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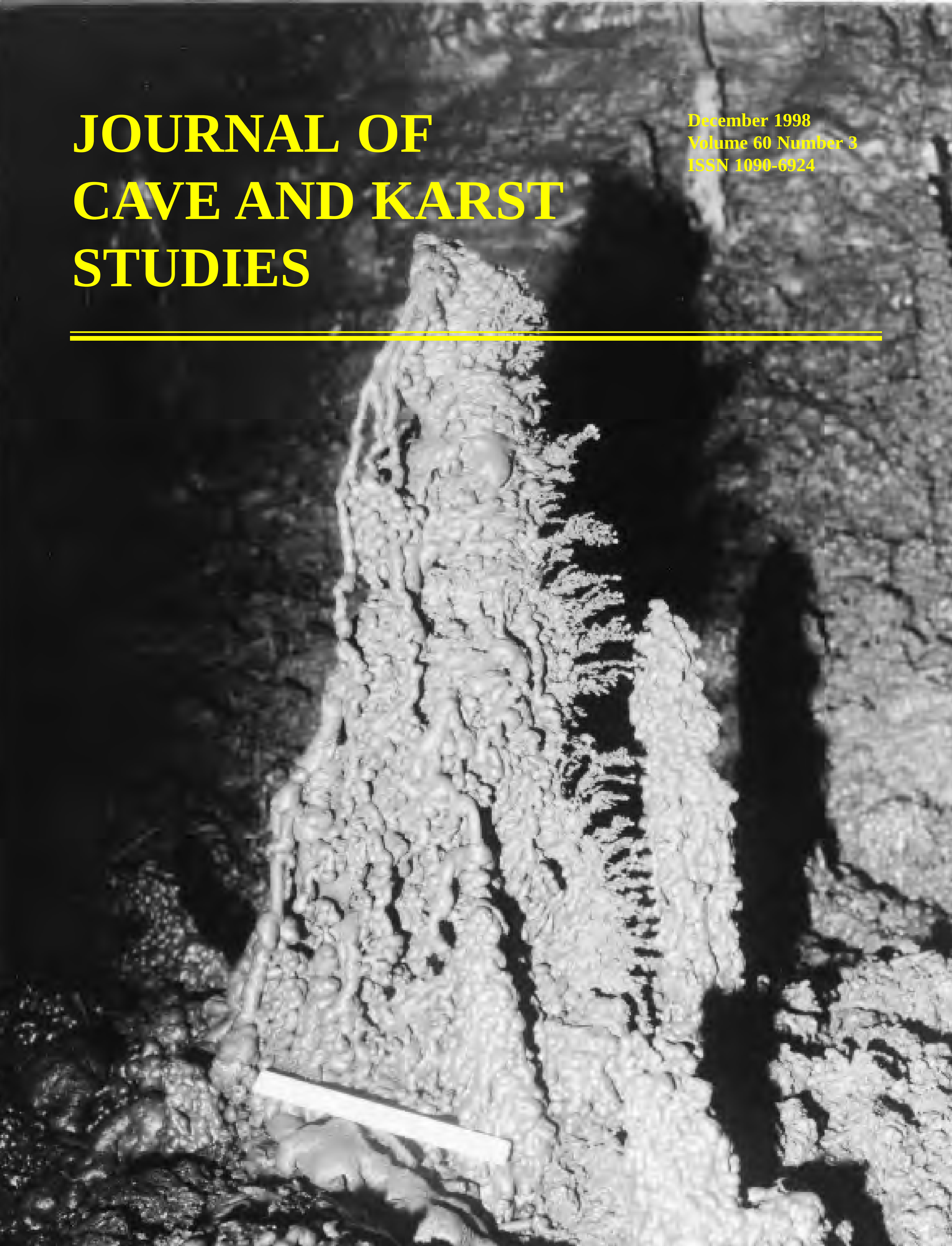

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Cover: Lava Coralloids, Eppersons Cave. See Allred and Allred page 131.

TUBULAR LAVA STALACTITES AND OTHER RELATED SEGREGATIONS

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Tubular lava stalactites are found in many lava tubes. Field observations, sample analysis, and comparative studies indicate that these are segregations extruded during cooling from partially crystallized lava at about 1,070° to 1,000°C. Retrograde boiling within the lava creates a vuggy fabric and provides a mechanism to expel the interstitial liquid. In addition to tubular lava stalactites, a variety of other lava formations can also result.

The study sites for this paper are four lava tubes totaling approximately 71 km of mapped passages on Kilauea Volcano, Hawaii (Fig. 1). Here, as in other well preserved lava tubes that we investigated in Hawaii and the western United States, interior surfaces are commonly coated with "a thin, smooth, vitreous surface" known as glaze (Larson 1993). This is underlain in places by a variable layer of dark rock, on either broken or smooth surfaces. Where thick, the dark deposits are usually associated with slender vermiform lava stalactites. Larson (1993) described these as follows:

"A tubular stalactite [is] composed of lava. Most are slightly and uniformly tapered. Their diameter, averages about .7 cm and often decreases slightly toward the tip, but extremes from .4 to 1 cm have been noted. Lengths range from the perceptible to a meter and more. The tip may be hemispherical, or open for a considerable distance, but the interior is usually an entrainment of elongated vesicles and septa, the outer surface may be macrocrystalline and partially or completely marked with shallow annular grooves thought to be growth increments. They often serve as conduits for considerable quantities of fluid lava; stalagmites of 100 times the volume of corresponding tubular stalactites are not uncommon. Frequently occurring in combination with lava helictites, they may be crooked, straight, branching, botryoidal, deflected, twisted, even deflated, or combinations of the above."

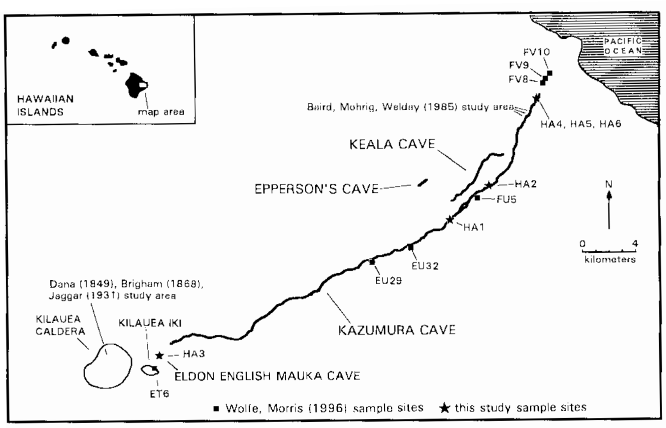

Figure 1. Study area showing sample sites. Keala from S. Kempe, (pers. comm.). Eppersons from W.R. Halliday (pers. comm.). Kazumura and Eldon English Mauka Caves after Hawaii Speleological Survey (NSS) files. Bulk rock samples from Wolfe and Morris (1996).

Figure 2. Runners and eccentric tubular lava stalactites, Eppersons Cave. Photo by K. Allred.

Previous investigators have theorized that these stalactites originated from (1) water vapor (Dana 1849; Brigham 1868; Dana 1889); (2) remelt (Jaggar 1931; Hjelmqvist 1932; Perret 1950; McClain 1974; Baird, Mohrig & Welday, 1985); and (3) other means (Williams 1923; Harter 1993; Favre 1993; Ogawa 1993; Allred 1994).

Some tubular lava stalactites and related lava formations clearly reveal that their fluids originated from within the rock itself. Most tubular lava stalactites that we found tended to be most eccentric and kinky nearest their ends (Fig. 2 & 3). Others had formed only as an incipient coralloidal shape (Halliday 1994). Tubular lava stalactites are called runners where they lie along a surface (Larson 1993). If runners flow down a tubular lava stalactite, the original free-dripping part can be identified by its horizontal grooves (growth rings).

Inasmuch as less dripping seems to have occurred in eccentric stalactites, matching eccentric stalagmites are not common. The droplets of the stalagmites tend to be more runny at the bases where they drained first (Fig. 3). The stalagmites were usually deposited after the lava stream had stopped moving (Fig. 4). Rarely, a line of driblets has fallen on a slowly

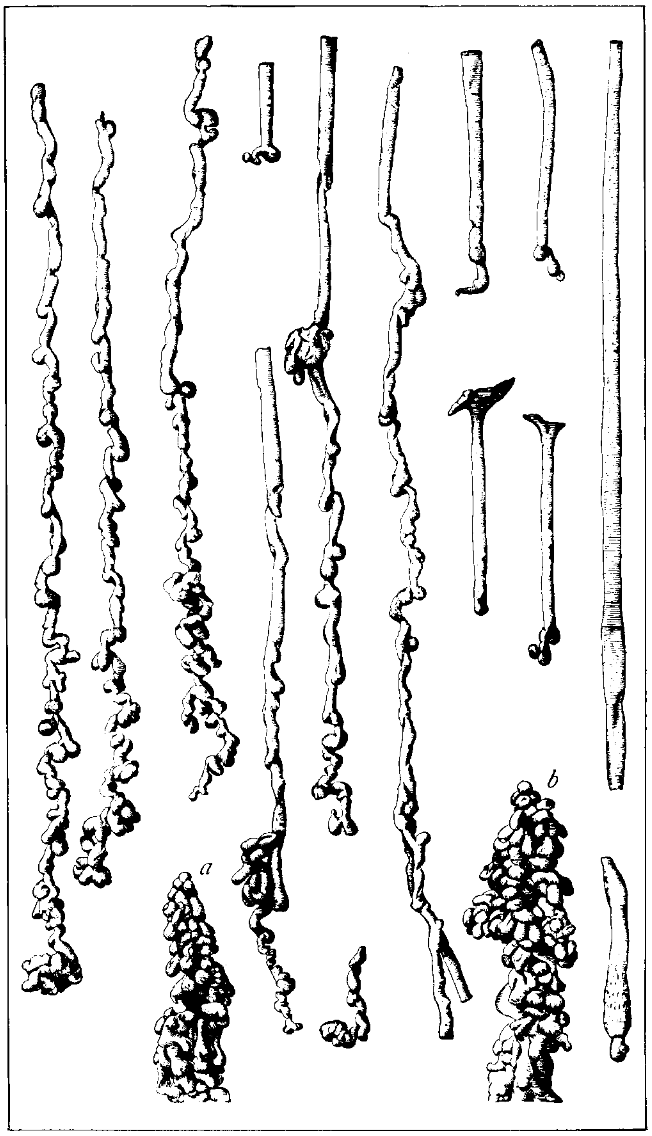

Figure 3. Tubular lava stalactites and lava stalagmites thought to be from Kaumana Cave near Hilo, Hawaii (Dana 1889). The lower ends of the stalactites tend to be more eccentric. As is typical, stalagmites show signs of more fluidity nearer their bottoms.

Figure 4. Tubular lava stalactite and lava stalagmites, Eppersons Cave. Photo by W.R. Halliday.

moving floor before a stalagmite was finally formed.

Other kinds of lava formations result from extrusions similar to those described above. Dripped "lava roses" (Larson 1993) can form by falling masses and sheets of lava originating from within ceilings. "Miniature volcanoes" (Jaggar 1931), or "small spatter cone[s]" (McClain 1974) were forced upward from ledges or floors. Those we observed had rounded caps (Fig. 5) and runners around their robust perimeters. These stalagmite-like forms may be classified as a form of "squeeze-up" as described by Larson (1993). Lava blisters are associated with some tubular stalactites and the squeeze-ups. Jaggar (1931) described "barnacle stalactites". We found these stretched, grooved, barnacle-like forms associated with tubular lava stalactites behind slumped ceiling linings (Fig. 6). They are also common around contracted perimeters of subsided plunge pools.

Unlike tubular lava stalactites, tapered "shark tooth" or "teat" stalactites (Larson 1993) grow where fluctuating lava adheres to ceilings (Fig. 7). As a result, these pendants and the surfaces between them are typically veneered with subsequent coatings and are, therefore, similar in composition to typical lava tube linings (stratified coats from lava flowing in the tube).

METHODS

Some tubular lava stalactite and ceiling lining samples were crushed and then tested for grain density using kerosene as a displacement medium. Eight thin sections were made of stalactite and ceiling lining samples, including one shark tooth stalactite. X-ray analyses for modal composition were done on a Philips X-ray diffractometer. Chemical analyses of 69 elements were made of a group of small tubular lava stalactites

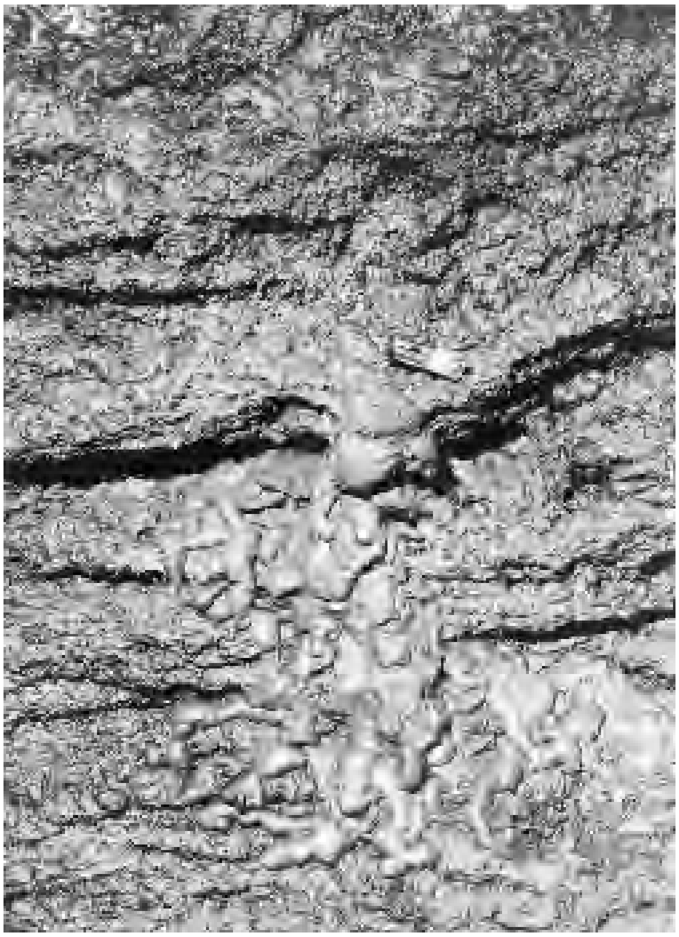

Figure 5 (above). Squeeze-up, Keala Cave. This erupted lava is suspected of being extruded in a similar fashion to tubular lava stalactites. The battery above the rounded cap is 5 cm long. Photo by C. Allred.
Figure 6 (below). Barnacle-like stretched lava, Kazumura Cave. Lava forming these features was extruded as the crack widened. If the lower part falls away, only the "stalactite" portion remains. The battery end is 14 mm in diameter. Photo by C. Allred.

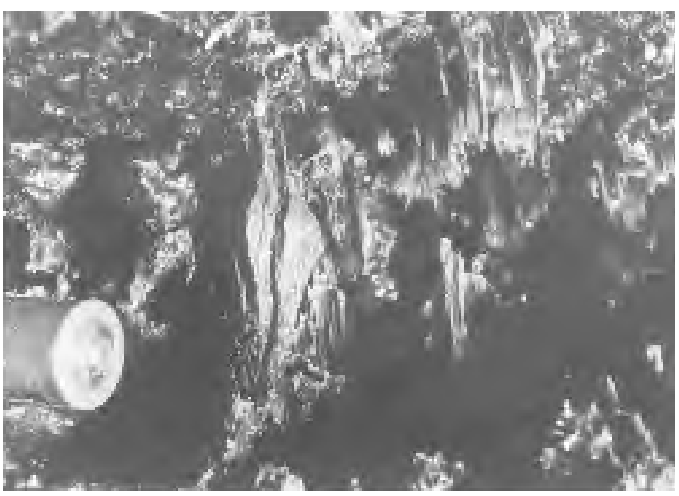

Figure 7. The HA1 shark tooth stalactite thin section. Eight linings are visible with magnification. The light voids are vesicles. The sample is 66 mm long. Photo by M. Palmer.

and the parent lining 1 to 3 cm above the stalactites. This was done primarily by ICP-AES (inductively coupled plasma atomic emission spectrometry), INAA (instrumental neutron activation analysis), ICP/MS (inductively coupled plasma-mass spectrometry), and XRF (X-ray fluorescence spectroscopy).

Cave observations of 1995 and 1996 were correlated with paraffin models used to simulate tubular lava stalactite growth. A caldron of liquid paraffin drained through a coarse filter, valve, and tube, into a small cooling reservoir. It then seeped through a sponge filter and out a final tube. The paraffin temperature was monitored with thermometers in both containers.

DISCUSSION

The extreme temperature of active lava tubes makes direct observation of forming tubular lava stalactites difficult, if not impossible. Hon (pers. comm. 1996) reported seeing a slowly dripping tubular stalactite from the vantage point of a nearby skylight, but we are still forced to puzzle out their origins by studying cooled lava tubes.

CONCEPTS OF FILTER PRESSED SEGREGATION

Wright and Okamura (1977) explained that lava can "segregate" from a partially crystallized melt at temperatures between 1,070° and 1,030°C. This results in veins of "relatively coarse grained, glassy, vesicular rock" differing in composition from the main body of lava. This process is called filter pressed segregation, and occurs in lava lakes of Kilauea Volcano. They describe it as follows:

"The crystal framework of the crust behaves as a filter, through which the liquid fraction moves into the open fracture. The efficiency of the filtration process is variable. Some segregations carry in crystals, so that the bulk composition of the segregation does not lie on the liquid line of descent for the lake as a whole, whereas other segregations are virtually free of early-formed crystals".

Wright and Helz (1987) concluded that highly differentiated segregations can occur in contraction cracks of these lakes between temperatures of 1,060° and 1,000°C, even when interstitial liquid equals 10% or less. The entry into the cracks was inferred to be gas-driven.

We submit that tubular lava stalactites and other related forms are segregations extruded by expanding gas into cave passages. Like the cracks in the cooling lava lakes of Kilauea, some open lava tube contraction cracks have been injected with interstitial liquid from both opposing surfaces after they split apart. This material did not come from flowing parent lava of the lava tube. Where cracks were widening during the extrusion, stretched barnacle-like forms grew (Fig. 6). It is important to note that the majority of lava tube cracks lack segregations, because of improper conditions, or they may have opened nearer to or below the solidus, given as 980°C by Wright and Okamura (1977). Not all extrusive phenomena are

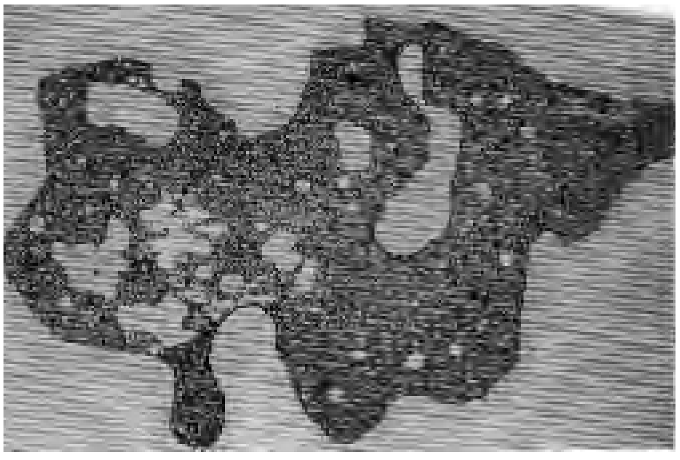

Figure 8. Vuggy fabric in HA2 lining above a small darker tubular lava stalactite. The stalactite is 8 mm long. Photo by M. Palmer.

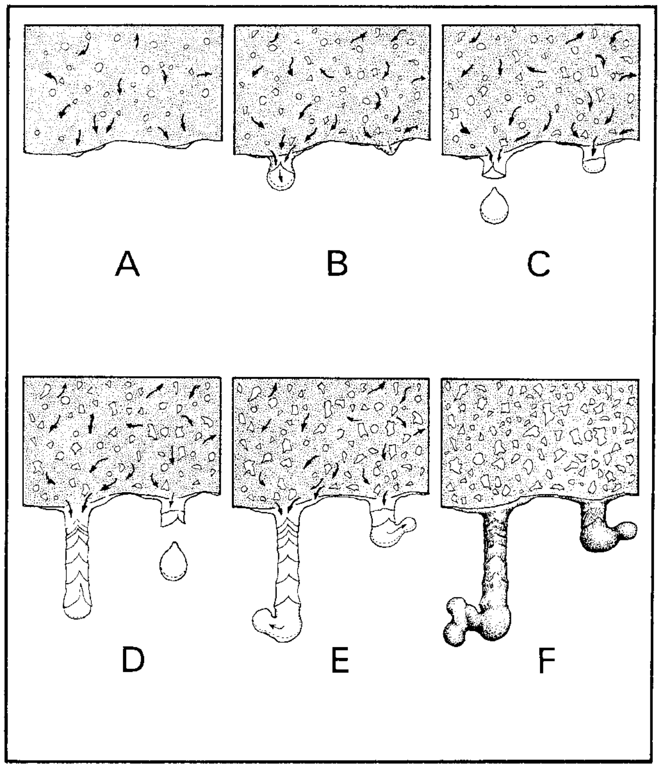

Figure 9. Proposed extrusion of tubular lava stalactites. A. Retrograde boiling in the lining creates vugs and begins extruding a thin discontinuous layer of residual melt. B. Continued residual outpourings collect in some discrete points. C. Incipient tubular shapes become more apparent, and vugs continue to form in the lining. D. Continued addition of drip segments creates growth rings. Splitting of the newest skin is perpetuated to additional segments as new driblets emerge. E. Cooling promotes crystallization of the bottom part of emerging driblets, forcing the liquid to the side or upward into eccentric shapes. Vesicle surfaces have become honeycombed by vuggy fabric. F. Cooled stalactites.

filter pressed. For example, settling of crusts may extrude some parent lava as squeeze-ups.

SEGREGATION EMERGENCE

Why and how did the lava tube segregation extrusions occur only after the lava had reached an advanced stage of crystallization? Rounded bubbles, or vesicles, are formed from volatile exsolution at a time when only a small percentage of lava has crystallized. When 50 to 55% of lava crystallizes at about 1070° to 1065°C, it ceases to flow (Wright & Okamura 1977; Peck 1978). This transition is called the crust-melt interface. With more progressed crystallization, interstitial liquids can effervesce between crystal faces to form irregular vugs (Peck 1978). This is because, as crystallization becomes more advanced, volatiles (chiefly H_2O) are concentrated in the residual melt and retrograde boiling occurs (Best

Figure 10. Lava coralloids (second-order segregations) extruded from a large lava stalagmite, Eppersons Cave. The coralloids formed during the cooling of the lava tube on the upstream side, and probably leeward of a breeze. The scale is 15 cm long. Photo by K. Allred.

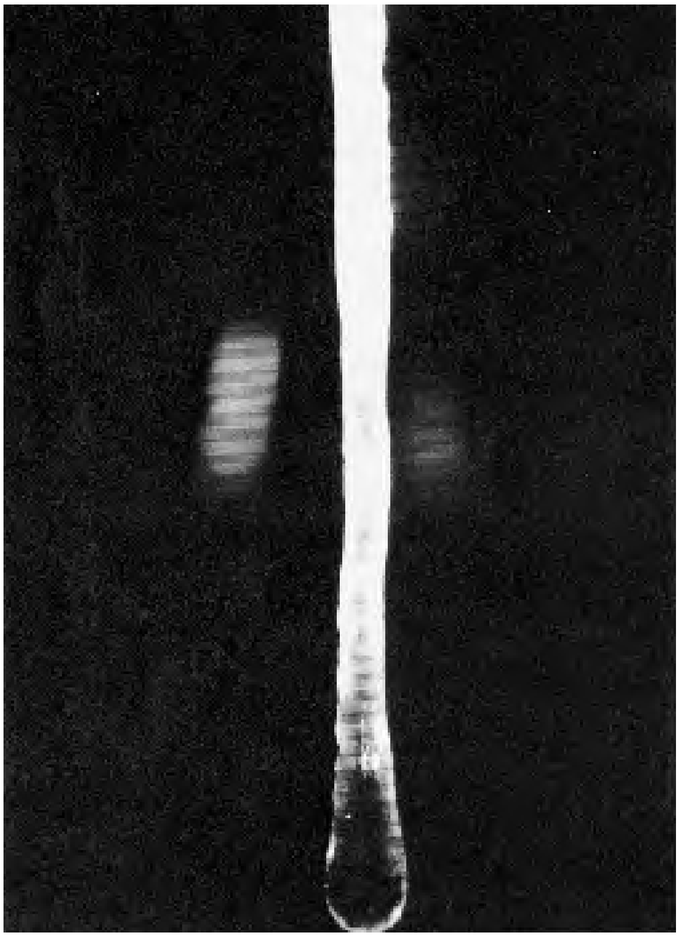

Figure 11. Tubular paraffin stalactite during growth. The stalactite diameter is 3 mm. Photo by C. Allred.

1995: 246, 292). We observed a more intensely vuggy fabric in linings having higher concentrations of tubular stalactites and other segregations (Fig. 8). In such a fabric, vesicle surfaces become honeycombed with vugs until only their general spherical shape remains. At least some of the interstitial melt is forced out into the cave to form tubular stalactites (Fig. 9).

The occurrence of coarse grains in segregations is evidence of increased diffusion of atoms because of high H_2O content. Low viscosity of residual liquid results from water molecules breaking some chains of SiO_4 tetrahedra. Addition of K_2O and Na_2O to silicate melts plays a similar role (Best 1995: 232, 293). With this in mind, we observed a tendency of brownish segregation material to have once been very fluid and to have almost none of the magnetite prevalent in the more common dark gray samples. This may indicate extensive oxidation to hematite under high H_2O conditions that would cause retrograde boiling. Vesiculation in segregations (Anderson *et al.* 1984) is further evidence that the driving force was retrograde boiling. Even later retrograde boiling can form vugs in tubular lava stalactites and stalagmites to extrude helictites or coralloids (Fig. 10). None of these second order segregations have yet been analyzed.

COMPARISONS WITH PARAFFIN MODELS

To help understand the origin of tubular lava stalactites, we were able to simulate their growth using colored paraffin of approximately 65° to 70°C. The most effective way of regulating paraffin flow was by inserting a sponge plug into the drainage tube which fed the stalactites. This is similar to the process of filter pressed segregation in lava, but where gravity takes the place of gas pressure. The resulting paraffin stalactites were 3 to 4 mm in diameter, and up to 15 cm long. As driblets drained quickly through a stalactite and dripped from the growing tip (Fig. 11), a thin flexible skin extended in segments. We sometimes observed the skins of newest segments splitting open and closing repeatedly parallel to the axis during cyclic driblet movement. This segmenting and splitting is reminiscent of growth rings and linear seams on some tubular lava stalactites.

