and Carol M. Wicks (eds.), Geological Society of America, Special Paper 404, 366 pages, 2006 - ISBN 978-0-8137-2404-1)

Arrigo Cigna
Acta Carsologica (new format).
(Kranjc A. (Editor), Gabrovsek F. (Co-Editor), Karst Research Institute ZRC SAZU – ISSN 0583-6050)

Paolo Forti
Hypogene Speleogenesis: hydrogeological and morphogenetic perspective.
(Alexander Klimchouk, National Cave and Karst Research Institute Special Paper n. 1, 106 pages, 2007 – ISBN-10 0-9795422-0-0 – ISBN-13 978-0-9795422-0-6)

Paolo Forti
Natural and anthropogenic Hazards in Karst Areas: Recognition, Analysis and Mitigation.
(Parise M. & Gunn J. (eds), Geological Society of London, United Kingdom, Geological Society Special Publication 279, 202 pages, 2007 – ISBN 978-1-86239-224-3)

Jo De Waele
Cave conservation and restoration (2006 Edition).
(Hildreth-Werker V. & Werker J.C. (eds), National Speleological Society, United States of America, 600 pages, 2006 – ISBN 978-1-86239-224-3)

World Karst Science Reviews

Acta Carsologica of the Karst Research Institute ZRC SAZU
Volume 35(2), 2006
Volume 36(1), 2007

Cave and Karst Science of the British Cave Research Association
Volume 33(1), 2006

Journal of Cave and Karst Studies of the National Speleological Society
Volume 68(3), 2006

Alpine Karst of the Alpine Karst Foundation
Volume 2, 2006

Karstologia of the Fédération Française de Spéléologie and the Association Française de Karstologie
Volume 48, 2006

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