Paraffin stalactites can be diverted into eccentric directions. The paraffin has a high solidification contraction of about 15%

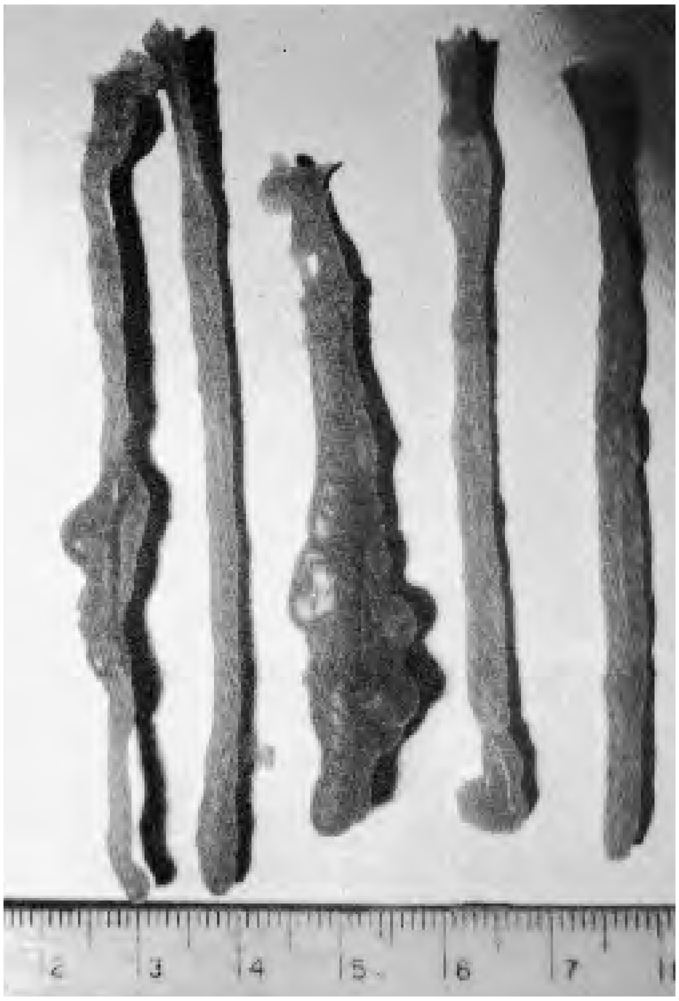

Figure 12. Some tubular paraffin stalactites. The scale is in centimeters. Photo by C. Allred.

volume. Since the solids are heavier, they tend to congeal at the bottom of the emerging driblet. The driblet is held to the preceding segment by surface tension, and the skin is thinnest around the sides of the driblet where spreading occurs. If the drainage is allowed to cool sufficiently (due to convection farther down the stalactite, or from diminished flow), pressured liquid pushes out or upward from the side of the driblet, beginning an eccentric form. These breakouts also can occur nearer the attachment point of a stalactite, resulting in a compound form. If a breeze is present, preferential growth is leeward. We suspect a similar process is involved in the formation of eccentric tubular lava stalactites, because lava contracts about 13% (Daly 1944) (compare Figs. 3 & 12).

If the paraffin temperature was too hot, a stalactite could not form, and all of each driblet fell to build puddles below. Only rudimentary stalagmites were possible with paraffin because of its extreme fluidity. This would indicate that paraffin is not a perfect model, even though mechanisms are comparable.

We also attempted to simulate stalactite formation according to the popular "remelt" hypothesis. We repeatedly flash heated a horizontal, flat, paraffin "ceiling". This only produced driblet projections less than 3 mm long. Any larger projections were quickly melted away when exposed to the heat. After experimenting with the paraffin, it became clear to us that tubular lava stalactites must necessarily develop from low viscosity cooling lava dripping from their tips.

Table 1. Modal compositions (volume percent). Segregations are shaded. 1, from Hjelmquist (1932); 2, the outer crust of the stalactite, and includes both hematite and magnetite; 3, all glass; 4, undetermined amounts of zeolite were detected in the glass; 5, uncorrected modes (Wright and Okamura, 1977, Table 14); 6, includes minor amounts of clay deposited on the exterior surfaces of stalactites after they were formed; *, olivine was visible in lining and may have been included in point counts for pyroxene.

	Sample	Olivine	Pyroxene	Plagioclase	Ilmenite	Magnetite	Hematite	Glass, Zeolite[4]	Apatite	Total
HA1	shark tooth stalactite composed of 8 linings	?	36.04	31.39	1.16	12.79	1.16	17.44		99.98
HA2	lining portion directly above tubular stalactite		29.16	30.55		15.27	5.55	19.44		99.97
HA2	tubular stalactite portion of sample		16.00	25.00	2.00	19.00	11.00	27.00[6]		100.00
HA3	both tubular stalactites & portion above are segregations		12.24	16.32		23.46		47.95[6]		99.97
HA4	stalagmite, transverse cross section		32.46	23.37		29.87	3.89	10.38		99.97
HA4	stalagmite, axial cross section		28.41	15.90	1.13	32.96	2.27	18.17	1.13	99.97
HA5	outer portion of HA6, directly above a small tubular stalactite	*	49.99	30.48		12.19	1.22		6.09	99.97
HA5	small tubular stalctite of HA6		39.60	22.77		24.75		8.91	3.96	99.99
HA6	lining from which tubular stalactites had grown	*	66.66	16.00		10.66	2.66		4.00	99.98
Hj[1]	tubular stalactite, Raufarholshellire Cave, Iceland		19.00	19.80		7.90	17.90[2]	35.40[3]		100.00
MLL[5]	Chemical mode for average Makaopuhi basalt	6.50	39.80	42.50	4.20	1.00		5.40[3]	.60	100.00

PETROGRAPHIC ANALYSIS AND DENSITY

Our sectioned samples (Table 1) were generally similar to tubular stalactites of previous petrographic studies (Dana 1889; Hjelmqvist 1932; McClain 1974; Baird *et al.* 1985). The segregations are darker, more coarsely grained, and are higher in magnetite and glass content, than the linings from which they extruded. We found that many tubular stalactites can be picked up easily with a magnet, due to high magnetite content throughout.

Glaze is a <50 µm magnetite skin, which has a characteristic silver luster from light reflecting off facets of tiny octahedrons. This magnetite ornamentation seems to have grown after the greenish pyroxene-rich surface had begun to crystallize on most lava tube surfaces. We found rare sites of greenish linings and tubular stalactites lacking much of the magnetite ornamentation. A reddish color can result when glaze has been oxidized to hematite. The magnetite indicates low temperature crystallization between 1030°C and the solidus (Table 2a). Thus, we question the prevailing assumption that glaze is evidence of remelting (Jaggar 1931; Peterson & Swanson 1974; Harter 1978; Allred & Allred 1997). The darker, coarsely grained layer under some glaze of our samples is segregated material.

We found that under magnification, the thin section of the shark tooth stalactite sample HA1 (Fig. 7) consists of eight distinct coatings (linings) ranging from 5 µm to 2.5 cm thick. In lining and tubular stalactite samples, the transitions between the linings and segregations are much less distinct than between the separate linings of the shark tooth stalactite. In the lining and stalactite samples, pyroxene crystals and laths of plagioclase commonly extend deep into either side of the transition zone, indicating segregation drainage through the crystalline framework.

Thin sections of the HA4 stalagmite show the distinct outlines of individual driblets (Fig. 13). Each has a finely crystalline pyroxene and magnetite rind with a well defined 50 µm magnetite glaze. The globs that fell onto this particular sample had congealed enough so that subsequent impacts did not deform them.

Some samples contain pseudomorphs from pyroxene partially altered to magnetite. Other identified minerals were a zeolite and probably sepiolite (M. Palmer, pers. comm. 1996).

Some hollow parts of tubular stalactites were partially filled with a delicate frostwork of pyroxene crystals and plagioclase laths and plates. Naughton (1975) suggested that the frostwork may be all that remains after interstitial liquid effervesced out.

The lava tube segregations generally follow the mineral paragenesis of Makaopuhi Lava Lake on Kilauea (Table 2a, Fig. 14). Wright and Fiske (1971) defined three stages in the crystallization sequence of nearby Alae Lava Lake. Filter pressed segregations occur in the third stage (Table 2b).

Table 3 shows the major and minor chemical compositions of segregations and average parent basalts. Makaopuhi data is included for comparison. When the crystallization of lava progresses beyond the crust-melt interface, the residual melt commonly becomes more enriched in Fe, Ti, Na, K, P, and Si, relative to Ca and Mg (Best 1995: 262, 292). Higher percentages of Ca and Mg are utilized in the earlier formed minerals. We expected the segregations to contain no earlier formed crystals of olivine if the filtering had been effective. This seems to be the case with the segregations in our thin sections, whereas olivine and olivine pseudomorphs are visible in at least some of the lining samples. The tubular lava stalactite samples of Table 3 are plotted on variation diagrams of Fig. 15 showing the liquid line of descent of Alae Lava Lake, Hawaii. All three analyzed lava tube segregations plot near the crust-melt interface. However such segregations may also occur at much lower temperature (Wright & Fiske 1971; Wright & Helz 1987). Bulk compositions that are higher in MgO than in the Alae Lake liquid line of descent (for example, HA6) may have segregations that occurred at slightly lower temperatures relative to that MgO scale.

Table 2. Crystallization of basalt, Kilauea Volcano.

a. Mineral paragenesis, Makaopuhi Lava Lake. Filter pressed segregation range is shaded (after Wright & Okamura 1977).

Mineral	Composition	Temperature (±10°C)	Glass (weight percent)
Olivine	Fo_{80-85}	1,205	100
Augite	$En_{47}Fs_{13}Wo_{40}$	1,185	94
Plagioclase	An_{67}	1,180	92
Ilmenite	$Ilm_{89}Hem_{11}$	1,070	44
Olivine	Fo_{55}	1,050	17
Pigeonite	$En_{61}Fs_{32}Wo_{7}$	1,050	17
Magnetite	$Usp_{63}Mag_{37}$	1,030	9
Apatite		1,020	7
Solidus		980	4 (residual glass)

b. Change of liquid composition during crystallization of Alae Lava Lake. Filter pressed segregation range is shaded (after Wright & Fiske 1971).

Stage	Temperature range (degrees C)	Minerals Crystallizing	Change of liquid composition with falling temperature
1	>1185	Olivine	Increase of all constituents except MgO and 'FeO'.
2	1185 - 1070	(Olivine) = Augite = Plagioclase (= Pigeonite? in prehistoric lavas)	Decrease of MgO, CaO, and once feldspar begins to crystallize, Al_2O_3. Decrease or no change in SiO_2. Increase in Na_2O, K_2O, FeO, TiO_2 and P_2O_5.
3	1070 - 1000	Augite = Plagioclase = Pigeonite = Ilmenite (= Magnetite at lower temperature)	Decrease in Al_2O_3, MgO, CaO. Increase in SiO_2, Na_2O, K_2O, P_2O_5. Increase in TiO_2 and FeO to a maximum and then decrease as Fe-Ti oxides crystallize in greater quantity.

Figure 13. A thin section of lava stalagmite HA4. The light voids are vesicles. Sample is 56 mm long. Photo by M. Palmer.

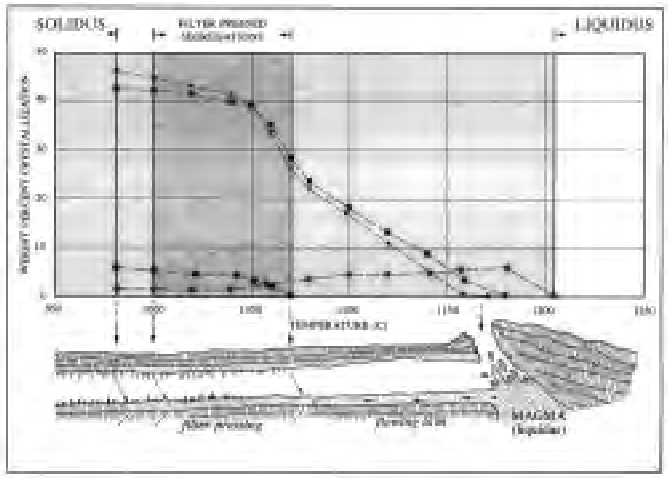

Figure 14. Crystallization of Makaopuhi Lava Lake basalt (data after Wright and Okamura, 1977; Wright and Hilz, 1987) compared with the inferred solidification and segregation range of a Kilauea lava tube. Approximately 4% of the olivine precipitated at higher temperature is later resorbed. Deflected temperature boundaries through the lava tube are due to a cooler conductive ceiling above the lava river. An eruption temperature of 1165ºC was chosen from Swanson (1973). ○, olivine; ■, pyroxene; ▪, plagioclase; ●, Fe-Ti oxides; ⁂, partially crystallized lava.

Many trace and rare earth elements are incompatible with the crystallization phases, so tend to remain in residual liquids. They are, therefore, more concentrated in the segregations than in the linings (Table 4). Many of the incompatibles in the stalactites were approximately double those of the lining. This is further evidence that the segregations occurred at about the crust-melt interface. Ni, Cr, and Co are compatible, and they substitute for MgO in olivine (Krauskopf & Bird 1995).

Table 3. Chemical composition of segregations and Kilauean parent lavas (weight percent). Segregations are boxed. 1, silica dioxide and disodium oxide were designated as SiO_2 and NaO respectively (Brigham 1868); 2, collected from Kazumura Cave (Baird, Mohrig& Welday 1985), total Fe calculated as FeO; 3, from Wolfe and Morris (1996); 4, segregation vein from Makaopuhi lava lake sample 68-2-10 (Wright & Okamura 1977); 5, Wright and Okamura (1977), Table 12; 6, detection limit of 0.01%.

Oxide	Tubular stalactite, Kilauea Caldera (1868)[1]	Tubular stalactites Kazumura Cave. (1985)[2]	Tubular stalactite HA6, Kazumura Cave. (this study)[6]	Parent lining of tubular stalactite HA6. (this study)[6]	Average parent lava of the Kazumura flow. (1996)[3] upper flow	lower flow	Segregation vein Makaopuhi Lava Lake. (1977)[4]	Average Makaopuhi basalt. (1977)[5]
SiO_2	51.9	53.3	49.14	48.74	50.70	50.70	50.77	50.18
Al_2O_3	13.4	13.8	12.49	13.70	13.13	13.00	12.27	13.26
Fe_2O_3	15.5		15.33	12.07	12.66	2.87	4.26	1.48
FeO		10.4			--	8.65	10.45	9.86
MgO	4.8	5.5	5.23	8.37	7.85	8.42	4.23	8.27
CaO	9.6	10.9	9.37	11.07	11.33	11.02	8.47	10.82
Na_2O	3.0	2.8	3.05	2.46	2.08	2.10	2.75	2.32
K_2O	1.1	0.5	0.65	0.33	0.38	0.39	1.11	0.54
TiO_2		2.8	3.63	2.08	2.52	2.30	4.49	2.64
P_2O_5			0.35	0.19	0.23	0.25	0.52	0.27
MnO	0.8		0.20	0.17	0.17	0.20	0.20	0.17

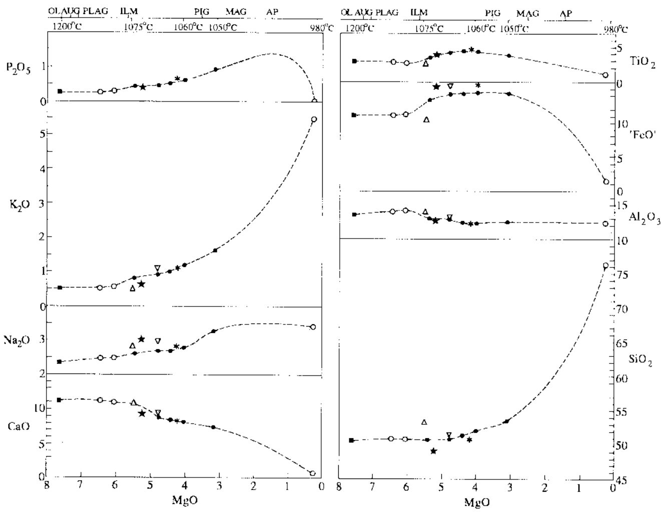

Figure 15. Liquid line of descent, Alae lava lake (Wright & Fiske 1971) with additional plotted lava tube segregations. ■, bulk composition; ○, separated and analyzed glasses; ●, naturally filter pressed oozes; ⋏, tubular lava stalactites, (Baird *et al.* 1985); *, segregation vein sample 68-2-10 (Wright & Okamura, 1977); ⋎, tubular lava stalactites (Brigham 1868); ✱, HA6 tubular lava stalactites.

Bulk rock densities of segregations average slightly higher than their parent linings. Grain densities of HA6 segregations and linings were 3.16 g/cm³ and 3.0 g/cm³, respectively.

RUNNER CHANNELS

In places, shallow incised "runner" channels extend vertically down the cave walls. Those we observed are up to 20 mm wide, 5 mm deep, and one meter long (Fig. 16). At first we thought these had been melted into the already solidified walls by hotter lava extruded into the cave through tiny holes in the walls. Now we believe the volatile-supersaturated segregations pouring from the orifices reacted with the residual liquid of the hot wall lining. This caused some residual liquid to become less viscous and flow away with the segregations. Best (1995: 234) calls this general process "depolymerization". In such circumstances, previously crystallized olivine and other minerals would be undermined and wash down the channels with the liquid. Exit holes and internal conduits

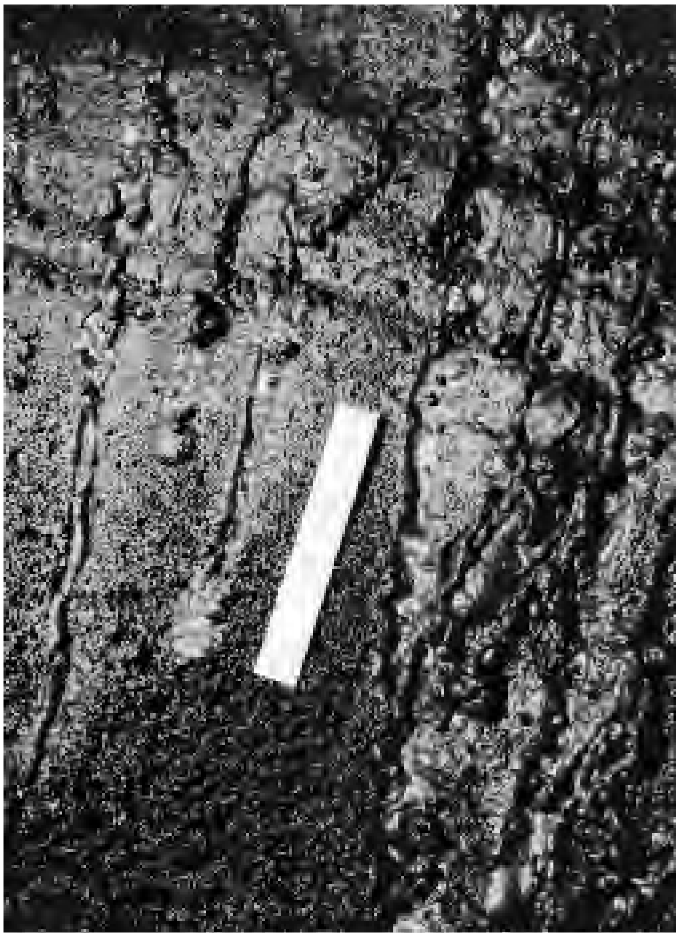

Figure 16. Runner channels with subsequent runners, Keala Cave. The scale is 15 cm long. Photo by K. Allred.

Table 4. Trace and rare earth elements of HA6 lining and stalactites. (-) Indicates below detection limits.

Element	Au	As	Ba	Br	Co	Cr	Cs	Hf	Ir	Rb	Sb	Sc
detection limit/unit	1 ppb	1 ppm	1 ppm	0.5 ppm	0.1 ppm	0.2 ppm	0.2 ppm	0.2 ppm	1 ppb	10 ppm	0.1 ppm	0.01 ppm
HA6 lining	-	2	105	-	45.1	695	-	7.7	-	-	0.4	29.1
HA6 tubular stalactites	8	2	173	-	42.1	351	-	7	-	-	0.7	27.5

Element	Se	Ta	Th	U	W	La	Ce	Nd	Sm	Eu	Tb	Yb
detection limit/unit	0.5 ppm	0.3 ppm	0.1 ppm	0.1 ppm	1 ppm	0.1 ppm	1 ppm	1 ppm	0.01 ppm	0.05 ppm	0.1 ppm	0.05 ppm
HA6 lining	-	0.7	0.7	-	-	8.4	21	15	4	1.43	0.7	1.76
HA 6 tubular stalactites	-	1	1.2	0.5	2	16.9	42	30	7.29	2.46	1.3	3.01

Element	Lu	Sr	Y	Zr	V	Mo	Cu	Pb	Zn	Ag	Ni	Cd	Bi	Be
detection limit/unit	0.01 ppm	1 ppm	1 ppm	1 ppm	1 ppm	2 ppm	1 ppm	5 ppm	1 ppm	0.5 ppm	1 ppm	0.5 ppm	5 ppm	2 ppm
HA6 lining	02.5	308	23	122	270	3	118	14	87	2.4	151	-0.5	25	-2
HA6 tubular stalactites	0.42	431	41	234	390	3	235	-5	129	2.9	58	-0.5	15	-2

above the channels seem to have been enlarged as well. Indeed, it may be that "roots" observed to extend above some tubular stalactites (Harter 1971, 1993) were formed by residual melts depolymerizing along the paths of segregations. As with the other segregated features, the depolymerization occurred during cooling of the lava tube. It is important to emphasize that none of these processes have anything to do with a "remelt" scenario. Although the eventual solidus temperature might be lowered by increased H_2O in residual melts, there is no change from crystalline to melt.

CONCLUSIONS

Based on evidence stated above, tubular stalactites and some other extrusions in lava tubes are filter pressed segregations extruded by retrograde boiling from partially crystallized lava. They occur at or below the crust-melt interface between about 1070º and 1000°C. Segregations differ from their parent linings in density, texture, mineral ratios, and chemical composition. In some cases, segregations depolymerized residual liquid in partially crystallized linings. Besides tubular lava stalactites and their drainages, filter pressed segregation is also responsible for barnacle-like stretched lava, and at least some lava roses, blisters, and squeeze-ups.

Genetically, the outer shells of tubular stalactites function like the insulative linings of the lava tubes in which they grow. The great variety of these and other interesting lava formations is influenced by the composition of the parent lavas, by when the segregations occur, by the efficiency of filtering, and by the complex open environment under which they cool.

ACKNOWLEDGEMENTS

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HISTORY AND STATUS OF THE MOILIILI KARST, HAWAII

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The Moiliili Karst occurs in Pleistocene reef limestone located in a populous, low-elevation area of Honolulu, Hawaii. A 1934 construction excavation intersected a previously unknown karstic master conduit at a depth of -7 m msl. Temporary dewatering of over 3.7 x10^9 L caused considerable economic loss due to collapses and subsidences in a wedge-shaped area about 1 km on each side. These outline a previously unrecognized dendritic karst drainage. Considerable retrograde flow of salt water also occurred. Subsequent urbanization again lowered the water table and dewatering phenomena are still occurring. A section of Moiliili Water Cave is the only clearly karstic feature that remains available for study. It serves as a floodwater conduit. Surprisingly, its water quality has improved since 1983. Its protection should be a prototype for other Hawaiian karsts and pseudokarsts. Other sections of Honolulu also are underlain by reef limestone and may be at risk.

Located downslope from volcanics of Oahu's Manoa Valley in a densely populated section of Honolulu, the Moiliili Karst is the most important of several recently delineated in Hawaii (Halliday 1994, 1997). At an elevation of 2 to 5 m msl, it consists of a wedge-shaped area about 1 km on each side, with the narrow downslope (southern) angle near the intersection of University Avenue and Kapiolani Boulevard (Fig. 1). Prior to recent bibliographic studies, it was not recognized as karst. First published reference to its karstic nature apparently was in 1994 (Halliday 1994). It now is clear that a dendritic karstic drainage system (Fig. 1) extends from ill-defined swallets near the volcanic/limestone contact to the coast. Localized subsidences and conduit passages in the mapped area sharply differentiate it from adjacent sections of the lowland coastal plain, also underlain by reef limestone, and outline a specific underground drainage basin.

RELATION TO URBAN FEATURES

The wide upslope section of this karst is centered around the intersection of University Avenue and South King Street, downslope from the University Avenue interchange of "Interstate" Highway H-1 (Fig. 1). On the upslope side of the 6-lane freeway, it underlies the lower part of the main University of Hawaii campus. Downslope from the freeway, it underlies the Moiliili business and residential district serving the university. Because of its critical location, its economic importance far transcends its small size.

Especially in its upslope section, karstic dissolution caverns, resurgences, and spring-fed ponds have been known from early times. Although Moiliili Water Cave now is truncated by construction fill and is enterable only through a manhole or sewer grate, a boating expedition was photographed in 1897 (Williams 1935) in what probably was part of it. Urbanization has destroyed most surface karstic features. A large pond fed by a karstic spring was located upslope of Beretania Street west of what now is University Avenue. This street extends north on the bed of another (Williams 1935). The former Hausten (Kumulae) Pond farther downslope (discussed below

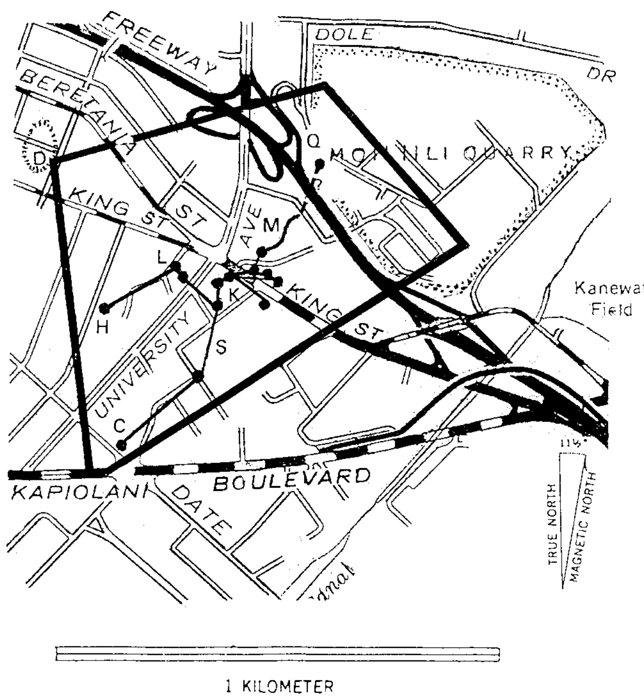

Figure 1. Re-creation of conduit drainage of Moiliili Karst, showing the wedge-shaped area in which karst features have been found. Base map from U.S. Geological Survey Honolulu Quadrangle (1983). C. Site of catastrophic 1934 excavation into master conduit below sea level, with upslope dewatering. Conduit continues seaward, presumably west or southwest. D. Shallow closed depression mentioned in text; possibly artificial. H. Hausten (Kumulae) Spring and fish pond at Willows Restaurant. K. South King Street complex of cave passages, collapses, and subsidences. L. Kuilei Lane complex of subsidence, caverns demonstrated by geophysical studies, and cave passage shown on 1935 Board of Water Supply map. M. Moiliili Water Cave. Q. University of Hawaii Quarry Cave. S. Area of maximum subsidence in 1934.

in detail) was another famous feature. Until recently, the perched water tables causing these ponds were interpreted as nonkarstic, due to the reef limestone serving as a confining layer barring seaward escape of artesian water from upslope Manoa volcanics (Wentworth 1953).

The residential part of this district includes an apartment section and a larger, heavily populated area of small homes. Some of these houses may still rely on septic tanks or cesspools. The section south of South King Street was long famous for "cesspools that were notable for never plugging or overflowing" (Lao n.d.). Even limited observation in 1934 immediately revealed raw sewage entering the main karstic water table stream (Kunesh 1934).

STRATIGRAPHY AND SPELEOGENESIS

As in much of southern Oahu, the karstifiable bedrock is reef limestone of the Pleistocene Sangamon Interglacial Stage, deposited during a sea level stand 8 m above modern sea level (Stearns 1939). The type locality is at Waimanalo, near the

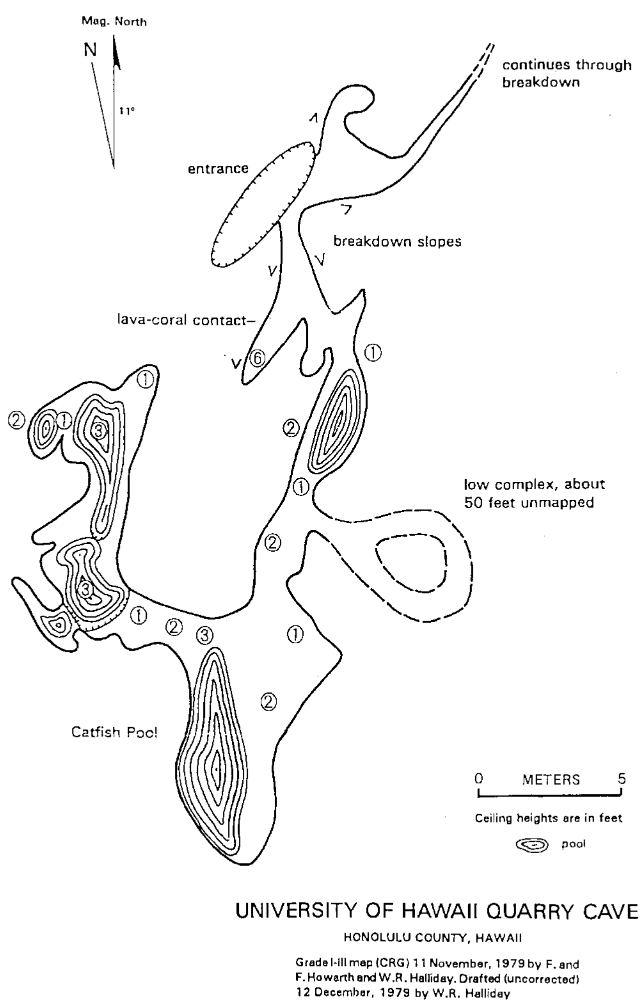

Figure 2. Map of University of Hawaii Quarry Cave.

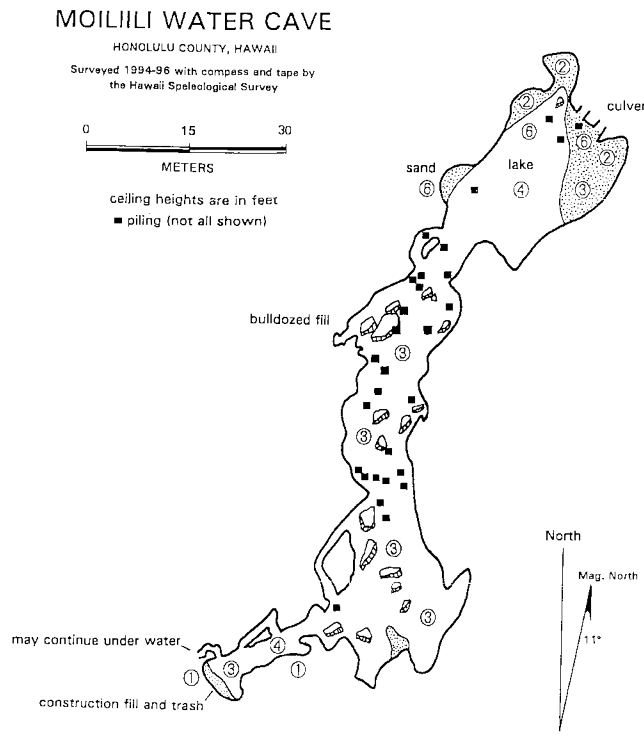

Figure 3. Map of Moiliili Water Cave.

south end of Oahu's eastern coast (Stearns & Vaksvik 1935). In the Moiliili Karst, the little that is visible today (i.e, in the walls of Moiliili Water Cave) is well cemented and massive. This is not typical of the Waimanalo formation as a whole, and may not be representative of the Moiliili Karst in general.

Atop some of the upslope part of the limestone, Sugarloaf lava (66-68 Ka) cooled in thicknesses of up to 12 m just below Dole Drive at what now is the University of Hawaii parking garage. It tapered rapidly downslope; one edge is just upslope from Highway H-1 at the site of the former entrance of University of Hawaii Quarry Cave which is partially roofed by the lava (Fig. 2). An eastern finger of this lava more than 300 m wide extended seaward across South King Street and Kapiolani Boulevard just east of the karst. Eventually it dipped into an existing channel where it is overlain by reef limestone. This lava diverted the lower part of Manoa Stream from its original course. Lao (n.d.) suggested that the cave system represents the old channel of that stream. Based on the morphology of Moiliili Water Cave (Fig. 3), another possibility is that it formed in the shallow phreatic zone beneath that stream where flow velocity and, hence, dissolution would be expected to be greatest. Two older lava flows also are interbedded with reef limestone at greater depth (Lao n.d.) but appear unrelated to karstification.

After cooling of the Sugarloaf lava, alluvium and marshy lagoon sediments accumulated atop much of the limestone. These were especially thick downslope from any manifestation of the karst, in an area behind a beach berm which developed at Waikiki. Here, the Ala Wai Canal now exposes reef limestone at low tide, but its excavation did not intersect the karst's master conduit and the canal has little or no effect on its water table. Accumulations of similar sediments overlie the limestone farther west. The best-known geological map of the island (Stearns 1939) shows these sediments in most of the coastal strip between Diamond Head and Pearl Harbor, rather than the underlying karstifiable reef limestone.

In the Moiliili Karst, most of the limestone was covered with soil. Its thickness was described as a few inches (Honolulu Board Of Water Supply 1933-34). Between Kapiolani Boulevard and South King Street adjacent to the lower part of the principal conduit, some bare limestone was exposed. Its karstic features evidently were obscure to absent, and none were recognized.

BASIC HYDROGEOLOGY OF THE HONOLULU LOWLAND COASTAL STRIP

The Moiliili Karst is immediately west of Manoa Stream and its channelization, the Manoa-Palolo Drainage Canal. The gully of this stream and/or an adjacent lava flow is the eastern boundary of the study area. On the opposite side of this stream gully, the name of Kanewai Field perpetuates the memory of a long-filled karstic pond; the easternmost of several perched water table ponds between Diamond Head and Punchbowl Crater. Westward toward and beyond the latter, buried or surficial reef limestone extends many kilometers, to and beyond Pearl Harbor, where Ford Island is entirely calcareous (Stearns 1939). Romantic journalism (e.g., Williams 1935) refers to "miles and miles" of caves here. Although considerable artesian water has been obtained by drilling, a few long drained ponds are the only karstic features known to have existed between the Moiliili Karst and Pearl Harbor. No clearcut surface drainage exists here, and the gully of the next perennial stream (Nuuanu Stream) is more than 5 km west of Moiliili, on the opposite side of the downtown business district. Several upland streams sink into alluvium in this area. Minimal traces of karstic ponds are the only residual of karstic features originally present. Urbanization is so extensive that it is not even certain that the shallow closed depression at the northwest corner of the area mapped as the Moiliili Karst (Fig. 1) is a natural feature.

KARSTIC FEATURES KNOWN IN MOILIILI PRIOR TO 1934

The Sugarloaf lava was quarried extensively, exposing some underlying limestone. Evidently in the early or mid-1920s, a cavern about 8 m wide and up to 5 m high was found in limestone originally overlain by lava, at 2 m msl (Stearns & Vaksvik 1935). Apparently this was a short distance east of University of Hawaii Quarry Cave, whose entrance opened spontaneously in 1978 or 1979 beneath an office building (although fish and invertebrates were observed, authorities soon filled the entrance). The earlier quarry cave is not known today, and may have been filled or destroyed in University development of the quarry floor. In the first decade of the century, another dissolution cave (not mentioned by Stearns) was entered upslope from South King Street. It is not clear whether this was part of Moiliili Water Cave, or another, now lost. In 1928, still another cave containing a large flow of water was intersected by sewer construction a short distance farther east. Its stream elevation was about 1 meter (Williams 1935; Stearns & Vaksvik 1935). Two pumps yielding 1.5 x 10^{10} L per day did not appreciably lower its water level, and special beams had to be installed to support sewer lines (Chester Wentworth, quoted in Williams 1935).

The best-known of the perched water-table ponds was Hausten (Kumulae) Pond, at what became the Willows Restaurant, about 0.3 km southwest of the King-University intersection. Mr. Hausten purchased and cleared the land in the early 1920s, and stocked the pond with koi which interbred with existing fish. This produced a large school of colorful fish which came on signal to be fed. The large clear fishpond quickly became a noted attraction.

THE 1934 DEWATERING

In the autumn of 1934 the karst and its drainage were altered profoundly. Five hundred meters downslope from the King-University intersection, construction activities struck a karstic master conduit -7 m msl. The excavation was 18 m^2 and ~8 m deep (Lao n.d.). A "gushing flow" quickly filled it. A telephone pole lowered into the hole found a bottom at -10 m msl (Kunesh 1934). The flow was not recognized as karstic, and was attributed to "a lamina of shallow secondary artesian water" (Honolulu Board of Water Supply 1933-34). For more than four months, an average of 3.8 x 10^7 L was pumped daily before the hole could be sealed and construction resumed: a total of more than 3.8 x 10^9 L.

Upslope, the results of this dewatering were dramatic. The Hausten pond disappeared without warning, draining in less than 24 hours. What was described as "a huge outlet" appeared in its bottom, -2 m msl (Kunesh 1934; Wentworth 1953). Some of the famous fish were stranded. Others disappeared into the conduit system. New sinkholes developed. "People living in the vicinity made their way into the caves through holes in their yards and speared fish by the hundreds" (Williams 1935). Several houses "lurched" and settled. Sidewalks cracked and water and gas mains ruptured. Some trees sank almost 1 m (Kunesh 1934; Lao n.d). No accurate determination of the total economic loss is known, but it must have been considerable.

THE KING STREET COMPLEX

Aside from the Hausten Pond area, the most serious effects were southeast of the King-University intersection. "Huge caverns were exposed to view", seemingly continuous from the conduit rupture to a point above South King Street—a distance of 0.5 km (Honolulu Board of Water Supply 1933-34). About

30 m downslope from the King-University intersection, "a room-sized cavern" suddenly appeared, 3 m below the surface. Some of the restaurant's missing koi were seen, and a hip-booted party found a passage extending 30 m downslope to another entrance. Still another passage extended east under South King Street to the 1928 cavern (Fig. 1).

In both upslope branches, water flow was toward the King-University intersection, thence down-slope along what became the southward extension of University Avenue. Direction of ordinary flow of the Hausten Spring branch is less clear. During the dewatering it flowed toward the University Avenue conduit. This may have been a reversal of its normal flow, which was unrecorded. A 1935 map shows another branch or a separate cave beginning beneath Kuilei Lane (between Hausten Pond and the King-University intersection) and crossing beneath the planned southward extension of University Avenue. The latter was rerouted, but its construction probably unroofed and filled part of the master conduit (Wolfe 1975).

In addition to this catastrophic dewatering, some retrograde flow came from the ocean. Ultimately the pumped water contained about 25% of the chloride content of the ocean (6500 ppm) (Kunesh 1934; Lao n.d.).

POST-1934 DEWATERING AND SUBSIDENCES

With resealing of the master conduit, the karst's water table temporarily recharged, but the karst never was the same again. Lao has admirably documented its later hydrological history, and much of its human side (Lao n.d.). Various sewer projects and other urbanization caused sequential lowering of the water table from 1935 to about 1955, and again in the late 1980s. Several relatively small "cave-ins" are well documented near the King-University intersection. One was in line with the lower end of Moiliili Water Cave. Economic loss was comparatively small, but on at least one occasion, a parked car had to be hauled out of a brand-new sinkhole. In 1991, the roof of a King Street cavern was deliberately breached in at least four places, with fill dumped in.

The continuing drop in the water table especially impacted the Willows Restaurant. The willow trees wilted and the remnant of the pond had to be lined with concrete. The restaurant lost its attractiveness and its customers. Today the property is tightly fenced and inaccessible.

Much of the basalt quarry was converted into athletic and other university facilities. Sewers were installed belatedly; for a time, the university gymnasium utilized septic tanks that evidently drained to Moiliili Water Cave. In 1983, the cave's water was warm, and soap scum was present (Lao n.d.).

SPELEOLOGICAL INVESTIGATIONS

In 1975, detailed gravity microsurvey revealed two water-filled caverns beneath Kuilei Lane, apparently unaffected by the dewatering. Apparently they are independent of the cave shown in this location in 1935. The larger of these is 9-11 m wide and up to 3.5 m high (Wolfe 1975).

The Hawaii Speleological Survey began investigations of Moiliili Water Cave in 1994. On all occasions, the water was cool, and clear until soiled by cavers feet. Despite further "cave-ins" as recently as 1997, it survives as a beautiful little cave currently 110 m long (Fig. 2). The limestone walls are relatively homogeneous and firm. It has the form of a karstic conduit with a little spongework and some protuberant corals. No cesspool nor petroleum odors have been found, nor any soap scum. Conditions have improved markedly since 1983. Floatable trash is stuck to its roof, indicating intermittent filling with flood waters. Construction fill is present in two areas, and numerous metal pilings extend downward through the cave from apartment buildings not far overhead. Nevertheless, it has returned to a state of beauty (Fig. 4 & 5). Due to installation of modern sewer lines, its bacterial count now is probably far less than during past ventures here and elsewhere beneath Moiliili, and fish are present.

IMPLICATIONS: PUBLIC HEALTH, PUBLIC SAFETY, AND ENVIRONMENT

With raw sewage dumped into the karstic reservoir, part of Moiliili's freedom from cholera and other water-borne epidemics must be partly attributed to pure luck. In comparison to parts of Honolulu underlain by volcanics, those underlain by limestone need much greater efforts to exclude sewage and the increasing burden of toxic and hazardous wastes.

Although theroretically feasible, artificial recharge of the Moiliili perched water table is not politically viable. Lacking such recharge, further subsidences and collapses are likely in Moiliili, although not at the 1934 scale. Elsewhere in the Honolulu coastal strip, such phenomena are not known to have been a significant problem. One costly 1989 subsidence in Waikiki, however, is on record (Lao n.d.) and in the present litigious era, future excavations in the reef limestone should be conducted in strict conformance with karstic engineering prin-

Figure 4. Solutional features, Moiliili Water Cave. Nearby water depth is 2 meters, so helmets are not worn.

Figure 5. Metal piling in main passage, Moiliili Water Cave.

ciples. The area downslope from the swallets of upland streams between Moilliili and Punchbowl Crater is at especially high risk of breaching unknown karstic conduits like the one intersected in Moiliili. Similar precautions are needed in some coastal areas elsewhere in Hawaii.

Environmentally, destruction and pollution in the Moiliili Karst speak eloquently for themselves. They especially reveal a need for a high level of public awareness and concern. The fortuitous improvement of water quality in Moiliili Water Cave is convincing evidence that even fragmented urban karsts need not be abandoned to whatever fate may bring. For their human values and as natural laboratories for a largely unstudied groundwater zone, its caves should be cherished and protected in every possible way. Protection of this resource should lead the way in popularizing the need for similar protection in other neglected karst and pseudokarst throughout Hawaii.

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Chester Lao kindly made available his masterful unpublished report on the hydrogeology and history of this and adjoining areas. Claude Higa provided guide service and field assistance in Moiliili Water Cave, and Frank Howarth, in University of Hawaii Quarry Cave. Kevin Kelly, Michael Kliks, Hunter Johnson and other members and cooperators of the National Speleological Society's Hawaii Grotto and Hawaii Speleological Survey also provided invaluable field assistance. Carlene Allred provided notable cartography, and the staffs of the Bishop Museum Library, Hamilton Library of the University of Hawaii, and the Hawaii State Library did their usual superb job. My thanks to all.

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GYPSUM SPELEOTHEMS OF FREEZING ORIGIN

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Seasonal freezing affects the development of gypsum speleothems in caves of the Pinega area of the Russian European North including two types of deposits not previously described. One type, called gypsum yozh (hedgehog), grows in dense clay sediment within a high supersaturation environment. Originally growing in a direction away from the freezing front, they later enlarge almost symmetrically. Their shapes and characteristics are dependent on various factors and provide interesting comparisons with gypsum roses from arid regions. A second, very rare, type of gypsum speleothem appears to be produced from concretions of gypsum powder accumulated in cavities within an underground ice body. Recrystallization of the gypsum is controlled by fluctuating local temperature and seasonal freezing in an environment of low supersaturation.

The Pinega Karst is a north-trending region of sulfate and carbonate karstified rocks 600 km long and 100-200 km wide in the Arkhangel'sk Region of the Russian European North. The most interesting and best-studied caves are located on the territory of the Pinega State Nature Reservation and adjacent protected territories at the southeast border of the Belomor-Kuloi Plateau (Fig. 1). The karstified rocks are Lower Permian gypsum and anhydrite of the Assel to Lower Sackmar Stages with layers of dolomite with a thickness up to 150 m. The caves are mostly located on the banks of rivers and canyons in the lower part of the gypsum deposits. A great variety of cave morphology is caused by a complex geologic history, including glacial epochs and sea transgressions, as well as often-changing modern hydrologic conditions. In modern caves and canyons, ancient caves filled by clay deposits have opened in places. The longest cave of the area is the Kulogorskaya System, 16.1 km in length.

The average annual temperature of the area is 0.5°C, which causes an abundance of ice speleothems and deposits in the caves. The temperature in remote parts of the caves varies near 1°-2°C and in near-entrance parts does not exceed 4°C in the summer and minus 10°-20°C in the winter (Pinega State Reservation, 1996).

The caves of the region are mostly horizontal, supplied with water from an abundance of underground rivers, sometimes very powerful during spring floods (up to 200-300 L/s). The variety of cave-forming processes and conditions, such as deep-phreatic, shallow-phreatic, temporarily flooded, oscillating water-table, glacial, subaerial, lake, stream, vertical-flow, and others, caused a diversity in cave morphologies. Collapse, abundance of clay deposits, and ice speleothems are typical.

The most diverse and plentiful speleothems in these caves are made of ice. Perfectly transparent ice crusts cover hundreds of meters of underground lakes overgrown with "bamboo" stalagmites. Ice crystals of both winter and summer generation cover all walls and ceilings of large chambers and also create complex formations. Monocrystalline labyrinthine hexagonal formations of skeletal crystals grown during tens of years can reach 30-40 cm in width. Ice flowers (antholites) and ice needles grow in the autumn-winter season; needles can reach 40 cm in length. Different stalactites, flowstone, draperies, spur helictites, as well as underwater and water-table crystals are widely distributed, especially in the wintertime. Some specific speleothems, for example ice "snakes," have never been described. A moving underground ice mass (2-3 cm/yr) in Ledyanaya Volna (Ice Wave) Cave is fed by both surficial-ice and cave-infiltration.

Figure 1. Sketch map of the Arkhangel'sk Region of the Russian European North.

Gypsum and calcite speleothems are varied, although not abundant. Besides well-known gypsum (corallite, crystal brush) and calcite (crust, crystal druse, soda-straw and other stalactite, stalagmite, flowstone, gour, corallite, conulite) speleothems that are widely distributed around the world, a low average surficial temperature causes rarer speleothems, some previously undescribed, whose origin is connected with seasonal or year-round frozen material.

GYPSUM POWDER OR PASTE

White powder is distributed in many of the Pinega caves that contain seasonally frozen material, covering cave ice masses (icing), frozen lakes, and other ice speleothems that are produced from water with a high gypsum content. During freezing of the water, small needle-like crystals of gypsum (up to 0.1 mm in length), together with ice crystals, grow mostly in a direction perpendicular to the surface. After sublimation of the ice during the winter-spring season, gypsum crystals remain as a porous layer on the surface of the ice. During melting of the ice, gypsum powder is gathered into hollows on the ice, increasing the speed of melting at those places and the growth of the cavities. The length and depth of the cavities in the ice with paste-like wet gypsum on the bottom can reach tens of centimeters. In relatively dry places, especially after removing any ice, slightly recrystallized gypsum powder can remain as very porous gypsum aggregates, called katyshki (pellets), which have a definite shape and structure and are not destroyed if removed carefully (Fig. 2).

If removed by a powerful flood, the gypsum powder can become a principal part of gypsum "foam" (which also includes some clay and organic matter) deposited on shelves and on the banks of streams. The thickness of this foam can reach 0.5 m. Gypsum "beards" of flood origin also sometimes appear.

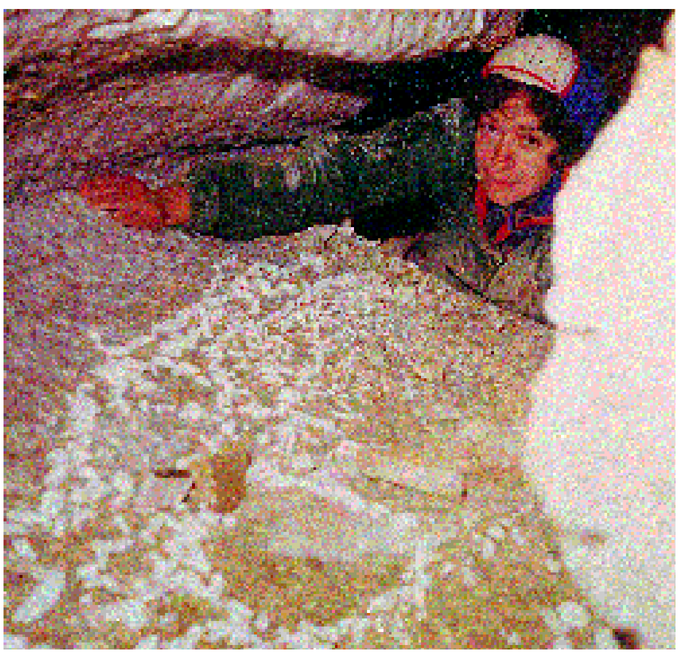

Figure 2. Concretions of gypsum powder in Ledyanaya Volna Cave. The second author provides scale.

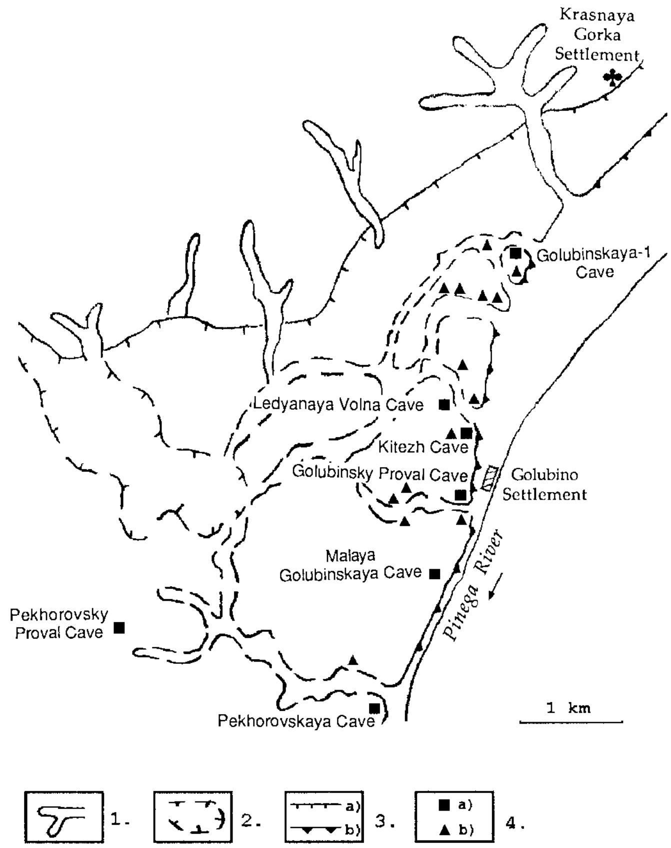

Figure 3. Sketch map of the Golubino District showing the caves mentioned in the text. 1, karst hollow; 2, shallow depression; 3a, margin of Upper Permian terra rossa; 3b, margin of gypsum rock along the Pinega River; 4a, cave containing gypsum yozh; 4b, other cave.

Two other types of speleothems, both called yozh (hedgehog), have thus far been found only in the Pinega Region.

NORMAL GYPSUM YOZH

This kind of yozh has been found in six caves in the Golubino District: Bolshaya Golubinskaya, Golubinskaya-1, Golubinsky Proval, Kitezh, Malaya Golubinskaya, and Pekhorovsky Proval (Fig. 3). One sample of yozh, found on the bank of the Sotka River, evidently came from one of the nearby caves. This kind of speleothem has not been described before, and only once has been noted in the literature (Malkov & Shavrina, 1991). This yozh consists of several crystals that are split to resemble opened books with fanned lens-shaped pages 3-7 mm long perpendicular to the surface. The color of the white to brown speleothems depends on the content of clay inclusions. Morphologically they can be divided into four groups:

1. Rather spherical in shape (ellipsoid-like, clam-like), dis-

Figure 4. Gypsum yozh that has grown inside of frozen clay.

tributed in thick clay sediment. Normally 2-4 cm but up to 10 cm in diameter. These clearly are the purest kind and almost always have a little cavity inside (1-4 cm, up to 15 mm), sometimes with a stone in the cavity that rattles when shaken. The degree of splitting varies widely and, based upon its distribution in these caves, is probably controlled by supersaturation (Russo 1981) (i.e. by the velocity of freezing, Fig. 4).

2. Hemispherical, found in thick clay sediment in contact with ceilings or walls. They are similar to the first group, but the cavities are open to the outside and often are small or absent.

3. Relatively flat, often with an extremely irregular morphology. The most widely distributed shape is similar to some mushroom caps with a flat cavity on the bottom. They are observed in thin (up to 10 cm) clay deposits, and reach 30 cm in length if a few have accreted together. Normally they have a great quantity of clay inclusions.

4. In the clay filling of fissures in cave walls, they follow the shape and curvature of the fissures. The crystals are normally bigger and less (or not) split as in the other groups, probably due to lower supersaturation caused by better heat exchange to the wall rocks. They reach 20 cm long.

This type of yozh is always found inside of clay deposits, or as a residue after clay removal from the floor, ceiling, and walls of caves, and in wall fissures in near-entrance areas that have undergone winter seasonal freezing. The purest samples (with little clay inclusion) were found relatively far from entrances, in places with a smooth change of temperature. Sometimes their content of sediment reaches 40%.

These speleothems grow due to supersaturation with respect to gypsum during the freezing of clay sediment in areas of seasonal freezing. Growth appears to start around a little cavity inside the clay. At first, the preferred direction of development is opposite to the front of freezing, according to the highest gradient of supersaturation. Following this, these speleothems have a mostly symmetrical growth, controlled by high supersaturation (5 to 10 times) at the surface (Russo, 1981) caused by the low permeability of compact clay.

At the beginning of the spring floods, water remains saturated with respect to gypsum for 1-2 weeks. This is a reason why these gypsum formations do not dissolve when the clay has been filled by flood water.

These speleothems are rather similar to desert gypsum roses, which have grown in friable sediment in arid regions, and also with gypsum roses in caves in arid regions. The term desert rose includes many different aggregates with a great variety of morphologies of both individual crystals and structures of aggregates. Cave gypsum rose is also a vague term, including both aggregates growing in cave sediment as well as subaerially growing speleothems, clearly corallites. Unlike the above described yozh, desert roses, in most cases, consist of unsplit, relatively isometric tabular, acicular, or lens-shaped crystals, that show a very low degree of supersaturation (1 to 1.5 times). Studies of gypsum crystal growth show that equidimensional tabular crystals grow slowly under conditions of low supersaturation, and elongated needle-like crystals grow rapidly under high supersaturation (Russo, 1981). The same is true for any crystal: Quick growth forms dendrites, whereas near-equilibrium crystallization forms crystals with minimum surface energy, which are close to equidimensional in appearance (Gregor'ev, 1961).

Previously described similar cave formations are obviously single crystals or simple crystal accretions, and appear to grow in thick sediment of drying clay in dry but periodically flooded cave areas (Hill & Forti, 1986, 1997; Maltsev, 1993; Rogozhnikov, 1984). Evidently, freezing of clay sediment can cause a much higher degree of supersaturation than drying of clay or changes in the temperature of a moving capillary solution.

Another characteristic feature of this type of yozh is the internal cavity (1 to 15 mm in diameter), sometimes with a stone inside the cavity that can rattle when shaken. Possibly there are two main reasons for this phenomenon that work together:

1. Growth preference toward a higher temperature gradient. A fact that the heat conductivity of wet clay is higher than that of gypsum can cause growth not only toward the surface of the clay deposit, but also, and even more, so along the edges of the formation, causing a "tucking up" of the edges, similar to a mushroom. This is clearly visible for the relatively flat subtype of yozh.

2. During freezing of the surface of the clay, water filling intergranular volumes of the yozh would be drawn out by capillary forces to areas of higher supersaturation, especially if ice crystallization inside the cavity is absent. Examination of frozen clay deposits shows that there are few centers of crystallization of ice under these conditions, and there is a low probability of the appearance of an ice center inside a cavity. During the spring-summer season, clay would be filled by slightly undersaturated water causing recrystallization and an enlargement of the internal cavity.

It is easy to estimate that these formations can be formed during hundreds to a few thousands of years. The content of water in dense clay ranges from 20 to 25% and averages 22%. The content of water in frozen clay (excluding ice veins) is 3-5%. Hence about 20% of the water is crystallized as ice veins, crystals, lenses, and antholites. The solubility of gypsum in water near the freezing point is about 2 g/L. The content of gypsum in ice veins and flowers in frozen clay is about 1.2 grams per kilogram of ice. The typical content of gypsum formations in clay is 5-10%.

Let's reckon the upper limit of annual growth of gypsum yozh in 1 kg of the clay as M = 0.2 x 1000 g/yr x (2 - 1.2 g) / 1000 g = 0.16 g/yr, meaning that a content of 10 wt% of gypsum yozh in the clay could be reached during T = 0.1 x 1000 g / 0.16 g/yr = 625 yr.

This result means that all these speleothems can have grown during post-glacial time (the past 8000 yr). Of course, this reckoning does not take into account the solubility of gypsum in residual supersaturated capillary solution. The relationship between capillary and constitutional water is unknown, but a half year seems to be enough time for diffusion of most of this water.

ANOTHER TYPE OF YOZH

Another speleothem has now been found only in Ledyanaya Volna Cave in the Golubino District. Only two samples have been collected for the museum of the Pinega State Nature Reservation. They are nearly spherical porous accretions, 6-8 cm in diameter, consisting of radial gypsum, very thin needle-like split crystals of the sheaf type, of which sub-individuals are 0.1-0.3 mm wide and 1-4 cm long. These white to light yellow speleothems are very delicate. Also, they are very porous and can absorb water nearly twice their weight (Fig. 5).

It is necessary to note that the sheaf type of splitting is not typical for gypsum and is not described in common reference books, so it is impossible to strictly estimate the degree of supersaturation. However, based on the shape of the crystals and not taking into account splitting (which is not so evident), it is possible to suppose a degree of supersaturation near 2-3 times, lower than for the first type of yozh, and close to that of needle-like unsplit crystals.

Figure 5. Another type of gypsum yozh that appears to have grown inside of a cave ice body.

A difference in structure and features might be caused not only by the degree of supersaturation, but also by other factors. Type and degree of splitting obviously depend on isomorphous inclusions in the crystals (i.e. on the composition of the solution) (Grigor'ev, 1961). Gypsum deposits as well as clay deposits contain much organic matter, which also could be a reason for the shape of individual crystals.

Pressure, which can become enormous during freezing, also seems to be a prominent influencing agent affecting the shape of individual crystal and the structure of aggregates. The first type of yozh seems to have grown under high pressure conditions, unlike this type.

The genesis of this type of yozh is not clear, but it appears to be controlled by a narrow seasonal change of temperature inside the large cave ice body (which is, in effect, a small underground glacier). Probably they have grown due to secondary recrystallization from thick deposits of gypsum powder or paste, as described above, that accumulated in cup-like cavities in the ice body. The location of speleothems found on a large block in the train of a degrading underground ice body supports this idea. Growth of needle-like gypsum crystals and their aggregates from gypsum paste of a different origin (often called moonmilk) have been described by some authors (Hill & Forti, 1986). Also, some small acicular transistor-shaped and hedgehog-shaped accretions of gypsum needles, which have grown from similar gypsum paste, were found in Kungur Ice Cave in the Ural Region of Russia (Andreichouk, 1989).

In the winter of 1997, one more sample of these speleothems was found: there is a spherical accretion 1.5-2.0 cm in diameter of needle-like crystals, exposed on the surface of the ice body of Ledyanaya Volna Cave due to warm air flow (Fig. 6). This find strongly supports our idea about the gene-

Figure 6. Small concretion of needle-like gypsum crystals exposed by the shrinking of a cave ice body.

sis of this kind of speleothem.

The age of these formations could be estimated very roughly by the velocity of ice-body movement as not to exceed 3000-4000 years.

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GEOCHEMISTRY OF FLUORITE AND RELATED FEATURES OF THE KUGITANGTOU RIDGE CAVES, TURKMENISTAN

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This paper presents a model explaining the fluorine geochemistry in the Cupp-Coutunn Cave System, in the Kugitangtou Ridge, southeastern Turkmenistan. By the corrosive activity of biologically derived sulfuric acid, HF gas is released by weathering of fluorite in residual cave deposits and in speleothems formed during a period of thermal activity. Secondary fluorite is produced, and conditions are provided for silica and aluminum mobility in the caves. The latter process helps to explain the origin of the clay mineral sauconite, $Zn_3(Si_4O_{10})(OH)_2 \cdot nH_2O$, and fraipontite, $(Zn,Al)_3(SiAl)_2O_5(OH)_4$, a member of the kaolinite-serpentine group.

Kugitangtau Ridge in southeastern Turkmenistan (Fig. 1) is an anticlinal horst with a core of Precambrian gneiss, intruded by a Hercynian granite batholith. Unconformably overlying these basement rocks is a 300 m sequence of undifferentiated Triassic and Lower Jurassic flysch containing local volcanics. The flysch is overlain unconformably by the Kugitang Series, which consists of Upper Jurassic limestones 350-500 m thick. The caves being studied are in these limestones. This series consists of massive reef limestones overlain by partly dolomitized thin-bedded limestones. The limestones were slightly metamorphosed by hot brines during the Eocene (Baikalov *et al.* 1974). The limestone occupies the western slope of the plateau and dips 5°-7° to the west-northwest. The limestone is very pure, about 98% $CaCO_3$. Above the limestone are isolated erosional remnants of the Upper Jurassic Gaurduck Series, about 200 m thick, which consists of shallow marine and continental gypsum and carbonates. The Gaurduck Series also contains caves, mostly unconnected with those in the Kugitang Series except for Fata-Morgana Cave in the nearby Gaurduck Ridge, which extends across the boundary between the two series.

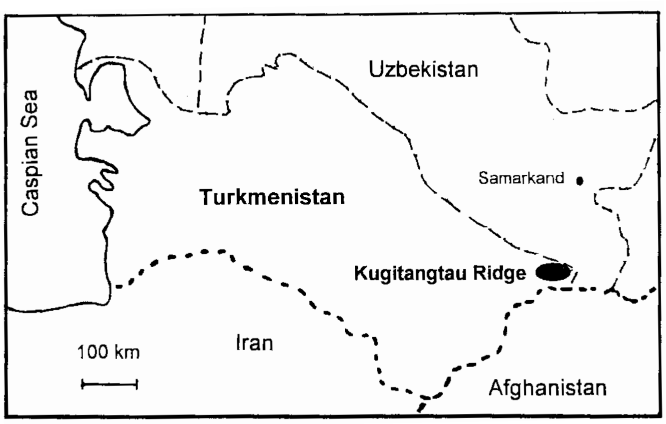

Figure 1. Location of Kugitangtau Ridge.

Uplift and thrust faulting began in the early Tertiary and underwent several phases, the last during the middle Quaternary Period. The ridge is now dissected by dry canyons 100-700 m deep that developed during the uplift. Lead-zinc sulfide ores occur in the northern part of the ridge and corre-

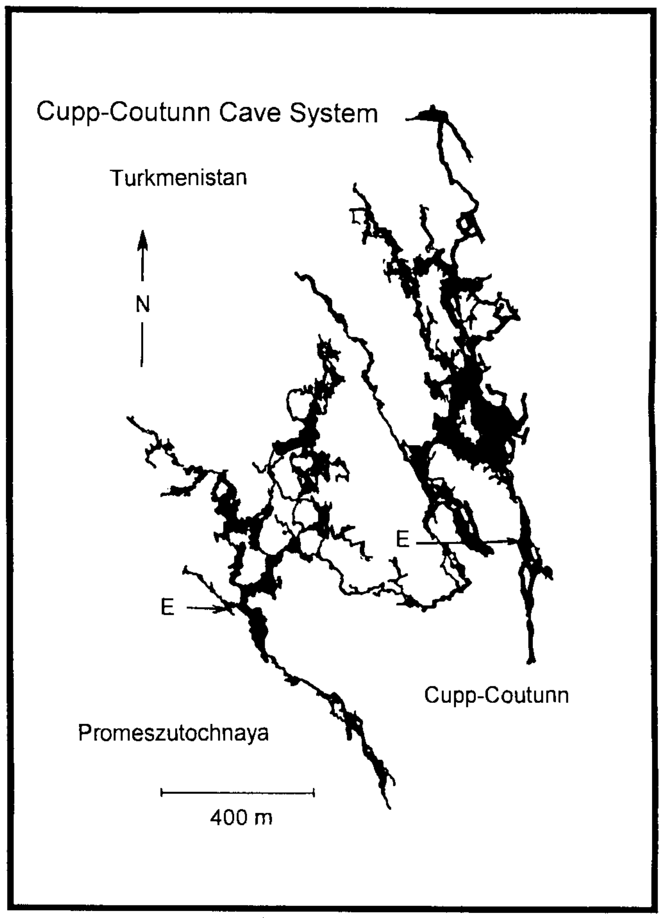

Figure 2. Map of the Cupp-Coutunn Cave System.

Figure 3. A remnant of thermal fluorite with visible traces of corrosion.

spond to sulfide veins in the caves. Their age relationship to the caves is disputed (see later discussion). There are also sulfur deposits from biologically mediated reduction of the Gaurduck gypsum beds and of the caprock over several salt domes.

The Cupp-Coutunn Cave is in the southern part of the plateau and is the largest limestone cave of the former USSR, at 53 km long and 310 m deep (Fig. 2). It represents only a small percentage of an extensive karst system containing many caves. The evolution of caves in the ridge is interpreted as follows: (1) During the Late Cretaceous, phreatic development of solution mazes took place below the contemporary erosional surface, which were later filled with clays. (2) These relict caves were rejuvenated by middle Quaternary tectonic uplift. Quaternary drainage through the caves was fed by phreatic water along faults. Therefore, surface canyons of the same age (in places only a few meters above the caves) have almost no connection with the underlying caves, except where there has been local collapse. (3) A thermal phase followed soon afterward, although the source of the thermal water is uncertain. Calcite, fluorite, and sulfide minerals were deposited at that time (Fig. 3). Oxygen isotope ratios in the thermal calcite suggest that the water was derived from the deep basement. (4) A dry phase followed soon after the thermal invasion and continues today. There is now no known active water flow in the cave, and only a few small lakes are present.

FLUORITE PRECIPITATION AND DISSOLUTION IN THE CAVE ENVIRONMENT

Fluorite deposits have been known in the caves of the Kugitangtou Mountains since 1985, particularly in the Cupp-Coutunn Cave System (Maltsev & Bartenev 1989), but many related features have remained unexplained until recently. Three types of fluorite occur in the caves: hydrothermal veins and deposits, residual weathering fragments derived from the veins, and modern secondary fluorite that is still being deposited in the caves.

Thin, light-purple fluorite veins of Upper Jurassic age are indigenous to the limestones of the Kugitangtou Series. The fluorite was precipitated at 150°-200°C, as shown by temperatures of homogenization (see also Berkeliev 1995). The number and density of fluorite veins in the cave are more than ten times greater than at the surface, suggesting that the fluorite may have formed during a hydrothermal phase of cave formation. This fluorite also shares the characteristics of hydrothermal fluorite known to have formed in other caves (from personal observation, corroborated by Berkeliev 1995). For example, it completely lacks rare-earth elements, so there is no phosphorescence or fluorescence. Weathering of the veins during and after cave development has produced abundant detrital fragments of fluorite, which in places form a granular debris on the cave floors. This concentration of detrital fluorite is fostered by the lack of high-velocity groundwater to remove the material. An unresolved question is the reason why the fluorite has undergone such intense chemical weathering. Although the crystals are transparent, euhedral, and unfractured, in some areas they shatter into small fragments when touched, while elsewhere they remain uncorroded. Physical weathering is impossible in the static cave climate, and the well-preserved euhedral faces of the crystals suggest that the weathering is not biological. The disintegration appears to be a cave-related process, because the interiors of the veins are less intensely weathered than the outsides.

Cave-related hydrothermal fluorite was also deposited at low temperatures of about 80°-170° C during the Quaternary hydrothermal phase of cave development (Maltsev & Malishevsky 1991). This fluorite has the same unusual properties as the vein fluorite described above but is not as strongly weathered, even though it has experienced lengthy exposure to the cave atmosphere. The relationship between these two processes is still unresolved.

Both of these non-recent types of fluorite show evidence of dissolution that penetrates as much as 4 cm along fractures in the crystals. Previously (Maltsev & Malishevsky 1991) this dissolution was thought to have occurred during the final phase of hydrothermal invasion of the caves, but it is now interpreted as corrosion by modern sulfuric acid produced by microbial activity, which is described later.

Recent studies show that this simple division of fluorite into residual and cave-related hydrothermal is in some doubt. In the Skazka-Dalnaya area of the Cupp-Coutunn Cave is a third type of "old" fluorite, which, although possibly deposited in a separate event, may instead be a combination of the two types described above.

The cave history includes a long period when the cave was at least partly filled with clays (Maltsev & Self 1992), although age estimates of troglobitic fauna by S. Smirnov (personal communication) indicate that the cave was partly open since the early Tertiary. In the Skazka-Dalnaya area of the cave this

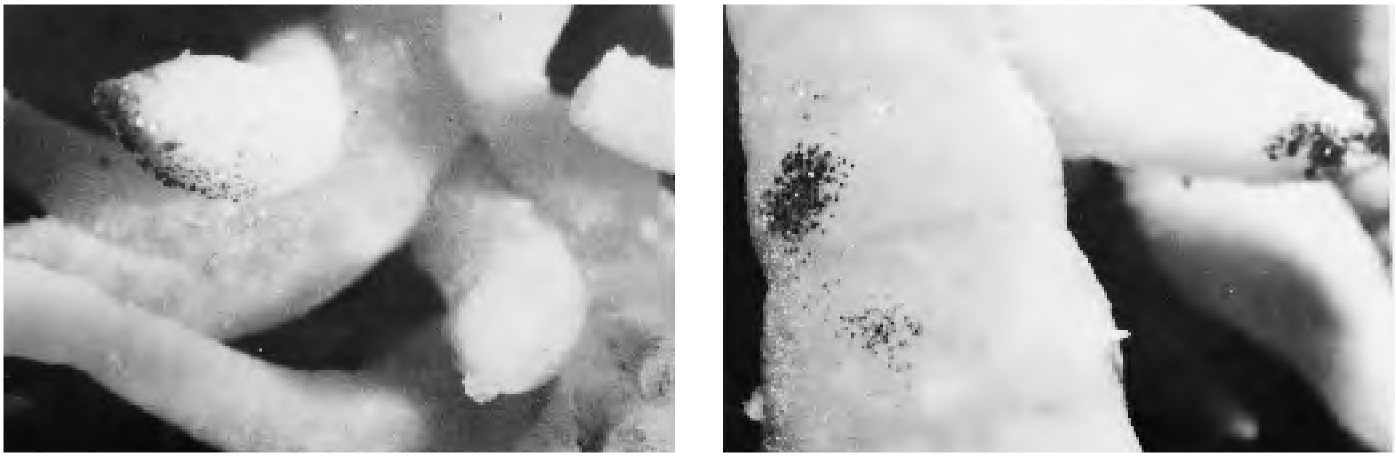

Figure 4. Two views of young secondary fluorite growing upon calcite helictites and gypsum crystals.

ancient clay has been completely altered by thermal waters, with fluoritization as the main alteration feature. The fluorite in this sediment has at least 5 generations, ranging from white to dark purple, in crystals up to 15 cm long. Some are faceted, but others with many clay inclusions are not. Druses of euhedral fluorite crystals have formed at the contact between the clay and the limestone bedrock, penetrating the limestone as much as 1-2 m along fractures, forming micro-veins and replacing the calcite in fossil bryozoa. Fluorite is accompanied by quartz, galena, several iron minerals, and dolomite, all of which are very finely crystalline. It is possible that some of the veins and druses in which the sediment has been removed were mistakenly considered "vein fluorite" or "cave-related thermal fluorite." Further study is needed to clarify these relationships.

Berkeliev (1995), who also studied this location, concluded that the fluoritization was of Eocene age. This does not contradict our general model of cave evolution, which envisions the cave being filled with clay throughout the Eocene. However, we cannot agree with Berkeliev's conclusion that this fluorite was a pre-karst vein, for the following reasons: (1) The location studied is a dense maze 200 m long and 60 m wide, in which the fluorite deposits are contiguous. Such a gross widening of a "vein" is improbable, and its discordance to the bedding and to tectonic structures disproves the pre-karst hypothesis. (2) The morphology of the fluorite deposits does not differ from those of other ancient cave fills, and contacts with the limestone are of exactly the same nature. The geometry of the fluorite zone is exactly the same as that of the filled cave. (3) The micro-veins and replaced fossils are localized within 1-2 m of the cave walls (now exposed by later karst processes). They are not related to tectonic structures. (4) The clay inclusions in unfaceted fluorite crystals show that the cave clays pre-dated the fluorite. This phenomenon is absent outside the caves.

Of greatest interest are abundant deposits of modern fluorite, which were first discovered in 1989 . The modern fluorite consists of small (up to 0.3 mm) dark purple crystals growing on the surfaces of calcite and gypsum speleothems (Maltsev & Belyakovsky 1992; see Fig. 4). Evidently the only way this fluorite could precipitate was by the reaction of airborne HF with calcium in or beneath thin films of water, where the calcium source is either calcite or gypsum in the substrate. The earliest suggestion for the presence of HF was in a hypothetical model proposed by Berkeliev *et al.* (1992), but they proposed that the HF was in aqueous solution. To the contrary, the only feasible method of transport of fluorine is as HF gas. Aqueous fluoride requires a very low pH, which would dissolve the calcite beneath the thin water films and cause immediate precipitation of fluorite on nearby calcite or gypsum surfaces.

It is interesting to note that the modern fluorite is actively precipitating in a non-hydrothermal environment. In one place it covers euhedral gypsum crystals that are 3-5 cm long, penetrating the gypsum no more than 0.05 mm. Gypsum speleothems in the Cupp-Coutunn Cave grow only during the wet season by recrystallization of older gypsum deposits. Euhedral gypsum faces are present only where crystal growth has been fast enough to offset periodic episodes of dissolution.

The surficial fluorite is estimated to be 30-100 years old. The measured rate of gypsum growth on calcite helictites in the Cupp-Coutunn Cave is 0.01-1.5 mm/yr, and some fluorite crystals extend 0.1 mm beneath the euhedral crystal faces of gypsum and project outward as much as 0.3 mm beyond them. This represents a 4:1 ratio of growth rate for the fluorite vs. gypsum. This relative rate is impossible in cold water that does not contain strong acids, but the pH of water films on the crystals is rather high (6.5-7.0). Any acid in capillary water seeping through the carbonate bedrock or speleothems would be almost immediately neutralized. The fluorite crystals are uniformly distributed along the helictites, and if the fluorite had been carried by the original speleothem-forming solution, its distribution would vary with evaporation rate. The origin of the fluorite must therefore be HF in the cave air.

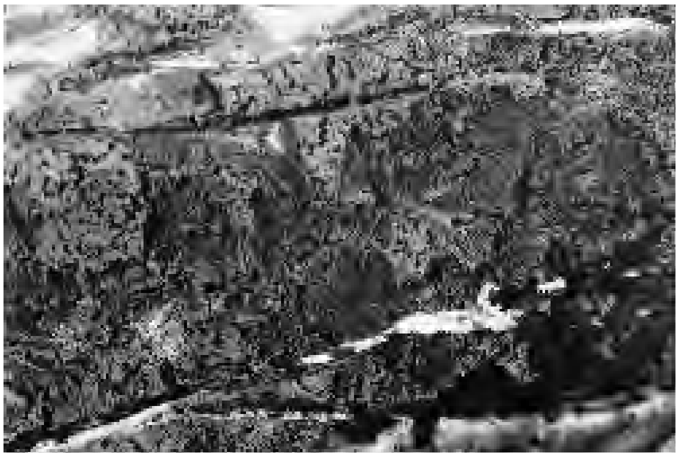

Figure 5. Okher coating on the cave wall, showing visible transformation of small calcite veins into gypsum boxwork.

Figure 6. Sauconite spherulites up to 1 cm in diameter.

PROPOSED MODEL FOR FLUORITE PRECIPITATION

So far the source of the HF gas has been explained only theoretically, because there are no reliable, direct methods for detecting it in the underground environment. The only substances in the cave containing fluorine are the two older fluorite deposits. Corrosion of these deposits to produce HF is feasible at the present cave temperatures only by sulfuric acid (Maltsev 1993).

The source of the sulfuric acid could not be from oxidation of sulfide minerals, since sulfide-rich veins are very sparse in the cave, and even where they are most abundant they represent only 0.5-1.5 kg of sulfides per meter of passage length. In contrast, these passages contain 70-100 kg of fluorite per meter of passage length, and the fluorite has been about 10% corroded. Therefore an additional source of sulfuric acid is needed. There is also no available mechanism for the transport of sulfuric acid, as it is not volatile, and if it moves as a thin film over carbonate surfaces it becomes neutralized almost immediately. Thus the sulfuric acid must be generated in the immediate vicinity of the fluorite and is apparently a byproduct of microbial activity in the weathered zone (Korshunov *et al.* in prep.). Corrosion of the fluorite is limited to areas in the immediate vicinity of highly weathered surfaces, whereas elsewhere it remains uncorroded.

Both bacterial sulfate reduction and sulfide oxidation are active in a red, clay-like coating, referred to here as "okher," on the walls and ceilings in the Kugitangtou Ridge Caves (Fig. 5). The term *okher* is not equivalent to the English word *ocher*, which is an earthy form of iron oxide. Okher consists of weathered bedrock in a reducing environment that grades into a residual clay-rich zone where oxidation of sulfides turns the surface into a red, iron-oxide rich powder. The sulfur cycle within the okher progresses from gypsum in infiltrating groundwater to H_2S to H_2SO_4, and this appears also to be the main cave-enlarging process still active in the Cupp-Coutunn Cave. H_2SO_4 is able to dissolve fluorite, liberating HF gas, and the modern fluorite precipitates in the vicinity of the okher. In support of this idea, deposits of fluorite that have broken off from the active okher sites are significantly less dissolved than the hydrothermal fluorite crystals and fluorite veins still in contact with the okher. Moreover, fluorite is absent in those areas where the okher is most extensive, probably having been completely removed by dissolution.

RELATED PROCESSES

HF gas in the cave air is further substantiated by the presence of secondary aluminosilicate minerals in the cave. The most obvious source of the aluminosilicates is residual material from the limestone in the okher crust. Aluminosilicates are highly prone to dissolution by hydrofluoric acid, and therefore SiF_4 gas, soluble hexafluoric siliceous acid (SiF_6), and similar aluminum compounds must form in the cave. SiF_6 and AlF_6 are relatively stable and their salts are very soluble. For example, $CaSiF_6$ is more than ten times more soluble than gypsum. The cave-related zinc silicates sauconite (Maltsev & Belyakovsky 1992), fraipontite (Berkeliev *et al.* 1992), and several unidentified minerals whose origin is still unclear, probably represent the secondary precipitation of the dissolved aluminosilicates. These minerals usually form spherules up to 1 cm in diameter located within 10 cm of sulfide veins in the limestone (Fig. 6). They occur beneath calcite flowstone and along fractures on the surface of the flowstone, which indicates that they originated in the cold water environment of the caves. The surrounding calcite is not especially altered, so the zinc silicates must have been deposited by local processes that rapidly lose their effect away from the veins. Sulfide veins cannot have been a source of silica and aluminum, as they contain few of these ions. The gases described above seem a likely source of ions for the observed mineral deposits, as they contain both silica and aluminum and are aggressive toward sphalerite. Other silicates found in the northern part of the cave may have an origin similar to that of the secondary alu-

Figure 7. An as-yet unidentified silicate replacing the interiors of gypsum "clouds."

minosilicates, but their amorphous structure and occurrence as mixtures of several different minerals makes them difficult to identify (Fig. 7).

The strongest evidence for the HF gas in the cave air is the alteration of metal objects left in the cave (Maltsev & Self 1992) . Where microbial processes are active, aluminum survey markers, installed in 1985, disintegrated entirely by 1989, leaving viscous to glassy spherules. Some of the spherules consist of allophane, while others have not yet been identified but appear to be aluminosilicates. The aluminum has apparently been attacked by a strong acid. In the case of the survey markers, sulfuric acid from the okher may have been responsible, but in other cases this is impossible. A five-meter-long ladder, consisting of steel wires with aluminum rungs, and hanging away from the walls and the okher, was also destroyed within three years. Sulfuric acid is not volatile, and the slow movement of water films would leave a trail of decreasing corrosion on the ladder, which was absent. This leads us to assume that the acid was airborne, and the local geochemistry suggests that it could only be hydrofluoric acid.

CONCLUSIONS

Fluorine plays a significant role in the geochemistry of the Cupp-Coutunn Cave System, both in depositing fluorine-bearing minerals, and in transporting silica. The latter may help to explain the origin of various silicates in the cave whose origin has previously been uncertain. Most of the fluorine-related processes appear to be activated by airborne HF, although the evidence is indirect, since it has not yet been measured. Measurement of HF and SiF_6 gas in the cave air is an important goal, as their concentrations in some places in the cave may approach toxic levels.

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Stewart B. Peck, Amador E. Ruiz-Baliú and Gabriel F. Garcés González- The Cave-inhabiting Beetles of Cuba (Insecta: Coleoptera): Diversity, Distribution and Ecology. *Journal of Cave and Karst Studies 60*(3): 156-166.

THE CAVE-INHABITING BEETLES OF CUBA (INSECTA: COLEOPTERA): DIVERSITY, DISTRIBUTION AND ECOLOGY

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The known cave-inhabiting beetle fauna of Cuba is summarized. Fifty-three species have been found in 70 low elevation caves in 11 provinces. Distribution of species by family is: Carabidae, 10; Dytiscidae, 4; Gyrinidae, 2; Hydrophilidae, 2; Histeridae, 5; Leiodidae, 2; Ptiliidae, 3; Staphylinidae, 1; Scarabaeidae, 4; Elateridae, 2; Lampyridae, 1; Nitidulidae, 1; Cerylonidae, 1; Tenebrionidae, 12; and Curculionidae, 3. Twenty-four of the species are judged to be accidental cave inhabitants. The remaining 29 species can be placed in the following ecological-evolutionary categories: trogloxenes, 3 species; first-level troglophiles, 21 species; second-level troglophiles (=unmodified neotroglobites), 5 species. No true troglobites are known (i.e., none of the species is morphologically specialized for cave life). About 59% of the non-accidental inhabitants are endemic to Cuba. The taxonomic composition is similar to that in caves in other West Indian Islands, and impoverished when compared to Neotropical continental caves. The abundance of food (bat guano) seems a prime factor preventing selection for cave-specialization in lowland West Indian and continental Neotropical cave beetles.

Cave-inhabiting insect faunas of the temperate parts of Europe and North America are becoming rather well known. In contrast, the cave insect faunas of many parts of the subtropical and tropical regions of the Americas are still very poorly known (Decu & Juberthie 1994).

About 70% of the surface area of Cuba, the largest West Indian island, is underlain by limestone and other soluble calcareous rocks. Under a tropical climate, these limestones have produced vast areas of karst landscapes, and subterranean solution has produced many caves, estimated to be about 10,000 in Cuba (Nuñez Jimenez 1984). Many organisms have occupied these caves and many have come to be evolutionarily highly modified for cave-life. At present, 45 species of aquatic invertebrates and 30 species of terrestrial invertebrates are known to have become troglobitic (morphologically highly specialized for life in cave habitats) in Cuba (Decu & Juberthie 1994; Armas & Alayon 1984).

Silva (1974) first summarized the entire cave fauna of Cuba and only nine species of beetles were reported from nine cave sites. Simultaneously, a massive program of cave biology field work was undertaken (1969-1973) by a series of joint Cuban-Romanian expeditions. Much has now been published from these expeditions. Silva (1988) contains a more up-to-date list of 388 caves that had been biologically prospected and 807 taxa identified to species level from these caves. Data on fauna from another 68 caves are in Pérez and García-Debrás 1997.

The purpose of this paper is to summarize the available (but often obscure) literature on Cuban cave-inhabiting beetles, to combine it with our new field data, and to provide the first ecological-evolutionary analysis of the Cuban cave beetle fauna.

METHODS AND MATERIALS

We here present a unified summary of both previously published and new information on Cuban cave-inhabiting beetles. In the taxonomic list of species we give (1) our hypothesis of its ecological-evolutionary status in caves, (2) its trophic status in cave food chains, (3) available data on its geographic distribution, (4) condition of its metathoracic flight wings, (5) the cave locations the species is now known from, followed by a map reference code number for the cave, (6) references to all published cave records, and (7) other relevant information. In (3) above we use the word endemic to mean that the species is restricted to Cuba, and in (4) we indicate the presence or absence of fully formed metathoracic flight wings as an available means of dispersal. The cave code numbers are cross referenced to a list of cave localities in an appendix, and on the map in Figure 1. Additional data on the caves is in Núñez *et al*. (1973), and Silva (1988). Our new records and additional records that confirm the continued presence of a species in a cave as a perpetuating population are both documented by year and collector. Data on distribution within and outside of Cuba are from a checklist of Cuban beetles (S.B. Peck, unpublished); and beetles of Florida (Peck & Thomas 1998).

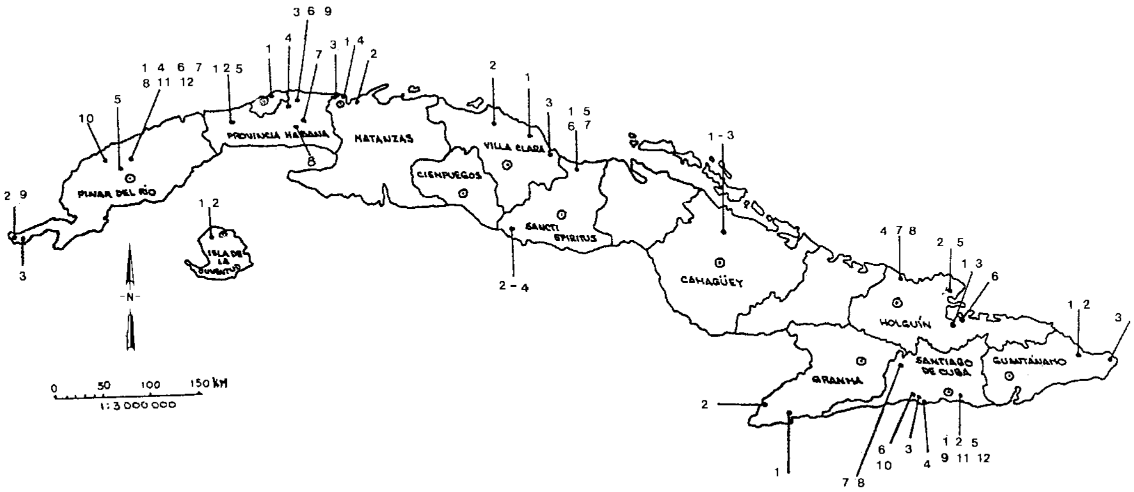

Figure 1. Outline map of Cuba and its provinces, showing location and code number of caves in which beetles have been found. The code number is the same as in the taxonomic list and in the appendix list of cave names.

New material is deposited in the collections of the institutions of the authors, and some in the collections of the Institute of Ecology and Systematics, Academy of Sciences, Havana, Cuba. The base for much of our field work in eastern Cuba was the former cave research laboratory of the Academy of Sciences at Atabex Cave, Siboney, 15 km southeast of Santiago de Cuba.

ECOLOGICAL ASSOCIATION WITH CAVES

Various schemes have been proposed as the basis of an ecological-evolutionary classification of cave faunas (Vandel 1965). We here use a slightly modified version of that of Hamilton-Smith (1971) which has the following categories relevant to populations of beetles in caves.

1. Accidental. Species that have no regular association with caves, and which do not complete their life cycle in caves.
2. Trogloxene. Species that regularly associate with caves, but for only part of their life cycles.
3. First-level troglophile. Species that complete their entire life cycle in caves, but are also known to occur in non-cave habitats.
4. Second-level troglophile. Species that are known only from caves, but show no morphological specialization for cave life. These have also been considered as "neotroglobites" or recent troglobites. Because cave faunas have often received more sampling attention than nearby forest habitats, it can be expected that some species now known only from caves as second-level troglophiles will eventually be found outside of caves and are actually first-level troglophiles.
5. Troglobite. Species that occur only in cave habitats and have ecological-morphological specializations for cave life (e.g., loss of eyes, wings, pigment, etc.). It is becoming common practice to use the terms "stygobite" or "stygobiont" for such organisms that live in aquatic subterranean habitats.

RESULTS

A total of over 400 Cuban caves have now been searched for arthropods by the 1969-1973 Cuban-Romanian expeditions, by later Cuban expeditions (Silva 1988; Peréz & García-Debras 1997) and by us. Beetles that have been identified to species level were found in 70 of these caves. The annotated taxonomic list follows.

SYSTEMATIC LIST

Family Carabidae

Dyschirius larocheli Bousquet, 1988; reported by Silva (1988: 114) as *D. erythrocerus* LeConte.

Accidental. Predator. Endemic species. Flightless. Halophilic. Cave records: Pinar del Río Province; Hoyo de Fanía 8. Reference: Mateu 1977: 377.

Macranthus (= *Masoreus*) *brevicillus* (Chevrolat, 1863)

First-level troglophile. Predator in moist guano. Infrequent in moist lowland forest habitats in Cuba; also known from caves in Puerto Rico (Peck 1981). Winged. Cave records: Holquin Province; Cueva de los Santos 8. Havana Province; Cueva de los Murciélagos 9. Reference: Mateu 1974: 28. The species is considered by Decu (1983) to be the most frequent and most abundant Cuban cave beetle in moist and guano rich areas.

Paratachys (= Tachys) abruptus (Darlington, 1934)

Accidental. Predator. The species is distributed in lowland and montane forests in Cuba, and eastward to the islands of Guadelupe and Dominica. Winged. Cave records: Santiago de Cuba Province; Cueva Jíbara 8. Reference: Mateu 1977: 378.

Paratachys (= Tachys) cubax (Darlington, 1934)

Accidental. Predator. Endemic species. It is widely distributed across Cuba in lowland and montane forests. Winged. Cave records: Santiago de Cuba Province; Cueva Atabex 1, Cueva Jíbara 8. Reference: Mateu 1977: 377.

Repeated searching in Atabex Cave has not found the species again.

Paratachys (= Tachys) striax (Darlington, 1934)
Accidental. Predator. Endemic species. Widely distributed in open lowland habitats. Winged. Cave records: Holquin Province; Cueva Bariay 1. This cave had a large population of these beetles in a room with an elevated temperature (28°C), but because they have not been found again in other caves, we class them as accidentals. Reference: Mateu 1977: 378.

Paratachys (= Tachys) vorax (LeConte, 1852)
Accidental. Predator. Distributed in moist habitats from southern USA to Mexico and Puerto Rico. Winged. Cave records: Pinar del Río; Hoyo de Fanía 8. Reference: Mateau 1977: 378.

Pentagonica flavipes (LeConte, 1853)
Accidental. Predator. Distributed in moist habitats from southern USA to Mexico and Puerto Rico. Winged. Cave records: Pinar del Río; Hoyo de Fanía 8. Reference: Mateau 1977: 378.

Platynus (= Colpodes) carabiai (Darlington, 1937)
Accidental. Predator. Endemic species. Distributed in moist habitats in eastern Cuba. Winged. Cave records: Holquin Province; Cueva Bariay 1. Santiago Province; Cueva Jíbara 8. References: Mateu 1977: 378; Silva 1988: 114.

Selenophorus chalybaeus (Dejean, 1829)
Accidental. Predator. The species ranges from the Bahamas to Jamaica and east to Antigua and Guadelupe. In Cuba it is widely distributed in lowland habitats. Winged. Cave records: Holquin Province; Cueva del Jaguey 6. Reference: Mateu 1977: 378.

Selenophorus pyritosus (Dejean, 1829)
Accidental. Predator. The species ranges from the Bahamas to Puerto Rico, and Mexico south to South America. In Cuba it is widely distributed in lowland habitats. Winged. Cave records: Havana Province; Cueva Cinco Cuevas 3. Santiago Province; Cueva Atabex 1. References: Mateu 1977: 378; Silva 1988: 114.

Family Dytiscidae

Copelatus posticatus (Fabricius, 1801)
Accidental. Predator. The species occurs in all of the Greater Antilles, as well as the Lesser Antilles, and Central and South America. Winged. Cave records: Pinar del Río; Hoyo de Fanía. References: Spangler 1981a: 153; Silva 1988: 114.

Derovatellus lentus lentus (Wehncke, 1876)
Accidental. Predator. The species is also distributed throughout the West Indies, to Trinidad and South America, and in Florida. It is infrequently known from streams in Cuba. Winged. Cave records: Camagüey Province; Cueva del Agua (de los Lagos) 1. References: Spangler 1981a: 145; Silva 1988: 114.

Laccophilus proximus Say, 1823
Accidental. Predator. Distributed from south Florida through all the Greater Antilles to Barbados. It occurs in streams throughout Cuba. Winged. Cave Records: Pinar del Río; Hoyo de Faniá. References: Spangler 1981a: 150; Silva 1988: 114.

Laccophilus venustus Chevrolat, 1863
Accidental. Predator. The species is also distributed in the Bahamas, Haiti, Guatemala, Mexico, and Florida. It is known from streams throughout Cuba. Winged. Cave records: Santiago de Cuba Province; Cueva Jíbara 8. References: Spangler 1973: 354; Silva 1988: 114.
Family Gyrinidae

Dineutus americanus (Linneus, 1767)
Accidental. Predator. The species is distributed throughout the Bahamas and Jamaica to the Virgin Islands, and in Florida. It occurs in streams throughout Cuba. Winged. Cave records: Santiago de Cuba Province; Cueva Jíbara 8. References: Spangler 1981a: 145; Silva 1988: 115.

Dineutus longimanus cubensis Ochs, 1938
Accidental. Predator. The species also occurs in Jamaica, Hispaniola, and Puerto Rico. It occurs in streams throughout Cuba. Winged. Cave records: Santiago de Cuba Province; Cueva Jíbara 8. Saneti Spiritus Province; Cueva Caja de Aqua. References: Peréz and García-Debras 1997: 26; Spangler 1981a: 145; Silva 1988: 115.

Family Hydrophilidae

Oosternum costatum (Sharp, 1882)
First-level troglophile. Scavenger in moist guano. The species is widespread from the United States through the West Indies and Central America to South America. Winged. Cave records: Provincia de Santiago de Cuba; Cueva de los Majaes 9 (many in moist guano, collected by Peck in 1995). This is not a frequent cave inhabitant.

Tropisternus mergus (Say, 1835)
Accidental. Scavenger. Distributed from Cuba to Mexico and south to Costa Rica. Winged. Cave records: Pinar del Río; Hoyo de Faniá 8. References: Spangler 1981a: 161; Silva 1988: 115.

Family Histeridae

Acritus analis LeConte, 1853
First-level troglophile. Predator. The species also occurs in Puerto Rico, Guatemala and Mexico. The species is common in Cuba outside of caves. Winged. Cave records: Havana Province; Cueva Galera 6. Pinar del Río Province; Cueva Incógnita 7. References: Decu and Therond 1977: 403; Silva 1988: 115.

Carcinops troglodytes (Paykull, 1811)
First-level troglophile. Predator. The species is tropicopolitan in distribution, and widespread across Cuba. Winged. Cave records: Granma Province; Cueva del Fustete 2. Holquin Province; Cueva de las Cuatrocientas Rozas 2. Sancti Spiritus Province; Cueva Guanayara 3. Matanzas Province; Cueva la Eloisa 2. Havana Province; Cueva el Mudo 8. References: Decu and Therond 1977: 403; Silva 1988: 115. Santiago de Cuba Province, Cueva de los Majaes 9 (collected by Peck in 1995).

Epieurus antillarum (Marseul, 1854)

First-level troglophile. Predator. The species occurs east to Puerto Rico, and is in Mexico, and the southeastern USA. Winged. Cave records: Guantánamo Province; Cueva de la Patana 3. Holquin Province; Cueva de las Cuatrocientas Rozas 2. References: Decu and Therond 1977: 404; Silva 1988: 115.

Epieurus pulicarius (Erichson, 1834)

Accidental. Predator. The species is otherwise known only from Mexico. The only Cuban records are from one cave. Winged. Cave records: Santiago de Cuba Province; Cueva Atabex 1. References: Decu and Therond 1977: 404; Silva 1988: 115. The species has not been found in this cave again in spite of repeated searching.

Euspilotus sterquilinus (LeConte, 1860)

First-level troglophile. Predator. Endemic species. Widely distributed in Cuba. Winged. Cave records: Ciudad de la Habana Province; Cueva de la Virgen, 5. Guantánamo Province; Cueva de Majana 2 (collected by Ruiz & Garcés in 1985), Cueva de La Patana 3 (collected by Ruiz & Garcés in 1985). Havana Province; Cueva del Mundo 6. Santiago de Cuba Province; Cueva Cativar 3, Cueva del Humo 6, Cueva de los Majaes 9 (collected in December 1984 by Ruiz & Garcés and Peck (1995) feeding on decomposing remains of bats (*Phyllonecteris poeyi* Gundlach)). Sancti Spiritus Province; Cueva Guanayara 3. Pinar del Río Province; Cueva Clara 4. References: Decu and Therond 1977: 403; Silva 1988: 115.

Family Leiodidae

Aglyptinus sp.

First-level troglophile. Scavenger in guano of fruit bats. Endemic species (first record of the genus from Cuba). The genus is widespread in the Neotropics, and species are often associated with guano in caves (Peck 1977). Winged. Cave records: Pinar del Río Province; Cueva la Barca, in fresh guano of *Artibeus* fruit bats. We have since found it frequently in forests near Santiago de Cuba.

Proptomaphaginus apodemus (Szymczakowski, 1969)

First-level troglophile. Scavenger in guano of fruit bats. Endemic species. Widely distributed across Cuba, but previously reported only from caves. Winged. Cave records: Guantánamo Province; Cueva de Majana 2 (collected by Ruiz & Garcés in 1985), Cueva de La Patana 3 (collected by Ruiz & Garcés in 1985). Santiago de Cuba Province; Cueva de la Cantera 2 (collected by Ruiz & Garcés in 1985), Cueva de los Majaes 9 (collected by Ruiz & Garcés in 1984), Cueva Atabex (collected by Peck in 1995). Granma Province; Cueva del Fustete 2, Cueva del Hoyito 5. Camagüey Province; Cueva del Agua (de los Lagos) 1, Cueva del Indio 2, Cueva de la Lechuza 3. Sancti Spiritus Province; Cueva de las Columnas 2, Cueva Grande de Caguanes 5, Cueva Humbolt 6, Cueva del Túnel 7. Ciudad de La Habana Province; Cueva del la Virgen 1. Pinar del Río Province; Cueva del Abono 1 (collected by Ruiz & Garcés in 1985), Cueva de Pio Domingo 9, Cueva de la Vela 11 (collected by Ruiz & Garcés in 1985). Isla de Juventud Province, Cueva del Abono 2. References: Decu 1973: 367; Silva 1988: 114.

Notes. References to *Ptomaphagus* sp. in Cueva de Bellamar 1 (Matanzas Province) and Cueva del Cura 4 (Havana Province) (Bolivar Pieltain 1944: 302, 303; Silva 1974: 28; 1988: 114) are for this species because *Ptomaphagus* does not occur in Cuba. *Proptomaphaginus* also occurs in Mexico as small-eyed flightless soil species and as winged species in caves in Hispaniola and Puerto Rico (Peck 1983). Because the Hispaniola and Puerto Rico cave-dwelling species also occur in forests, we predicted that *P. apodemus* would also be found in forests in Cuba. We actually found it there by using baited pitfall traps and flight intercept traps in the Santiago Botanical Garden (Jardin Botanico T. Roig) in December 1995. The species was previously considered to be a second-level troglophile (a neotroglobite), but our discovery of it in several non-cave sites reduces it to the status of a first-level troglophile. *Proptomaphaginus darlingtoni* (Jeannel) is another species in the genus known from lowland forests at Soledad; near Cienfuegos, Cuba (Peck 1970).

Family Ptiliidae

Ptiliidae genus 1 sp.1.

First-level troglophile. Scavenger. Winged. In drier guano.

Ptiliidae genus 1 sp.2.

First-level troglophile. Scavenger. Winged. In drier guano.

Ptiliidae genus 2 sp.1.

First-level troglophile. Scavenger. Winged. In drier guano. Cave records combined for above 3 species: Santiago de Cuba Province; Cueva de los Majaes 9 (collected by Ruiz & Garcés in 1984), Cueva de Cativar 3. Granma Province; Cueva del Fustete 2. Havana Province; Cueva de Emilio 5. References: Decu 1983: 15; Silva 1988: 115.

Note: These are all undescribed species (H. Dybas, pers. comm.).

Family Staphylinidae

Aleocharinae sp.

First-level troglophile. Predator. Cave records: Santiago de Cuba Province; Cueva del Humo 7 (collected by Ruiz en 1986), Cueva de los Majaes 9 (collected by Peck in guano in 1995). These beetles are notoriously difficult to identify. They must exist in other Cuban caves.

Family Scarabeidae

Ataenius gracilis (Melsheimer, 1845)

First-level troglophile. Scavenger. Widely distributed from southeastern USA and West Indies to Peru. Winged. In moist guano. Cave records: Provincia de Santiago de Cuba; Cueva de los Majaes 9 (several collected by Peck in guano in 1995). Not previously known to maintain populations in caves.

Canthochilum histeroides (Harold, 1868)

Accidental. Scavenger. An endemic in lowland forest in northern and western Cuba. Winged. Cave records: Matanzas Province; Gran Caverna de Fuentes. Reference:

Silva 1988: 115.

Gymnetis lanius sternalis (Chevrolat, 1865)

Trogloxene. Scavenger. Endemic species. Widely distributed across Cuba. Winged. Cave records: Villa Clara Province; Cueva El Gato 2 (collected by Luis Grande in 1986), Cueva El Majá 3 (collected by Luis Grande in 1986). Havana Province; Cueva del Mudo 8. References: Decu 1983: 16; Silva 1988: 115. These beetles were found in large numbers in caves where there is guano as a food for the larvae. The larvae occurred in balls of rather dry guano.

Tiarocera cornuta (Gory & Percheron, 1833)

Trogloxene. Scavenger. Endemic species. Widely distributed across Cuba. Cave Records: Havana Province; Cueva de la Mariana 7. References: Silva 1974: 28; 1988: 115. These beetles are found in caves when there is guano near the entrances as a food for the larvae. Other cetonine scarabs are known to occur as larvae and adults in guano deposits in caves in Trinidad (S.B. Peck, unpub.).

Family Elateridae

Conoderus posticatus var. *sticturus* Candeze, 1859 (as *C. p. esticturus* in Silva 1988: 114).

Trogloxene. Predator. Scavenger. Widespread across Cuba. The species is also widespread from Mexico to Brazil. Winged. Cave records: Havana Province; Cueva de los Murcielagos 9. References: Hardy 1963: 160; Silva 1988: 114. The larvae develop in guano, and this is known for other elaterids (Martin 1980).

Pyrophorus noctilucus Linneaeus, 1758

First-level troglophile. Predator. Scavenger. The species is widespread in the West Indies, and from Mexico to Argentina. Winged. Cave records: Santiago de Cuba Province; Cueva del Humo 7 (collected by Ruiz in 1986), Cueva de los Majaes 9. Sancti Spiritus Province; Cueva de Colón 1, Cueva de la zona de Guanayara 4. Villa Clara Province; Cueva de los Bichos 1 (collected by Luis Grande in 1986), Cueva El Majá 3 (collected by Luis Grande in 1986). Havana Province; Cueva del Mudo 8. Pinar del Río Province; Cueva de las Catacumbas 3 (collected by Ruiz & Garcés in 1985), Cueva de las Columnas 5 (collected by Ruiz & Garcés in 1985). References: Decu 1983: 16; Hardy 1963: 160; Silva 1988: 114. These luminescent beetles occur in caves when there is guano for the larvae to feed on. Larvae were found in Cueva El Mudo and Cueva de los Majaes.

Family Lampyridae

Photinus nefarius J.E. Olivier, 1912

Accidental. Predator. Endemic species. The distribution in Cuba is poorly known. Winged. Cave records: Havana Province; Cueva de la Marina 7. References: Silva 1974: 28; 1988: 115.

Family Nitidulidae

Carpophilus sp.

Accidental. Scavenger. Some 12 species in this genus occur in Cuba. Winged. Cave records: Ciudad de Havana Province; Cueva del Tunel 4. Reference: Silva 1988: 115.

Family Cerylonidae

Euxestus erithaeus Chevrolat, 1863

First-level troglophile. Scavenger. Widespread but uncommon in litter in Florida and Greater Antilles. Winged. Cave records: Santiago de Cuba Province; Cueva Atabex 1 (collected in bat guano by Peck in 1995), Cueva de los Majaes 9 (in bat guano by Peck in 1995). These are the first Cuban cave records. The species is also known from bat guano in a cave in Jamaica (Peck 1992).

Family Tenebrionidae

Alphitobius diaperinus (Panzer, 1832)

First-level troglophile. Scavenger. Cosmopolitan and in stored products. Widespread throughout Cuba. Winged. Cave records: Sancti Spiritus Province; Cueva de Guanayara 3. Villa Clara Province; Cueva el Gato 2 (collected by Luis Grande in 1986). Havana Province; Cueva de la Mariana 7; Cueva el Mudo 8. References: Ardoin 1977: 383; Silva 1988: 115. The species is especially found in dry guano, and populations may number in the tens of thousands. It is known in guano caves, attics, chicken coops, etc. from Ontario to Venezuela (Peck 1981, 1992).

Alphitobius laevigatus (Fabricius, 1781)

First-level troglophile. Scavenger. Cosmopolitan, common in stored products. Winged. Cave records: Santiago de Cuba Province; Cueva de las Golondrinas 5, Cueva de los Majaes 9 (collected by Ruiz & Garcés in 1984, and S.B. Peck in 1995). Granma Province; Cueva del Fustete 2. Hoguin Province; Cueva de las Cuatrocientas Rozas 2. Sancti Spiritus Province; Cueva Guanayara 3. Havana Province; Cueva Galera 6, Cueva el Mudo 8. Villa Clara Province; Cueva de los Bichos 1. References: Ardoin 1977: 391; Silva 1988: 115. The species is known to be abundant in bat caves in Texas, Mexico, and the West Indies (Peck 1992). It may build up to very large populations in moist guano.

Blapstinus cubanus Marcuzzi, 1962

Accidental. Scavenger. Distributed throughout Cuba and the Bahamas. Winged. Cave records: Havana Province; Cueva Cinco Cuevas 3, reported from a single specimen. References: Ardoin 1977: 390; Silva 1988: 116.

Blapstinus cf. *fortis* LeConte, 1878

First-level troglophile. Scavenger. Endemic species. Widespread throughout Cuba. Winged. Cave records: Sancti Spiritus Province; Cueva Colón 1, Cueva Grande de Caguanes 5. References: Silva 1974: 28; 1988: 116.

Orghidania torrei Ardoin, 1977

First-level troglophile. Scavenger. Endemic species. Probably widespread throughout Cuba. Winged. Cave records: Sancti Spiritus Province; Cueva Colón 1. References: Ardoin 1977: 384; Silva 1988: 116.

Trimytantron cavernicolous Garrido and Gutiérrez, 1997

First-level troglophile. Scavenger. Endemic species. Wingless. Cave records: Sancti Spiritus Province; Cueva el Pirata, Cayo Caguanes (type locality); Cueva de Colon 1; Cueva de los Chivos; also from one epigean locality (Punta de Judas, Yaguajay). Reference: Garrido and Gutiérrez 1997: 34.

Trimytantron cubanum Ardoin, 1977

Second-level troglophile. Scavenger. Endemic species. Known only from one cave locality. Wingless. Cave records: Holguin Province; Cueva de los Panaderos (type locality) 7. References: Ardoin 1977: 388; Silva 1988: 116.

Trimytantron decui Ardoin, 1977

Second-level troglophile. Scavenger. Endemic species. Known only from caves. Wingless. Cave records: Santiago de Cuba Province; Cueva Cativar (type locality) 3, Cueva de las Golondrinas 5 (collected by Ruiz & Garcés in 1984), Cueva del Humo 6, Cueva de los Murciélagos 10, Cueva del Terrarium 11 (collected by Ruiz & Garcés in 1984), Cueva de la Virgen 12 (collected by Ruiz & Garcés in 1984). Granma Province; Cueva de los Petroglifos. Guantanamo Province; Cueva de la Patana 3 (collected by Ruiz & Garcés in 1985). References: Ardoin 1977: 382; Garrido & Gutiérrez 1997: 21; Silva 1988: 116.

Trimytantron negreai Ardoin, 1977

Second-level troglophile. Scavenger. Endemic species. Known only from one cave. Wingless. Cave records: Holguin Province; Cueva del Guano (type locality) 4. References: Ardoin 1977: 387; Silva 1988: 116.

Trimytantron poeyi Ardoin, 1977

Second-level troglophile. Scavenger. Endemic species. Known only from caves. Wingless. Cave records: Granma Province; Cueva del Futete (Fustete) 2. Guantanamo Province; Cueva de la Patana 3 (type locality) (collected by Ruiz & Garcés in 1985). Habona Province; Cueva del Mundo 6. Sancti Spiritus Province; Cueva de Colón 1, Cueva de las Columnas 2. Santiago de Cuba Province; Cueva de Cativar 3; Cueva del Humo 6. References: Ardoin 1977: 383; Garrido & Gutiérrez 1997: 21; Silva 1988: 116.

Trimytantron vinai Ardoin, 1977

Second-level troglophile. Scavenger. Endemic species. Known only from one cave locality. Wingless. Cave records: Matanzas Province; Cueva La Pluma (type locality) 4. References: Ardoin 1977: 388; Silva 1988: 116.

Zophobas rugipes Kirsch, 1866

First-level troglophile. Scavenger. Widespread from Mexico to Brazil, and from Cuba to the Lesser Antilles. It is distributed throughout Cuba (Garrido & Gutierrez, 1994). Wingless. Cave records: Guantanamo Province; Cueva de la Patana 3 (collected by Ruiz & Garcés in 1985). Villa Clara Province; Cueva el Majá 3 (collected by Luis Grande in 1986). References: Ardoin 1977: 385; Garrido and Gutierrez 1994: 243; Silva 1988: 116.

Family Curculionidae

Anchonus suillus (Fabricius, 1792)

Accidental. Scavenger. Widespread in West Indies, from the Bahamas and Cuba, through to Puerto Rico and south to Guadeloupe. Winged. Cave records: Santiago de Cuba Province; Cueva de los Majaes 9 (one collected by Peck in 1995 in bat guano). A soil-litter dwelling feeder on roots and litter.

Caecocossonus sp. (cf. *decuanus* Osella, 1973)

Accidental. Scavenger. Only one species, *C. decuanus*, is reported from Cuba. This is an eyeless and flightless soil-inhabiting species (see Howden 1992: 18). Cave records: Matanzas Province; doline of Cueva la Pluma 4. References: Silva 1988: 114; Osella 1977: 399.

Stenancylas colomboi Casey, 1892

Accidental. Scavenger. Reported from Jamaica, St. Vincent, and south Florida (Anderson & Peck 1994) as well as Cuba. Winged. Cave Records: Santiago de Cuba Province; Cueva de los Majaes (one collected by Peck in 1995 in bat guano). Known from roots and foliage of *Asplenicum* ferns and litter in coastal deciduous forests.

DISCUSSION

In addition to the above records, Nuñez *et al*. (1973), Orghidan *et al*. (1977), Perez and García-Debrás (1977), and Silva (1988) mention beetles in other caves, but give no species level identifications. We have not repeated these records in the above list because they cannot be used in the following analysis.

The known fauna of beetles that have been found in caves in Cuba and identified or segregated to species are now 53 species. Of these, 24 are judged to be accidentals, with no repeated pattern of ecological-evolutionary relationship with cave habitats. The following analysis, thus, treats only the remaining 29 species that have a non-accidental association with caves, and these are summarized in Table 1. This cave-dwelling beetle fauna is richer than that of caves in the island of Puerto Rico (10 species, Peck 1974, 1981a, 1994) and similar to that in the island of Jamaica (23 species, Peck, 1992). By contrast, a single continental tropical cave, Cueva del Guacharo in Venezuela, has 29 resident beetle species (Peck *et al*., 1989).

CAVE RESTRICTION AND ENDEMISM

The Cuban cave beetle fauna has no morphologically specialized cave-limited species (troglobites). There are five tenebrionid species that are now known only from caves (second-level troglophiles) but all of these are expected by us to occur in epigean habitats (Table 1); we predict that these are actually first-level troglophiles. The rest of the fauna (24 species) are more frequently known from non-cave habitats. Of the 29 non-accidental cave-occurring beetles, 17 (59%) are thought to be endemic to Cuba (Table 1). This compares favorably with the entire Cuban beetle fauna, which contains about 55% endemic species (S.B. Peck, unpublished). Three of the caver-

Table 1. Summary of characteristics of the non-accidental cave beetles of Cuba.

Name	Cave Status	Trophic Status	Flight Wings	Distribution	Cuban Status	Habitat Association
Carabidae						
Macranthus brevicillus	1st troglophile	predator	yes	West Indies,	native	wet guano
Hydrophilidae						
Oosternum costatum	1st troglophile	scavenger	yes	Neotropics	native	wet guano
Histeridae						
Acritus analis	1st troglophile	predator	yes	Neotropics,	native?	moist guano
Carcinops troglodytes	1st troglophile	predator	yes	Neotropics,	introduced?	moist guano
Epiurus antillarum	1st troglophile	predator	yes	Neotropics,	native	moist guano
Euspilotus sterquilinus	1st troglophile	predator	yes	Cuba	endemic	moist guano
Leiodidae						
Aglyptinus sp.	1st troglophile	scavenger	yes	Cuba	endemic	moist guano
Proptomaphaginus apodemus	1st troglophile	scavenger	yes	Cuba	endemic	moist guano
Ptiliidae						
Species 1	1st troglophile	scavenger	yes	Cuba	endemic	moist guano
Species 2	1st troglophile	scavenger	yes	Cuba	endemic	moist guano
Species 3	1st troglophile	scavenger	yes	Cuba	endemic	moist guano
Staphylinidae						
Species 1	1st troglophile	predator	yes	Cuba	endemic?	moist guano
Scarabaeidae						
Ataenius gracilis	1st troglophile	scavenger	yes	Neotropics	native	moist guano
Gymnetis lanius	trogloxene	scavenger	yes	Cuba	endemic	moist guano
Tiarocera cornuta	trogloxene	scavenger	yes	Cuba	endemic	moist guano
Elateridae						
Conderus posticatus	trogloxene	predator	yes	Neotropics,	native	dry guano
Pyrophorus noctilucus	1st troglophile	predator	yes	Neotropics,	native	dry guano
Cerylonidae						
Euxestus erithaeus	1st troglophile	scavenger	yes	West Indies	native	moist guano
Tenebrionidae						
Alphitobius diaperinus	1st troglophile	scavenger	yes	Neotropics,	introduced?	moist guano
A. laevigatus	1st troglophile	scavenger	yes	Neotropics,	introduced?	moist guano
Blapstinus cf. fortis	1st troglophile	scavenger	yes	Cuba	endemic	dry guano
Orghidania torrei	1st troglophile	scavenger	yes	Cuba	endemic	moist guano
Trimytantron cavernicolous	1st troglophile	scavenger	no	Cuba	endemic	moist guano
T. cubanum	2nd troglophile	scavenger	no	Cuba	endemic	moist guano
T. decui	2nd troglophile	scavenger	no	Cuba	endemic	moist guano
T. negreai	2nd troglophile	scavenger	no	Cuba	endemic	moist guano
T. poeyi	2nd troglophile	scavenger	no	Cuba	endemic	moist guano
T. vinai	2nd troglophile	scavenger	no	Cuba	endemic	moist guano
Zophobas rugipes	1st troglophile	scavenger	no	Neotropics,	native	dry guano

nicolous species have been introduced to Cuba through human commerce, so the faunal mix of cave beetles is now richer than in Pre-Columbian times.

CAVE ADAPTATIONS

Many of the adaptations that species have for life in caves are physiological, such as an ability to live in perpetual darkness, and in moist environments. These leave no morphological evidence on the body of the beetle. What can be taken as morphological evidence for cave restriction is reduction or loss of pigmentation, eyes, and flight wings; and elongation of antennae, legs and sensory hairs. None of the Cuban cave beetle species shows cave-related loss or gain of either pigmentation, eyes, appendages, or flight wings (Table 1). There are seven species of Tenebrionidae which have lost the metathoracic flight wings, but these are in phylogenetically wingless lineages associated with semi-arid environments. The wings were probably lost in ancestral species before cave colonization occurred. Thus, no Cuban cave beetles show evidence of morphological adaptation to cave habitats.

HABITAT ASSOCIATION

Cuban cave environments. The physical conditions of caves, which seem to especially affect terrestrial tropical cave life, are: 1, elevation; 2, temperature; 3, humidity; 4, food availability.

1. Elevation. Cuba is a relatively low island. More than 80% of its surface is below 300 m elevation. Most of the caves that have been studied are at elevations between sea level and 100 m. Only a few are as high as 150 m elevation. This may have an impact on the suitability of the caves for the development of troglobitic species. It is a general observation that most terrestrial troglobites in tropical caves occur at higher elevations, from 1000 to 2000 m

(Peck & Finston, 1993; Vandel, 1965). More data are needed on this topic.

2. Temperature. The air temperature in Cuban caves generally ranges from 21°-28°C with 22°- 26°C being frequently encountered. Some upper chambers with impediments to air flow (heat traps) may reach temperatures as high as 37°C. These chambers are often occupied by the pollen feeding bat *Phyllonycteris poeyi* Gundlach, and the elevated temperature is caused by metabolic heat from the bats and their decomposing guano. If humidity is high and food abundant, our observations are that beetles are present without regard to high or low cave temperatures.
3. Humidity. The relative humidity (RH) of Cuban cave air ranges from "dry" caves with about 70% RH, to the usual condition of near saturation from 95-98% RH. With high humidities, a variety of beetles are usually present. In dry caves, only some species of tenebrionids (which are normally drought adapted beetles) are present.
4. Food. Perhaps up to 90% of Cuban caves are occupied by bats. These have diverse diets and different species are specialist feeders on insects, fruit, pollen, and nectar. This produces a mix of guano types of varying nutrient content, which occur in scattered patches. In some caves the guano may be present in tremendous amounts. The guano varies in moisture content from dry to wet. Guano of intermediate moisture content has the richest assemblage of scavenger beetle species and the largest population sizes, which may reach tens of thousands of individuals. In the guano in Cuban caves, predator beetles are fewer in individual numbers and number of species (8) than are scavenger species (16). The predators feed on a variety of scavenging arthropods, such as mites, collembola, and fly larvae in the guano.

One of the common themes of specialization to life in temperate caves is adaptations to low levels of unpredictable food resources (Vandel 1965). The overabundance of predictable food resources (especially guano) has been seen as one factor retarding the development of cave-restricted terrestrial species in tropical caves (Vandel 1965). This matches our experiences, but this is not the place to present data on this topic.

WHY ARE THERE NO TROGLOBITIC BEETLES IN CUBA?

Because of the abundance of caves in Cuba, it would be reasonable to expect the presence of cave-evolved species. The absence of troglobitic beetles raises the question about why they are absent. To set the stage we present a summary (Table 2) of the known troglobites of the Greater Antilles. Totals and island characteristics are given in Table 3.

Notice that there are appreciable numbers of aquatic species modified for subterranean life (stygobites) on all four of the Greater Antillean islands. There are also appreciable numbers of terrestrial troglobites, except for Hispaniola which has not had any survey effort for terrestrial cave faunas. Notice also that the bulk of aquatics are crustaceans, and the bulk of

Table 2. Comparison of numbers of known species in the cave-evolved invertebrate faunas of the Greater Antilles (data from Decu & Juberthie, 1994; Peck 1992, 1994, and unpublished).

	Cuba	Jamaica	Hispaniola	Puerto Rico +Virgin Islands
Aquatic - Marine (eyeless or small-eyed stygobites)				
Platyhelminthes	0	1	0	0
Oligochaeta	0	0	1	0
Crustacea				
Remipedia	0	0	0	0
Ostracoda	3	3	4	0
Copepoda	19	0	1	0
Mysidacea	5	2	1	1
Thermosbaenacea	4	1	4	6
Isopoda	4	1	7	0
Amphipoda	2	4	15	6
Decapoda	7	2	3	1
Insecta (Coleoptera)	0	0	3	0
Total	**45**	**14**	**39**	**14**
Terrestrial (troglobites)				
Onychophora	0	1	0	0
Arachnida				
Pseudoscorpiones	2	4	0	0
Opiliones	2	2	0	0
Schizomida	2	1	0	0
Amblypygi	1	0	0	0
Aranea	2	9	0	1
Isopoda	5	1	0	0
Diplopoda	0	1	0	1
Chilopoda	2	0	0	0
Insecta				
Thysanura	3	0	0	1
Collembola	7	2	0	0
Orthoptera	3	0	0	0
Blattodea	1	1	0	1
Homoptera	0	2	0	1
Coleoptera	0	2	0	0
Total	**30**	**35**	**0**	**5**

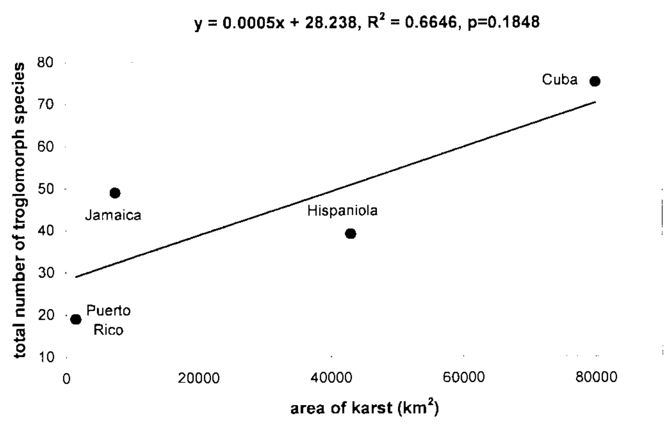

Figure 2. Linear regression of the total number of known troglomorph (troglobite + stygobite) species against island karst area. The relationship is suggestive but not statistically significant.

Table 3. Summary of characteristics of Greater Antilles and their cave faunas.

Island	Total Area (km^2)	Area of Karst (km^2)	No. Sp. aquatic stygobites	No. Sp. terrestrial troglobites	Total No. Sp.
Cuba	111,000	80,000	45	30	75
Hispaniola	76,476	≈43,000	39	0	39
Jamaica	11,700	≈7,500	14	35	49
Puerto Rico (+ Mona &Virgin Islands)	9,399	≈1,500	14	5	19

terrestrials are arachnids, not insects. Within insects, there are only 5 troglobitic beetles for the whole Caribbean, and only 2 are terrestrial species. Why there are more tropical troglobite arachnids than troglobite insects is an unaddressed question.

There are interesting trends in these figures when explored as species-area relationships, a common analytical approach in comparative biogeography. In summary, for total subterranean faunas the species-area relationship is not significant (Fig. 2). When only aquatics are analyzed, there is a significant species-area relationship for the islands' karst areas (Fig. 3). It is interesting to note that, for the aquatic species, species number in relation to total island area is an even more significant regression than that for area of karst (not shown). This is reasonable because we know that the groundwater fauna can occupy groundwater spaces in non-limestone terranes as well as those in limestones.

The scarcity or absence of troglobite beetles is not unique to Cuba, but is a generalization for the entire West Indian cave fauna. The three species known from Hispaniola are aquatic elmids (Spangle, 1981b). And since the two eyeless beetle species known from Jamaica are from montane regions, the generalization can be extended to an absence of terrestrial troglobite beetles in lowland West Indian caves. This fits the general picture for tropical lowland terrestrial faunas as a whole, and the scarcity or absence of troglobite beetles in both continental and insular tropical lowland caves. This generalization in the New World is based on an analysis of 241 terrestrial troglobites in Mexico, Guatemala, and Belize, of which 86% were from upland caves, and the bulk of the 14% from lowland caves were arachnids, terrestrial isopods, and collembola; not beetles (Peck & Finston 1993).

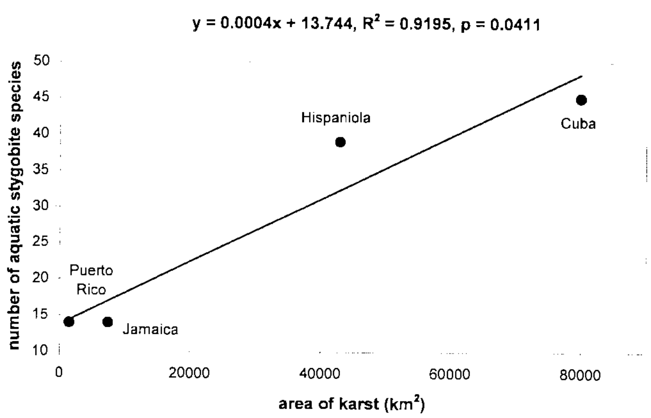

Figure 3. Linear regression of the total number of aquatic stygobite species against island karst area. The relationship is statistically significant.

The absence of troglobitic beetles is not due to a lack of evolutionary time. The islands are certainly old enough, and many other terrestrial troglobites have evolved in these islands. The resolution of the question must be one of an absence of selective pressure and appropriate environmental conditions. These have been present for other groups such as West Indian arachnids, terrestrial isopods, and some insects, mostly collembola. Again we turn to the most obvious factor. Where troglobites do occur there is a strong selective factor of limited food availability. Terrestrial troglobites occur most frequently in food-poor (bat-poor) montane caves, and in food-rich (bat-rich) lowland caves they usually occur only in the food-poor part of the caves. Other terrestrial groups have responded to these environmental conditions and selective pressures to become cave limited and morphologically evolved for cave life, but West Indian beetles have not.

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APPENDIX

Cuban cave localities from which beetles are known. Province symbol and number of cave as in list of beetle taxa (see Fig. 1). Following the cave name may be the neighbouring town or village, and then the municipality in which it is located.

Pinar del Río Province
1. Abono, Cueva del; Gran Caverna de Sto. Tomás. El Moncada.
2. Agua, Cueva del; Península de Guanahacabibes.
3. Barca, Cueva la; Peninsula de Guanahacabibes.
4. Catacumbas, Cueva de las; Gran Caverna de Sto. Tomás. El Moncada.
5. Clara, Cueva; Los Portales, San Diego de los Baños.
6. Columnas, Cueva de las; Gran Caverna de Sto. Tomás. El Moncada.
7. Fango, Cueva del: Gran Caverna de Sto. Tomás. El Moncada.
8. Hoyo de Fanía: Gran Caverna de Sto. Tomás. El Moncada.
9. Incógnita, Cueva; Gran Caverna de Sto. Tomás. El Moncada.
10. Jaguey, Cueva del; Península de Guanahacabibes.
11. Pio Domingo, Cueva de; Sumidero, Minas de Matahambre.
12. Represas, Cueva de las; Gran Caverna de Sto. Tomás. El Moncada.
13. Vela, Cueva de la; Gran Caverna de Sto. Tomás. El Moncada.

La Habana Province
1. Animales, Cueva de los; Las Cañas, Artemisa.
2. Baño, Cueva del; Las Cañas, Artemisa.
3. Cura, Cueva del; Tapaste.
4. Emilio, Cueva de; Las Cañas, Artemisa.
5. Galera, Cueva; Galera, Sta. Cruz del Norte.
6. Mudo, Cueva del; Catalina de Güines.

Ciudad de La Habana Province
1. Cinco Cuevas, Cueva; Boca de Jaruco, Sta. Cruz del Norte.
2. Mariana, Cueva de la; Quivicán.
3. Murciélagos, Cueva de los; Boca de Jarúco, Sta. Cruz del Norte.
4. Tunel, Cueva del; Quivicán.
5. Virgen, Cueva de la; 15 km east of Puerto de La Habana.

Matanzas Province
1. Bellamar, Cueva de; Matanzas.
2. Eloisa, Cueva de la; Camarioca, Varadero.
3. Jarrito, Cueva del; al SE de Matanzas.
4. Pluma, Cueva la; Bacunayagua, Matanzas.

Villa Clara Province
1. Bichos, Cueva del los; Zuleta.
2. Gato, Cueva El; Mogote de Sagua.
3. Majá, Cueva El; Caibarien.

Sancti Spiritus Province
1. Colón, Cueva de; Cayo Caguanes, Yaguajay.
2. Columnas (del Veterano), Cueva de las; 10 km west of Trinidad.
3. Guanayara, Cueva; 10 km al W de Trinidad.
4. Guanayara, Caves in the area of; 10 km west of Trinidad.
5. Grande de Caguanes, Cueva; Cayo Caguanes, Yaguajay.
6. Humbolt, Cueva; Cayo Caguanes, Yaguajay.
7. Túnel, Cueva del; Caya Caguanes, Yaguajay.

Camagüey Province
1. Agua (de los Lagos), Cueva del; Sierra de Cubitas.
2. Indio, Cueva del; Sierra de Cubitas.
3. Lechuza, Cueva de la; Sierra de Cubitas.

Holguín Province
1. Bariay, Cueva; Loma El Pilón, Mayarí.
2. Cuatrocientas Rosas, Cueva de las; Banes.
3. Grande de Pilón, Cueva; Mayarí Abajo.
4. Guano, Cueva del; Gibara.
5. Hoyito (de las Cuatrocientas Rozas #2), Cueva del; Banes.
6. Jaguey, Cueva del; Cuesta de Seboruco, Mayarí.
7. Panaderos, Cueva de los; Gibara.
8. Santos, Cueva de los; Gibara.

Granma Province
1. Banega, Cueva; Matias.
2. Fustete, Cueva del; Niquero.

Santiago de Cuba Province
1. Atabex, Cueva; Playa Siboney, Santiago de Cüba.
2. Cantera, Cueva de la; Playa Siboney, Santiago de Cuba.
3. Cativar, Cueva; Guamá.
4. Colorada del Maso, Cueva de la; Guamá.
5. Golondrinas, Cueva de las; Playa Siboney, Santiago de Cuba.
6. Humo, Cueva del; La Uvita, Guaná.
7. Humo, Cueva del; Los Negros, Baire, Tercer Frente.
8. Jíbara, Cueva; Tercer Frente.
9. Majaes, Cueva de los, Siboney, Santiago de Cuba.
10. Murciélagos, Cueva de los, La Uvita, Guamá.
11. Terrarium, Cueva del; Playa Siboney, Santiago de Cuba.
12. Virgen, Cueva de la; Playa Siboney, Santiago de Cuba.

Guantánamo Province
1. Golondrinos, Cueva de los; Majana, Baracoa.
2. Majana, Cueva de; Majayara, Baracoa.
3. Patana, Cueva La; Maisí, Baracoa.

Municipio Especial Isla de la Juventud
1. Abono, Cueva del; Sierra de Casas.
2. Agua, Cueva del; Sierra de Casas.

Veronica A. Toth- Spatial and Temporal Variations in the Dissolved Organic Carbon Concentrations in the Vadose Karst Waters of Marengo Cave, Indiana. *Journal of Cave and Karst Studies 60*(3): 167-171.

SPATIAL AND TEMPORAL VARIATIONS IN THE DISSOLVED ORGANIC CARBON CONCENTRATIONS IN THE VADOSE KARST WATERS OF MARENGO CAVE, INDIANA

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In order to better understand the organic content of microbands in speleothems, seasonal variations in the organic concentrations of vadose drip waters were examined in relation to climatic and environmental variables. Seasonal variations in the organic concentrations of the vadose waters were observed by documenting the fluctuations of Dissolved Organic Carbon (DOC) and its corresponding fluorescence. Tracer dye tests established that the larger drips depositing calcite in Marengo Cave were fed by waters with a short residence time. A strong seasonal variation in DOC concentrations and natural fluorescence was detected at quickly responding sites. Slow, constant drip sites displayed a weaker seasonality. Further investigation is required to distinguish low fluorescing DOC and to determine if the same fluorophors identified in the vadose water can be identified in the organics trapped in the recipient calcite. The overall conclusions are that fluorescence is well correlated with DOC when the fluorescence range is high but it is not a strong indicator of DOC at low fluorescence values; that the value of fluorescence as a predictor of DOC may vary significantly with individual sampling sites; and that the highest fluorescence values occur in springtime and the weakest in summer and fall.

The organic content of microbands in speleothems is a promising but poorly understood field for paleoclimatic interpretation. Paleoclimatic studies of stalagmites and flowstones have included the isotopic records contained in the calcite of vadose-zone speleothems (Schwarcz 1986; Gascoyne 1992; Dorale *et al.* 1992, Baker *et al.* 1993). Many speleothems show varve-like submillimeter-scale color bands. Gascoyne (1977) and White (1981) determined that the color of such speleothems is chiefly due to the presence of variable amounts of clay or humic substances which coprecipitated or absorbed onto calcite surfaces from drip waters that passed through soil before entering the cave. Lauritzen *et al.* (1986) found that humic and fulvic acids are readily soluble and may be expected to enter speleothem feed waters preferentially during growing seasons. The two groups found in speleothems may be taken as indices of productivity in the overlying soil and plant cover and, therefore, as a proxy measure of paleoclimate (Lauritzen *et al*. 1986). Shopov *et al.* (1994) found a well-defined annual cycle in many vadose-zone speleothems that could be used to define the chronology of short-term events. This cycle is probably a response to hydrological events in the recharge to the cave. The most basic research on the response of organic material to climatic and environmental variables is still lacking. In this study, seasonal variations in the organic concentrations of vadose drip waters were examined in relation to climatic and environmental variables. The results will help to set up transfer functions for paleoenvironmental interpretation of organic content of speleothems, at least from Marengo Cave, Indiana.

Organic (humic) substances occluded in the calcite crystals of many vadose speleothems cause luminescence in UV light. This may produce varve-like bands parallel to growth, and visible color layers are often resolvable down to micrometer scales. Shopov (1987) and White and Brennan (1989) showed that the luminescence is caused by calcium salts of humic and fulvic acids along with some low-molecular-weight organic esters. Shopov (1987) provided the first indirect evidence that the banding may reflect paleoenvironmental parameters. By assuming that the finest bands were annual, 11 to 22 year cycles were demonstrated in some samples. It appears that some variable of the paleo-ecosystem caused variations in the amounts of clay or humic substances to be coprecipitated with, or adsorbed onto, calcite. The first step in order to understand this paleoenvironmental signal is to study the relationship of ecosystem parameters and organics in drip water today. In the study reported below, drip water sites were monitored over the spring and summer of 1995 in order (i) to characterize the organic matter in the vadose waters and its fluorescence, and (ii) to determine any seasonal variations in organic concentrations.

STUDY SITE

Southern Indiana today has a strongly seasonal climate with a mean annual precipitation of 1110 mm of which approximately 420 mm falls in winter, and a mean annual temperature of 13.4ºC with a typical annual range of -5° to 25.5°C. The topography of the region consists of hills, ridges, valleys and sinkholes. Marengo Cave, 50 km northwest of Louisville, Kentucky (Fig. 1) is situated beneath a mature forest producing significant amounts of organic matter, and has many active speleothems within easy access. The cave is located under a sandstone-capped ridge in the 152 m thick Middle Mississippian Limestone of the Blue River Group (which

Figure 1. Location of Marengo Cave, Indiana.

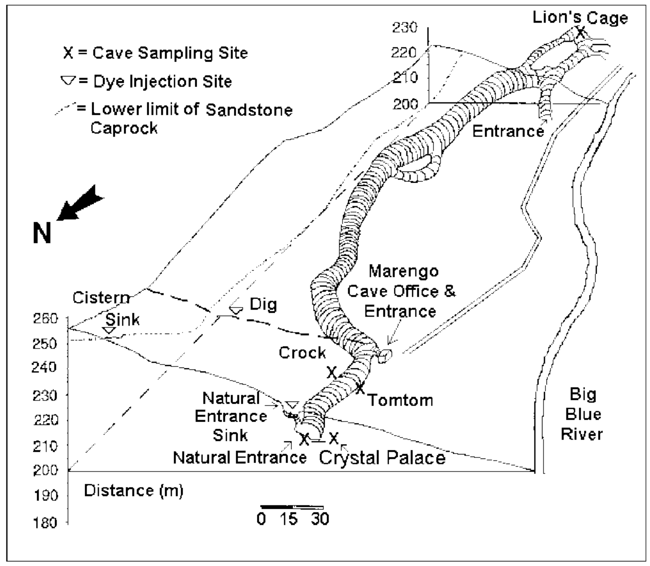

Figure 2. 3-D Model of Upper Marengo Cave, Indiana, a simple low gradient, abandoned river cave. Sites for injection and recovery of dye during the tracer dye tests.

includes the St. Louis, Ste. Genevieve and Paoli Formations). Sampling sites were chosen from the upper cave, a simple low gradient river cave now abandoned by flowing water and truncated at both ends by breakdown (Fig. 2). The majority of the sampling sites were located at the two ends of the cave where the overlying bedrock is not very thick and decorations are profuse. The distribution of speleothems reflects the behavior of modern drips: the highest volume drips coincide with the highest volume of speleothems towards the cave ends (e.g., the Crock, Lions Cage), and the lower volume drips with the fewer speleothems of the cave center.

METHODS

The route of water flow from the forest floor to the cave drip sites (Fig. 2) was traced with eight dye tests in early May 1995 (Table 1). For each test an automatic water sampler operated for 24 hours after injection at the site deemed most likely to be the relevant drip point. Sampling was augmented by manual collection from 18 other possible sites for up to six weeks after injection. The results of the dye tracing provided the basis for subsequent drip water sampling.

Samples for DOC and fluorescence were collected from Tomtom, Crystal Palace, Lions Cage and the Crock (Fig. 2) on a weekly basis between February and October 1995, using Teflon tubing attached to the stalactite with copper wire and protecting the mouths of the 2.5 L collecting jugs with aluminum foil (folded to prevent the shiny, possibly organically contaminated side from coming into contact with the water).

A suite of smaller (200 mL) samples was collected daily, directly into Teflon bottles, from May to mid-June 1995 from 8 dripping stalactites, 8 drips into pools and 2 drips from fractures. Temperature and conductivity were measured *in situ*. The samples collected daily, directly into Teflon bottles, were analyzed for total fluorescence (on a Turner Fluorometer, with a blue filter) usually within a few hours of collection, at the cave site and, thus, at ambient cave temperature. The samples collected weekly, approximately a quarter of the total, were stored in a cold room and analyzed within 2 to 3 months of collection at McMaster University, Ontario, Canada. Ninety-nine samples representing the widest range of measured fluorescence (from 30 to 700 total fluorescence measured on a relative scale) were analyzed in McMaster University for Dissolved Organic Carbon (DOC) by syringe injection into a DC-180 DOHRMANN Carbon Analyzer. Each sample was acidified with HNO_3 to a pH of 2 and degassed with argon for 5 to 10 minutes in order to remove the dissolved inorganic carbon.

RESULTS

DYE TRACING

Dye traces showed both the underground water routes and the response times. Results are shown in Table 1. Flow rates may have been abnormally fast because May 1995 was an especially wet month with 284.2 mm of rain. In spite of the rain, water had to be added along with dye for most of the tests to flush it into the system. Only three of the tracer dye tests, all at the north end of the cave, were successful.

The peak of the dye injected at the Cistern appeared 7.5 hours later and 45 m lower, at the Natural Entrance. A second

Table 1. The results of the tracer dye tests - injection and recovery sites shown in Figure 2. All samples were analyzed with a Turner Systems Fluorometer, Model 10, using an orange filter for Rhodamine WT, Sulpho-Rhodamine B and Eosine, and a green filter for Fluorescein, Pyranine and Eosine.

Test No.	Date	Flow Rate (m/sec)	Injection Point	Recovery Point	Dye	Mass of Dye Injected/Recoverd	Weather Conditions	Water Added	Success/ Failure
1	8-May	$1.67*10^{-3}$	Cistern Sink	Natural Entrance	Rhodamine WT	1.74 g / 1.36g	Dry	Yes	Success
2	9-May	$1.67*10^{-2}$	Cistern	Natural Entrance	Fluorescein	2.57 g / 1.59 g	Rain Storm	No	Success
3	9-May	N/A	Natural Entrance Spring	Natural Entrance	Sulpho Rhodamine B	NA	Rain	Yes	Failure
4	10-May	$4.32*10^{-3}$	Gift Shop "Dig"	Crock	Eosine	60 g / 39.37 g	After Storm	No	Success
5	11-May	N/A	Bonaza Sink	No Recovery	Pyranine	N/A	Dry	Yes	Failure
6	11-May	N/A	Coral Sink	No Recovery	Sulpho Rhodamine B	N/A	Dry	Yes	Failure
7	11-May	N/A	Dig	No Recovery	Fluorescein	N/A	Dry	Yes	Failure
8	11-May	N/A	Nicks Sink	No Recovery	Sulpho Rhodamine B	N/A	Dry	Yes	Failure

injection at the same site during a storm event emerged in only 45 minutes. These fast flow rates (1.67 x 10^3 m/sec for the first test and 1.67 x 10^3 m/sec for the second) and the absence of any dye at the nearby site of Tomtom suggests a simple pipe connection. The other successful dye trace, from the Gift Shop "Dig" to The Crock was done shortly after a storm event and also showed a fast response rate (4.32 x 10^3 m/sec through 70 m of overburden) and a simple pipe connection.

The other tests were done during drier conditions and the added water to flush the dye in may have been insufficient. Although monitoring continued throughout the summer no traces of the dye were found. There is a possibility that the dye did emerge at some low elevation springs close to the injection points, but these were checked with only a few hand samples and the peak may have been missed.

The conclusion from the dye tests was that some of the larger drips (e.g. the Crock) are fed by waters that are underground for no more than a few hours to a few days, that the drip rate and volume responded quickly to surface water conditions, and that the route is usually a simple unbranched pipe connection. These sites also showed a large range of organic content and fluorescence and were classified as strongly responding sites. Other evidence indicates that some drips behave in a different way: for example, Tomtom showed no dye traces, and had a more consistent drip rate, volume and fluorescence than other sites. This suggests that the waters at Tomtom are well mixed and remain in the vadose zone longer. Slow flowing drips such as Tomtom also showed low values of organic content and fluorescence and were classified as weakly responding sites.

TOTAL FLUORESCENCE AND DISSOLVED ORGANIC CARBON (DOC) CONCENTRATION

For the analysis of total fluorescence and DOC concentration, it was expected that the majority of the fluorescence of vadose drip waters would come from dissolved organic carbon because particulate organics are filtered by the overburden through which the waters flow. The relationship between DOC and natural fluorescence was tested for all waters to see if fluorescence is a good predictor of DOC; the results, divided according to the time of collection, are shown in Figure 4. Work by Smart *et al.* (1976) has shown that the total organic carbon concentration in a range of polluted natural waters correlates linearly with fluorescence. The DOC concentration was expected to increase and peak throughout the summer and decline in the dry fall. To test this hypothesis, DOC and natural fluorescence were plotted against time. Only the strongly responding sites showed much seasonal change.

The spring waters (collected between March and mid-June 1995, Fig. 3) showed a statistically significant positive relationship of fluorescence and DOC (with an r^2 value of 0.617 and a one-tailed t value of 1.68, significant at the 0.05 level of probability). Spring waters, thus, show that the measured fluorescence of the waters was caused by the DOC; that fluorescence is simply and linearly proportional to the amount of DOC; and that the waters did not contain significant non-fluorescent DOC (the line begins close to the origin).

This trend did not continue in the summer waters (collected between mid-June and August 1995, Fig. 3). Although concentration of DOC increased to some extent during the summer months related to the increase in biological activity, fluorescence did not always increase, and no correlation between flu-

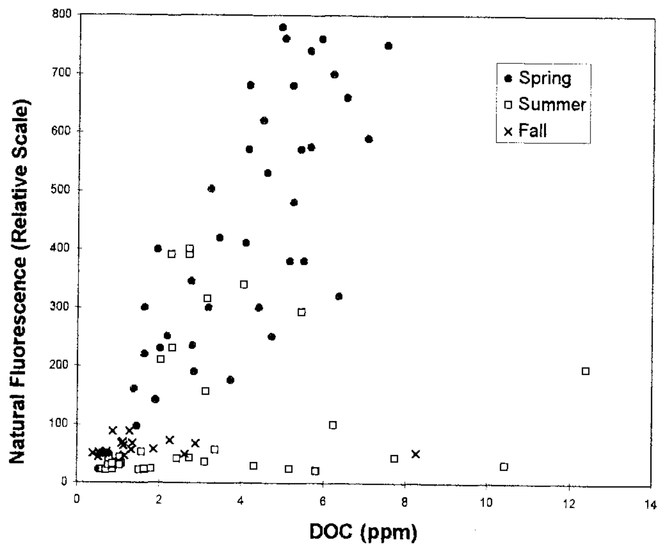

Figure 3. Total Natural Fluorescence vs. Dissolved Organic Carbon (DOC) Concentration (ppm) March - October, 1995 (Divided according to the time of collection).

orescence and DOC was found. The DOC must, therefore, be composed of mainly low-fluorescent organics, possibly due to long non-fluorescent carbon chains.

It was anticipated that the greatest fluorescence and DOC might reach the cave in summer with the greatest accumulation of organic matter on the forest floor. However, the highest values for fluorescence and DOC occurred in spring (rather than in summer or fall as expected). The fall waters (collected between September and October 1995, Fig. 3) showed a dramatic decrease in both concentration of DOC and fluorescence but with no apparent relationship between the two. The marked reduction in precipitation in the fall may have halted the transport of DOC to the cave site so that the organics remained in the upper soil layers. The high spring DOC and fluorescence values may result from a flushing out of organic material which accumulated and decomposed during the previous fall and winter.

CONCLUSIONS

(i) Spring waters showed the highest values for, and the strongest correlation between, fluorescence and DOC. These organics have probably been in storage in the soil over the winter and are well decayed into short length, high-fluorescent carbon chains. Spring waters, thus, behave as expected and support the basic working assumption for high resolution studies of speleothem fluorescent banding, that DOC concentration will be in simple proportion to fluorescence.

(ii) Fluorescence values fell sharply in summer and fall while DOC remained relatively high. These organics may be composed of less decayed, long length, low-fluorescent carbon chains. The absence of a correlation between fluorescence and DOC in the summer months, thus, contradicts the basic working assumption: low fluorescing bands may actually contain high levels of DOC.

(iii) Both fluorescence and DOC values were low during the fall. This may be related to a reduction in flow rate and flushing rate in the dry weather. The fall data probably represent the end of the annual cycle of soil organic flushing. Although no sampling was done in winter it is assumed that the vadose waters will probably freeze in the winter.

(iv) A strong seasonal effect was apparent only in the quickly responding sites with the fastest drip rates and fastest growing speleothems. Slow, constant drip sites exhibited a much weaker seasonality.

The overall conclusions are (i) that fluorescence is well correlated when the fluorescence range is high; (ii) that fluorescence is not a strong indicator of DOC at low fluorescence values; (iii) that the value of fluorescence as a predictor of DOC may vary significantly with individual sampling sites; (iv) that the highest fluorescence values occur in springtime and the weakest fluorescence occurs in summer and fall. The implications are that a speleothem with a high range of fluorescence is likely to show a strong paleoclimatic signature; that the highest fluorescing bands probably represent spring floods or storm activity; that the fastest growing speleothems are likely to show the clearest seasonal signal; that each speleothem may record paleo-ecosystem parameters in an individual way and each site should be tested before any environmental conclusions are drawn. This type of study has not been conducted elsewhere so it is not known to what extent Marengo Cave is typical and to what extent these conclusions can be applied to all caves and speleothems.

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D.W. Webb, L.M. Page, S.J. Taylor and J.K. Krejca- The Current Status and Habitats of the Illinois Cave Amphipod, *Gammarus acherondytes* Hubricht and Mackin (Crustacea: Amphipoda). *Journal of Cave and Karst Studies 60*(3): 172-178.

THE CURRENT STATUS AND HABITATS OF THE ILLINOIS CAVE AMPHIPOD, *GAMMARUS ACHERONDYTES* HUBRICHT AND MACKIN (CRUSTACEA: AMPHIPODA)

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Gammarus acherondytes *is a rare amphipod endemic to Illinois subterranean streams. It previously was recorded from five cave streams in Monroe and St. Clair counties, Illinois. An examination of 164 caves from 1986 to 1995 produced only one new record, Madonnaville Cave, in Monroe County. These recent collections have documented a large population of* G. acherondytes *in Illinois Caverns, a moderate-sized population in Fogelpole Cave, and a small population in Krueger-Dry Run Cave. Pautler Cave, a previously known locality, has been bulldozed shut by the landowner. No specimens of* G. acherondytes *have been collected in Stemler Cave since 1965, and no specimens were collected in Madonnaville Cave in 1995 although a single specimen was collected in 1986.*

Gammarus acherondytes Hubricht and Mackin is a rare endemic amphipod found in the subterranean streams of Monroe and St. Clair Counties, Illinois (Bousfield 1958; Cole 1970a, 1970b; Holsinger 1972; Hubricht & Mackin 1940; Nicholas 1960; Page 1974; Peck & Lewis 1978; Webb 1993, 1995; Webb *et al.* 1993). It originally was recorded from Illinois Caverns [as Morrisons Cave], Monroe County, and Stemler Cave, St. Clair County (Hubricht & Mackin 1940). Holsinger (1972) reported it from four caves in Monroe County and one cave in St. Clair County, but did not specify which caves. Peck and Lewis (1978) reported it from Fogelpole Cave, Krueger-Dry Run Cave [as Fruths Spider Cave], Illinois Caverns and Pautler Cave, all in Monroe County. These are the four caves from Monroe County referred to by Holsinger (1972) (J.R. Holsinger, personal communication, 1996). Eighty caves were searched in 1992 and 1993 for *G. acherondytes* (Webb 1993; Webb *et al.* 1993) including four of the five caves from which it was previously recorded. The entrance to the only other previously recorded site, Pautler Cave, has been bulldozed shut.

During this time (1992-1993), it was collected only in Fogelpole Cave and Illinois Caverns. In addition, material collected during a study of 84 Illinois caves by Oliver and Graham (1988) was examined. A single specimen from Madonnaville Cave (Monroe County) was found in this material and constitutes a new locality record for this species.

Gammarus acherondytes is on the Illinois list of threatened and endangered species (Herkert 1992), and is now listed as a federally endangered species (U.S. Department of the Interior, Fish & Wildlife Service, 1998). In 1993 and 1995, the Fish and Wildlife Service requested a status report from the Illinois Natural History Survey (INHS) on this species that included a reexamination of all known localities in Illinois as well as other subterranean streams. The request called for examination of the species' habitat, its association with, and population size in relation to, other amphipod species, and evaluation of environmental conditions that might impact the species.

The following is an assessment of the current status of *Gammarus acherondytes* in Illinois caves.

Fogelpole Cave (Monroe County)

This is the longest cave in Illinois (Bretz & Harris 1961; Frasz 1983; Webb *et al*. 1993). It passes under a broad area of upland karst containing crops and livestock farmland, rural dwellings, and several small communities. Throughout the area, small woodlots containing sinkholes receive runoff from fields, residential land, and roads. This runoff eventually drains into the main cave stream of Fogelpole Cave. The passage over the main cave stream is 10 m high by about 12 m wide, with the stream 3-6 m wide and 0.3-1.2 m deep. Both upstream and downstream of this area are several side passages. The main cave stream is characterized by deep pools, shallow riffles, and raceways, with large gravel bars and breakdown blocks. The cave is in excess of 24 km long (J. Sherrill, personal communication, 1996). A wide variety of other habitats are found in this cave.

Fauna: Aquatic organisms recorded from this cave (Peck & Lewis 1978; Webb *et al.* 1993) are Platyhelminthes: Turbellaria: *Sphalloplana hubrichti* (Hyman); Mollusca: Gastropoda: *Physa halei* Lea; Arthropoda: Crustacea: Amphipoda: *Bactrurus brachycaudus* Hubricht and Mackin, *Crangonyx forbesi* (Hubricht and Mackin), *Gammarus acherondytes*, *G. troglophilus* Hubricht and Mackin; Isopoda: *Caecidotea brevicauda* (Forbes), *C. packardi* Hubricht and Mackin; Chordata: Pisces: *Cottus carolinae* (Gill).

In 1995, five sites in this cave were examined for amphipods (Table 1).

Current Status: The two main entrances of Fogelpole Cave

Table 1. The abundance and habitat of *Bactrurus brachycaudus*, *Crangonyx forbesi*, *Gammarus acherondytes*, and *G. troglophilus* collected from five sites in Fogelpole Cave, Monroe County, Illinois on 24 August 1995.

Habitat Type	Width	Depth	Substrate	*Bactrurus brachycaudus*	*Crangonyx forbesi*	*Gammarus acherondytes*	*Gammarus troglophilus*
mainstream riffles, pools	6 m	8-10 cm	limestone rocks, breakdown, gravel, organic debris	0	27	14	140
stagnant side channel	0.6 m	up to 1 m	silt overlying bedrock	0	1	0	1
overflow channel	8 cm-5 m	1-90 cm	silt overlying bedrock	1	57	0	21
small rivulet	15-60 cm	1-10 cm	sand & gravel overlying bedrock	0	2	0	61
sidestream riffle, pool	0.3-1.2 m	<15 cm	calcite gravel, sand, rubble, silt, bedrock	0	6	19	13
			TOTAL	1	93	19	236
			%	0.3	26.6	5.4	67.6

are closed with welded steel grates that allow for the passage of bats, and the other entrances are protected by landowners or difficult passages. Thus, human visitation is not a major threat to the cave and its life. Surface runoff from a heavy rainstorm in 1995 was observed to pour down a previously dry streambed and into this cave through the lower of the two main entrances. This runoff was heavily laden with silt from nearby agricultural fields.

Gammarus acherondytes was collected in association with *G. troglophilus* and *Crangonyx forbesi* (Table 1) in gravel-cobble riffles in the main cave stream and in the calcite-gravel-sand-silt riffles and pools of a small lateral stream. Of 349 amphipods collected from the five sites, *G. acherondytes* made up 5.4% of the specimens. In the two riffle sites where collected it made up 9.3% of the amphipods. *Gammarus acherondytes* was collected in Fogelpole Cave in 1965 (1 specimen, J. Holsinger collection), 1986 (1 INHS), 1993 (10 INHS), and 1995 (19 INHS).

A nitrate nitrogen concentration of 4.14 ppm was detected in a water sample taken February 24, 1992, which is below the U. S. Environmental Protection Agency maximum contaminant level (USEPAMCL) (USEPA 1988, 1990, 1991) of 10 ppm. The pesticides o,p-DDE, p,p'-DDE, o,p-DDD, Dieldrin, Aldrin, Heptachlor, Heptachlor epoxide, DDT, and Aroclor 1254 as well as PCBs were not detected in water samples collected February 24, 1992 and September 29, 1992. No mercury was detected in water samples collected on those dates, but concentrations of 658 ppb and 327 ppb were measured in the bioassay of amphipods and isopods, respectively, collected in Fogelpole Cave on February 24, 1992 (Webb *et al.* 1993). Amphipod samples from this same collection were too small for pesticide and PCB bioassays, but Dieldrin and the persistent breakdown products of DDT were detected in the isopods from this cave (Webb *et al.* 1993).

ILLINOIS CAVERNS (MONROE COUNTY)

This is one of the largest cave systems in Illinois (Bretz & Harris 1961; Frasz 1983; Webb *et al.* 1993). It passes under an area of upland karst supporting crops and livestock farmland and rural dwellings. Throughout the area are small woodlots containing sinkholes that receive runoff from fields, residential land, and roads. The main entrance is located in a moderate-sized wooded sinkhole that has been modified to allow easy but controlled access to the cave. The cave contains 8.8 km of mapped passages (Frasz 1983) and carries a significant amount of water. The passages show evidence of flooding, and often have an accumulation of surface organic debris such as large logs and leaves.

Fauna: Aquatic organisms recorded from this cave (Peck & Lewis 1978; Webb *et al.* 1993) are Platyhelminthes: Turbellaria: *Sphalloplana hubrichti*; Mollusca: Gastropoda: *Physa halei*; Bivalvia: *Musculium* sp.; Arthropoda: Crustacea: Amphipoda: *Bactrurus brachycaudus*, *Crangonyx forbesi*, *Gammarus acherondytes*, *G. troglophilus*; Isopoda: *Caecidotea brevicauda*, *C. packardi*.

In 1995, 19 sites in this cave were examined for amphipods (Table 2).

Current Status: This cave is open to the public and access is controlled by the Illinois Department of Natural Resources. Anyone may visit the cave during daytime when it is open, provided that they sign a liability release. Due to the heavy human visitation it receives, many speleothems are broken, and graffiti and human trash are common. Even so, this cave supports a diverse terrestrial and aquatic fauna.

Gammarus acherondytes was collected only in the gravel-cobble riffles and pools of the main cave stream (Table 2) in association with *G. troglophilus* and *Crangonyx forbesi*. *G. acherondytes* made up 25.1% of the 223 amphipods collected, and comprised 30.6% of the amphipods in the two riffle-pool sites where it was collected. *Gammarus acherondytes* has been collected in this cave in 1938 (25 plus specimens, U.S. National Museum [USNM]), 1965 (14 specimens, J. Holsinger collection), 1974 (6 INHS), 1992 (20 INHS), 1993 (1 INHS), and 1995 (56 INHS).

A nitrate nitrogen concentration of 5.89 ppm was detected in a water sample taken February 24, 1992, but at concentrations below the USEPAMCL of 10 ppm. Mercury, PCBs, and the pesticides o,p-DDE, p,p'-DDE, o,p-DDD, Dieldrin, Aldrin, Heptachlor, Heptachlor epoxide, DDT, and Aroclor 1254 were not detected in water samples collected February 24, 1992 (Webb *et al.* 1993).

KRUEGER-DRY RUN CAVE (MONROE COUNTY)

The two main entrances of this cave (Frasz 1983; Webb *et al.* 1993) are located in adjacent wooded sinkholes, each about 12 m in diameter, surrounded by farmland. A third entrance is

Table 2. The abundance and habitat of *Bactrurus brachycaudus*, *Crangonyx forbesi*, *Gammarus acherondytes*, and *G. troglophilus* collected from 19 sites in Illinois Cavern, Monroe County, Illinois on 7 June 1995.

Habitat Type	Width	Depth	Substrate	*Bactrurus brachycaudus*	*Crangonyx forbesi*	*Gammarus acherondytes*	*Gammarus troglophilus*
mainstream riffles, pools	1.5-3 m	5-60 cm	gravel, cobblestone	2	2	39	43
small rivulet	13 cm	2.5 cm	pea gravel	0	0	0	16
small rivulet	3.8 cm	1.3 cm	bedrock, silt, gravel	0	0	0	3
rimstone pool			bedrock	0	0	0	0
mainstream			leaf pack	0	0	0	0
small rivulet				0	2	0	1
rivulet				0	0	0	0
drip pool			bedrock	0	0	0	0
mainstream riffle, pools		60 cm	gravel, cobble, silt & sand	0	1	17	79
Drip pool & rivulet			bedrock	0	0	0	0
pools			bedrock	0	0	0	0
rimstone dam pool	60 cm	1.3-8 cm	silt overlying bedrock	0	0	0	8
rivulet	10 cm	2.5 cm	bedrock	0	0	0	0
drip pool	1 m	2.5-5 cm	bedrock	2	0	0	2
rivulet	5-10 cm	2.5 cm	gravel, silt overlying bedrock	0	0	0	0
rivulet	20 cm	5 cm	gravel	0	0	0	0
several small pools		<2.5 cm	bedrock	0	0	0	0
rivulet	2.5-25 cm	0.5 cm	bedrock	0	0	0	0
drip pool & rivulet	0.6 m	<5 cm	silt overlying bedrock	0	0	0	6
			TOTAL	4	5	56	158
			%	1.8	2.2	25.1	70.9

Table 3. The abundance and habitat of *Crangonyx forbesi*, *Gammarus acherondytes*, and *G. troglophilus* collected from 2 sites in Krueger-Dry Cave, Monroe County, Illinois on 25 August 1995.

Habitat Type	Width	Depth	Substrate	*Crangonyx forbesi*	*Gammarus acherondytes*	*Gammarus troglophilus*
mainstream riffle	1.8 m	1.3-90 cm	gravel, cobble	22	2	11
upper level side stream	0.3 m	5-60 cm	silt overlying bedrock	4	0	25
			TOTAL	26	2	36
			%	40.1	3.1	56.3

in a wooded sinkhole surrounded by farmland that is heavily used by cattle. This cave contains approximately 11 km of mapped passages (J. Sherrill, personal communication 1996), ranging from belly crawls to a mainstream passage up to 3 m high by 6 m wide, with water up to 1.8 m deep. There is evidence that the cave frequently floods to the ceiling. The stream substrate is mainly gravel, sand, or silt. Kelly Spring is the resurgence of the cave stream.

Fauna: Aquatic organisms recorded from this cave (Peck & Lewis 1978; Webb *et al.* 1993) are Platyhelminthes: Turbellaria: *Sphalloplana hubrichti*; Arthropoda: Crustacea: Amphipoda: *Crangonyx forbesi*, *Gammarus acherondytes*, *G. troglophilus*; Decapoda: *Orconectes virilis*; Isopoda: *Caecidotea brevicauda*, *C. packardi*; Chordata: Pisces: *Ameiurus natalis* (Lesueur), *Lepomis cyanellus* Rafinesque.

In 1995, two sites in this cave were examined for amphipods (Table 3).

Current Status: In 1992, scattered human trash that apparently had washed in from sinkholes was present, but little vandalism was visible. Some broken glass and candle wax suggest that humans often visit this cave, but frequent flooding probably keeps the cave relatively free of debris. The biggest threat to this cave appears to be agricultural activity in the watershed.

Gammarus acherondytes was collected in a gravel-cobble riffle of the main cave stream in association with *G. troglophilus* and *Crangonyx forbesi* (Table 3). At this riffle site, *G. acherondytes* made up 5.7% of the sample, but constituted 3.1% of the 64 amphipods collected from this cave. *Gammarus acherondytes* was collected in this cave in 1965 (1 specimen, J. Holsinger collection) and 1995 (2 INHS). It was not collected here in 1986 or 1993 (Webb 1993).

From water samples collected at Kelly Spring on November 16, 1994, February 24, 1995, May 23, 1995, and August 23, 1995, nitrate nitrogen concentrations ranged from 2.97 to 5.16 ppm, below the USEPAMCL of 10 ppm. A mercury concentration of 0.49 ppb, which was below the USEPAMCL of 2 ppb, was detected in the November sample. The herbicide Atrazine was detected in the November (0.45 ppb), February (0.16 ppb), and August (0.31 ppb) samples but not at concentrations above the USEPAMCL of 3 ppb. The herbicide Metolachlor was detected in the May (0.18 ppb) sample but not at concentrations above the USEPA Health Advisory Level (USEPAHAL) of 100 ppb (USEPA, 1988, 1990, 1991; Schock *et al.* 1992). The herbicides Alachlor and Cyanazine were not detected in any of the water samples.

Table 4. The abundance and habitat of *Gammarus minus* and *G. troglophilus* collected from 2 sites in Madonnaville Cave, Monroe County, Illinois on 25 August 1995.

Habitat Type	Width	Depth	Substrate	*Gammarus minus*	*Gammarus troglophilus*
mainstream riffle	0.75	8 cm	gravel	408	15
mainstream riffle	0.75	5-15 cm	gravel	239	11
			TOTAL	647	26
			%	96.1	3.9

MADONNAVILLE CAVE (MONROE COUNTY)

This cave is smaller than the other caves examined in this study. It passes under an area of upland karst containing woodlands and crops. The entrance, which is also the resurgence of the cave stream, is 1.5 m high and 5 m wide, but then narrows to a passage 1.2 m high and 3 m wide. A cave stream 0.3-0.75 m wide and 5-15 cm deep with a gravel substrate flows down the middle of the passage. The passage runs back some 120 m before the ceiling drops to the level of the streambed.

Fauna: Aquatic organisms recorded from Madonnaville Cave (Webb *et al*. 1993) are Arthropoda: Crustacea: Amphipoda: *Crangonyx forbesi, Gammarus acherondytes, G. minus, G. troglophilus*; Isopoda: *Caecidotea brevicauda*.

In 1995, two sites in this cave were examined for amphipods (Table 4).

Current Status: This cave receives little visitation by humans and no sign of vandalism was evident in 1995. Occasional flooding keeps the cave clean of debris. Following heavy rains, a considerable amount of sediment is flushed through the cave. The biggest threat to this cave is probably from agricultural activity in its drainage basin.

Although a single specimen of *Gammarus acherondytes* was collected in 1986 (Webb 1993) in association with two specimens of *G. troglophilus* and one specimen of *Crangonyx forbesi*, no specimens of *G. acherondytes* were collected among the 673 specimens of amphipods collected in 1995. *Gammarus minus* made up 96% of the specimens collected in 1995. This is the only cave of the five examined in 1995 in which *G. minus* was the dominant species of amphipod. *Gammarus acherondytes* has been collected in this cave only in 1986 (1 specimen, INHS).

In water samples collected at Madonnaville Cave on November 16, 1994; February 24, 1995; May 23, 1995; and August 23, 1995; nitrate nitrogen concentrations ranged from 6.72 to 7.64 ppm, which are below the USEPAMCL of 10 ppm, but are higher than the concentrations found in any of the other caves from which *G. acherondytes* has been reported. The herbicide Alachlor was detected in the May sample at 0.15 ppb, which was below the USEPAMCL of 2 ppb. The herbicide Atrazine was detected in the May (1.74 ppb) and August (0.29 ppb) samples but never at concentrations above USEPAMCL of 3 ppb. The herbicide Metolachlor was detected at 0.37 ppb in the May sample which is below the USEPAHAL of 100 ppb. Mercury and the herbicide Cyanazine were not detected in the water samples.

PAUTLER CAVE (MONROE COUNTY)

The entrance to this cave has been bulldozed shut (Webb *et al. 1993*). The status of *Gammarus acherondytes* in this cave could not be determined. No specimens of *G. acherondytes* have been collected here since 1965 (4 specimens, J. Holsinger collection).

Fauna: Aquatic organisms recorded from Pautler Cave (Hubricht 1941; Holsinger 1972; Hubricht & Mackin 1940; Peck & Lewis, 1978): Arthropoda: Crustacea: Amphipoda: Crangonyctidae: *Crangonyx forbesi.;* Gammaridae: *Gammarus acherondytes, G. troglophilus;* Isopoda: Asellidae: *Caecidotea brevicauda, C. packardi*; Diplopoda: Polydesmida: Nearctodesmidae: *Ergodesmus remingtoni;* Trichopolydesmidae: *Antriadesmus* sp.

STEMLER CAVE (ST. CLAIR COUNTY)

This cave is located in a wooded sinkhole surrounded by farmland and rural residential development (Webb *et al. 1993*). The main entrance is a sinkhole 12 m long by 3 m wide that drops vertically 4.6 m to a breakdown-covered floor by a large stream 1.5-3 m wide and up to 1 m deep. Ten meters upstream the passage sumps. Downstream the passage continues 1-3 m high by 1.5-6 m wide. This cave is 1800 m long (J. Sherrill, personal communication 1996). During one visit (June 25, 1993) shortly after a heavy rain, a strong odor of sewage could be detected 6 m from the entrance sink. There were accumulations of foam 1.2 m in diameter, and the water was murky. During a subsequent visit in 1995, no sewage odor was detected.

Fauna: The aquatic organisms recorded from this cave (Hubricht & Makin 1940; Peck & Lewis 1978; Webb *et al.* 1993) are Platyhelminthes: Turbellaria: *Sphalloplana hubrichti*; Mollusca: Gastropoda: *Fontigens antroecetes* (Hubricht); Arthropoda: Crustacea: Amphipoda: *Bactrurus brachycaudus*, *Crangonyx forbesi*, *Gammarus acherondytes, G. minus, G. troglophilus*; Isopoda: *Caecidotea brevicauda, C. packardi*.

In 1995, five sites in this cave were examined for amphipods (Table 5).

Current Status: This cave receives some human visitation and periodically receives sewage and sediment, particularly during floods. Threats include continued input of sediment, human and animal wastes, and agricultural chemicals.

This cave has a fair diversity of aquatic habitats. Collections were made at five sites in 1995, but no specimens of *Gammarus acherondytes* were among the 561 amphipods collected. Historically, this cave is one of the type localities for *G. acherondytes* and additional specimens were collected in 1965 (numerous specimens, J. Holsinger collection; syntype specimens in USNM). We have seen no *G. acherondytes* collected here since 1965, although sampling was conducted in

Table 5. The abundance and habitat of *Crangonyx forbesi* and *Gammarus troglophilus* collected from 5 sites in Stemler Cave, St. Clair County, Illinois on 25 August 1995.

Habitat Type	Width	Depth	Substrate	*Crangonyx forbesi*	*Gammarus troglophilus*
mainstream riffle	1.8 m	2.5-15 cm	breakdown, bedrock, gravel	65	307
mainstream riffle	1.5 m	2.5-10 cm	breakdown limestone	0	66
mainstream pool	3.7 m	15-45 cm	silt over bedrock	11	88
rivulet	2.5-20 cm	0.3 m	silt over bedrock	1	4
mainstream riffle	2.4-3.1 m	5-15 cm	gravel, breakdown, limestone	1	18
			TOTAL	78	483
			%	13.9	86.1

1993 and 1995.

DISCUSSION

Gammarus acherondytes was originally described from Illinois Caverns and Stemler Cave in Illinois (Hubricht & Mackin 1940). Subsequently (Holsinger 1972; Peck & Lewis 1978) it was collected from Fogelpole, Krueger-Dry Run, and Pautler caves, and later it was reported from Madonnaville Cave (Webb 1993). The entrance to Pautler Cave was bulldozed shut by the landowner (Webb 1993). *Gammarus acherondytes* has been proposed for inclusion on the federal list of endangered and threatened species (U.S. Department of the Interior, Fish & Wildlife Service 1997). In 1992, 1993, and 1995, attempts were made to collect *G. acherondytes* from 80 caves in Illinois and to examine material collected from 84 Illinois caves by Oliver and Graham (1988). *Gammarus acherondytes* specimens collected in the present study include: Fogelpole Cave, 10 (1993) and 19 (1995) specimens; Illinois Caverns, 20 (1992), 1 (1993), and 56 (1995) specimens; Krueger-Dry Run Cave, 2 (1995) specimens; Stemler Cave, 0 (1992, 1993, 1995) specimens; and Madonnaville Cave, 0 (1995) specimens. Although a wide diversity of aquatic habitats were sampled, all specimens of *G. acherondytes* collected were from gravel riffles in the mainstream (87% [94 specimens]) or side passage streams (13% [14 specimens]).

Gammarus acherondytes was generally found in association with *G. troglophilus* and *Crangonyx forbesi*. *Gammarus troglophilus* was the most abundant amphipod in subterranean streams of the Salem Plateau Section of Illinois, generally followed by *C. forbesi*. Exceptions include Illinois Caverns, where *G. acherondytes* was the second most abundant amphipod collected, and Madonnaville Cave where *G. minus* was the most abundant species of amphipod. *Gammarus minus* has been shown to be a predator of other amphipods (MacNeil *et al.* 1997; Jenio 1972, 1979; Culver & Fong 1991), and Fong and Culver (1994) suggest that predation by *G. minus* may account for the absence of the isopod *Caecidotea holsingeri* (Steeves) (a know prey species for *G. minus*) and the amphipod *Stygobromus spinosus* Holsinger from parts of a West Virginia cave system.

Gammarus acherondytes appears to be well established in Fogelpole and Illinois Caverns. It is particularly interesting that in Illinois Caverns, *G. acherondytes* was collected only in the mainstream, an area that receives considerable disturbance from the many visitors that annually walk through this cave stream. In Krueger-Dry Run Cave, *G. acherondytes* was not collected in 1993, but a small population was present in 1995. No specimens of *G. acherondytes* have been collected in Stemler Cave since 1965, even though *G. troglophilus* and *C. forbesi* are abundant. A single specimen of *G. acherondytes* was collected in Madonnaville Cave in 1986, but no specimens were collected in 1995, even though other amphipods were abundant.

Surface runoff of sediments and pesticides are the principal threats to the general well-being of *Gammarus acherondytes* populations in the cave streams of Monroe and St. Clair counties. During periods of heavy rains, cave streams in these counties become very turbid and loaded with silt. In addition, nitrate nitrogen can generally be detected every month of the year from the groundwater in this karst region, and is often at levels above USEPAMCLs (Panno *et al.* 1996; Webb *et al*. 1993, 1996). Similarly, the herbicides Alachlor, Atrazine, Cyanazine, and Metolachlor were detected during various months, occasionally above USEPAMCLs or USEPAHALs (Panno *et al.* 1996; Webb *et al*. 1993, 1996). Mercury is not often detected in groundwater samples from this region, but evidence of its accumulation to concentrations of 658 ppb was found in bioassays of amphipods collected from Fogelpole Cave.

Another threat to the amphipods of Monroe and St. Clair counties is the rapid increase in residential development. There is concern that this situation may lead to increase in raw sewage input into cave streams, which typically results in degradation of natural cave communities and the replacement of troglobitic species by more opportunistic troglophiles. Panno *et al.* (1996), in a study of groundwater contamination in the karst terrain of Monroe County, found that in nine springs and one cave stream (Illinois Caverns) all water samples collected contained coliform, fecal coliform, total (aerobic) bacteria, and other types of bacteria. The species present suggested that the bacteria were from both human and livestock sources. All of their water samples from the nine springs and the one cave stream exceeded the drinking water standard of less than one colony of coliform and fecal coliform bacteria/100 mL of water. They document a rapid increase in coliform bacteria from 1987-1995 in Monroe County well water samples, and attribute this increase to the increase in residential development in the county. Panno *et al.* (1997) suggest that a significant portion of the bacterial contamination of this karst aquifer may come from private septic systems. The detection of sewage at Stemler Cave, the abundant population of *Gammarus minor* at Madonnaville Cave, and the absence of *G. acherondytes* from both sites in the 1990s suggest that this type of habitat degradation may already be taking place. The apparently healthy populations of *G. acherondytes* at Illinois Caverns, the most frequently visited of the caves in this study, suggests that human visitation is not adversely affecting populations of this species.

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SELECTED ABSTRACTS FROM THE 1998 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN SEWANEE, TENNESSEE

BAT CONSERVATION INTERNATIONAL SESSION

COOPERATIVE IDENTIFICATION AND CONSERVATION OF ENDANGERED BAT CAVES IN TENNESSEE

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Since 1995, The Nature Conservancy (TNC), Tennessee Field Office has conducted its Tennessee Caves Initiative to identify and protect critical endangered bat caves across the state. By collecting information from cave, bat, and herpetological experts representing over a dozen organizations and agencies, TNC began the process by ranking caves in need of protection according to each site's rare species, threats, and current landowner situations. The resulting list of highly threatened caves is now used by TNC for prioritizing ecological site mapping, landowner outreach and education, and the ensuing obtainment of management agreements, conservation easements, and/or outright purchases of biologically significant caves. The cooperation and enthusiasm of other nonprofit groups, state and federal agencies and local grottos have been key to the initiative's success.

BAT CONSERVATION AND MANAGEMENT IN PENNSYLVANIA

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Pennsylvania has maintained an active program of bat conservation, management and education since about 1985. Surveys are conducted during the winter in caves, mines, and abandoned tunnels to assess the overwintering population of bats. Twelve sites have been designated as monitoring sites, and surveys are conducted annually or semi-annually. Several hundred additional sites have been surveyed 1 - 3 times each. A few of the most important caves and mines have been gated. These typically have had an increase in bat populations and, in one case, Indiana bats have re-colonized a historic site. Harp trapping at cave and mine entrances has produced two new locations of the Indiana bat as well. Summer work includes maternity roost surveys, mist netting, bat house construction and monitoring, and the purchase of a church that is home to over 15,000 little brown bats and at least a few Indiana bats. Much bat house experimentation and development has taken place. Of the 33 bat houses currently monitored, 30 are being used by bats. A "Bat Condo" was constructed, which may hold over 4000 bats at capacity, and in 1997 over 700 bats were using it. A second Bat Condo was constructed in 1998. Pennsylvania has also been working in cooperation with Bat Conservation International for the past four years, hosting 2 one-week seminars each fall. These seminars offer hands-on instruction, and have been attended by people from across the United States.

ON-GOING SURVEY OF PAST BAT USAGE AT MAMMOTH CAVE, MAMMOTH CAVE NATIONAL PARK, KENTUCKY

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The past usage of Mammoth Cave by bats is of considerable interest from the standpoints of bat conservation, cave management, paleontological resource protection, paleoecology, biogeography, and interpretation. This interest has led to a cooperative project between the Illinois State Museum and Mammoth Cave National Park that seeks to document past usage by inventorying and analyzing bat remains and signs of bat utilization in the cave. We are in the first year of the project.

The inventory has focused on areas near the Historic entrance of the cave and along one of the main tour routes. During the inventory, museum personnel and volunteers identify, evaluate, map, and photograph bat remains. In addition, some remains are being dated in order to help understand temporal patterns of bat usage. Preliminary work has documented that a larger variety of bat species used the cave in the past. In addition, our analysis has confirmed historic accounts that indicated much more intense bat usage of the cave before major modification by historic activities.

The project continues and will make contributions to the following efforts: 1) understanding the effects of entrance and passage modification, 2) mitigating modification effects, and 3) re-establishing colonial usage of the cave by some bat species.

BAT CAVE MANAGEMENT IN MISSOURI

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The Missouri Department of Conservation (MDC) and other agencies became more involved in bat cave management in the late 1970s after the failed attempt by the U.S. Army Corps of Engineers to construct the Meramec Lake. This proposed reservoir would have flooded numerous bat caves harboring Indiana and gray bats. In the 1980s, MDC began to acquire critical bat roosts for protection of hibernating Indiana and gray bats and maternity colonies of grays. Various types of gates, fences, monitoring, and management plans have been tried and modified. Large half gates for gray bats have been successful usually, but Indiana bats are generally declining despite good gates. Ozark big-eared bats are now thought to be absent from the state, but one caver has made a possible sighting in southern Missouri. Temperature and light data loggers are used in some caves.

INFRARED PHOTO-MONITORING OF MEXICAN FREE-TAILED BATS ROOSTING IN CARLSBAD CAVERN

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Carlsbad Cavern hosts a colony of several hundred thousand Mexican free-tailed bats (*Tadarida brasiliensis mexicana*). Investigators have estimated bat colony size using a variety of methods ranging from gross ocular counts, to video and still photography. However, few methods have provided a measure of statistical precision. Colony size, roost geography, repeatability of methods, and cost efficiency are all concerns when determining appropriate methods for estimating abundance. Investigators and managers need a variety of procedures to choose from so that consistent and useable data can be obtained. This inventory and monitoring method involves taking repeated infrared photographs from fixed points under the roost. Colony size is then estimated from the area of cave ceiling covered by bats. The development of reflective infrared photo-monitoring has provided a means of estimating colony size and assessing long-term trends at Carlsbad Caverns National Park.

BIOLOGY SESSION

THE CAVE FAUNA OF MISSOURI

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Missouri has at least 5,600 caves containing more than 400 recorded species. Important populations of two cave crayfish and endangered Indiana bats, gray bats, and Ozark cave fish occur in the southern part of the state. Gardner systematically reported on the fauna of 436 caves and 10 springs in 1986. Craig, Hubricht, Lewis, Martin, Nicholas, Pflieger, Sutton, and others have added to the state fauna list. To date, at least 39 troglobitic species have been identified, but many more probably will be found as more invertebrates are sampled. Accurate identification of species as troglophiles or troglobites depends on good biogeographic and taxonomic data. The declining pool of invertebrate taxonomists has made the basic task of identification and description more difficult.

SNAPSHOTS OF SUBTERRANEAN BIODIVERSITY: 1888, 1960, AND 1997

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In 1888, A.S. Packard gave a complete list of known stygobites and troglobites, with their distribution. Brother Nicholas Sullivan did the same in 1960, as did Hobbs and Culver in 1997. In 1888, 13 counties were reported as having at least one obligate cave species. In 1960, this number was 176, and in 1997 it was 630, ~ 20% of all U.S. counties. Mean number of species, due to more counties with at least one species, actually declined from a high of 6.7 in 1888 to 4.7 in 1997. Overall, the distribution became more skewed with time. An analysis of the 13 counties known to have an obligate subterranean species in 1888 declined to 3.8 in 1960 and rose to 11.6 in 1997. The original decline was the result of Packard's tendency to believe every cave inhabitant was cave-limited. Nowhere was this more pronounced than in Mammoth Cave.

PRELIMINARY REPORT ON THE BIOLOGY OF CUEVA DE VILLA LUZ, TABASCO, MEXICO

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We present a preliminary overview of the biology of Cueva de Villa Luz in Tapijulapa, Tabasco, Mexico. Much of the cave is a stream passage,the water milky-white with sulfur. Many passages in the cave have very high levels of H_2S, varying from 0 to 57-127 ppm. Most passages were above 10 ppm. The pH of the environment was generally more acidic than typically found in a limestone cave. Exceptionally low pHs were associated with"snottites" or microbial veils (pH 0.3-0.7), and in one area we identified a deposit of bat guano mixed with gypsum paste which had a pH of 0.0. Sulfate-reducing bacteria were present in very high numbers (105-106 +) in all sediments. Coliform bacteria survived in the mainstream passage, but were not detected in springs entering the cave. Microbial involvement is evident in the formation of white filaments in the cave stream and in microbial veils suspended from gypsum, possibly in association with webs of spiders or fungus gnats. The most abundant organisms are the midges, *Tendipes fulvipilus*, which are the main prey for the molly, *Poecilia sphaenops*, which consumes both the aquatic larvae and adults. The fish are in turn preyed upon by a hemipteran (not identified). There was a very high density of predatory invertebrates throughout the cave, particularly spiders, fungus gnat larvae, and amblypygids. We found little evidence for terrestrial troglobites, with the possible exception of a spider and nematodes found in highly acidic vermiculations.

DISTRIBUTION AND ABUNDANCE OF CAVE CRICKETS IN MAMMOTH CAVE NATIONAL PARK DUE TO WEATHER FROM 1995 TO 1997 AND ENTRANCE RETROFITTING IN 1996

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Five out of 9 entrances were retrofitted in 1996 to stop air movement. Two of these entrances had existing steel doors that slowed air movement and 2 had antiquated open gates. All retrofitted entrances incorporated exit/entry tubes for animal movement in their designs. We censused 4 to 16 10-m transects, depending on cave size and decline in animal abundance away from the entrance, 2-4 times per year in 1995 and 1996 and bimonthly in 1996-1997. Except for one cave, where the positions and lengths of the exit tubes were not conducive to cave cricket use, there were no negative effects of retrofitting on animals other than pipistrelles. Air movement, but not winter temperature gradient, was also eliminated with the retrofits. There was a slow increase in cave cricket numbers from 1995 through 1997 correlated with short-term winter weather but not with average or extreme monthly temperatures. From 1995 to 1997 there were fewer and shorter periods with temperatures remaining below 5°C and more short respites of 2-3 days when temperatures remained above 10°C due to light rain. On these favorable nights, after many days or even weeks with no foraging, cave crickets exited in synchrony and foraged in large numbers. In summer there were no temperature constraints and cave crickets exited every night. Exiting was asynchronous with the usual 9-12 days between the summer foraging bouts.

CAVE CRICKETS AT MAMMOTH CAVE NATIONAL PARK: YOU ARE WHAT YOU EAT

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What do cave crickets eat? In aquaria with single food types, crickets do not gain weight on partially decomposed leaf litter with fungal hyphae, moss, lichens, leaves, or live earthworms and other litter organisms. Crickets gain 5-35% of crop empty live weight (CELW) on overripe fruit, fresh mushrooms, and deer fecal pellets. Crickets gain 70-120% of CELW on rotting mushrooms. But, crickets gain 100-250% of CELW on both our 'high quality' canned cat food baits and 'low quality' wet cereal or metamucil mush that they readily locate in the field. The mystery is that high quality foods seem to be rare in the field whether we use extensive walking surveys of mushrooms and deer pellets or intensive 1 m^2 searches for mouse and invertebrate feces or small carrion. Nonetheless, crickets gain as much weight foraging on natural foods as they do when feeding on our artificial bait patches. Certainly crickets are better at finding quality items than we are, using their acute olfactory senses. However, the low Na/K ratios and low caloric density of their crop contents suggests they are not getting much carrion, even though we have seen them quickly locate and carry off horseflies killed at cave entrances.

CORROSION RESIDUES FROM LECHUGUILLA CAVE: COZY HOME OR LIVING HELL FOR MICROBES?

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Many ceiling and wall areas of Lechuguilla Cave, New Mexico, exhibit deposits called "corrosion residues'' (CRs) which appear to be breakdown products of several minerals. These CRs may be colored black, gray, pink, orange, red, or ocher and are distributed throughout the cave. Geologists have hypothesized that Lechuguilla's extensive CRs are the long-term result of upwelling corrosive air. Using enrichment cultures and Scanning Electron Microscopy, Cunningham and Northup discovered extensive bacterial and fungal communities in CRs. Preliminary evidence, including the presence of presumptive bacterial filaments in pits in the wall rock underlying CRs, implies that microorganisms may play an active role in corrosion of parent rock. Potentially, microorganisms could oxidize reduced compounds from the atmosphere or wall rock. The resulting acidity and other redox effects could consequently degrade the rock substrate. Our molecular phylogenetic studies are identifying the nature of this microbial community. Energy Dispersive X-Ray (EDX) analyses of these residues and underlying wall rock reveals the presence of a heterogeneous makeup including the presence of iron and manganese oxides, as previously shown by Cunningham, along with phosphorus, clays, and sulfur. We have also identified rare earth elements, probably associated with apatite in the original limestone, and vanadium in some of the CRs. We are investigating the possible association of these potential inorganic energy sources with microorganisms present.

PHYLOGENETIC ANALYSIS OF BACTERIAL COMMUNITIES ISOLATED FROM FOUR WINDOWS CAVE: ARE THEY ACTINOMYCETES?

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Silvery clusters of bacteria pepper the limestone walls of Four Windows Cave in El Malpais National Monument, New Mexico. In an effort to identify the types of bacteria in these colonies, we have utilized techniques developed at Los Alamos National Laboratory to extract DNA from colonies on wall rock. From this DNA, we utilized polymerase chain reaction (PCR) amplification and cloning to generate a library of 16S ribosomal RNA gene (rDNA) clones of the organisms present. Comparison of rDNA sequences from 30 of the clones with sequences available in the Ribosomal Database Project (RDP) revealed considerable genetic diversity. Many sequences were most closely related to those of actinomycetes, including *Actinosynnema*, *Nocardia* and *Frankia* sp., while some clones show relatedness to rDNAs of unknown organisms recovered from soils. Actinomycetes are a group of related bacteria that produce filaments during their development. These bacteria break down complex organic matter and thrive in environments where nutrients are sparse and conditions extreme. This description fits well the phenotype and habitat of this sample community.

SPECIAL BIOLOGY SYMPOSIUM: *New Frontiers of Biospeleology*

The Cave Loaches of Thailand: Phylogenetic Relationships Among Populations and Species

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Five of the seven known cave fishes in Thailand are balitorid river loaches, a family common in the surface waters. The evolutionary relationships among species and genera in this family are unknown. Samples of the five troglobitic and 20 epigean Thai balitorids are under study using DNA fingerprint markers generated with AP-PCR techniques. AP-PCR data show genetic relatedness of populations and species and will be used to reconstruct the phylogenetic relationships of the Thai species and to study their population genetics. All eight cave populations studied (including species of *Schistura, Noemacheilus* and ("*Homaloptera*") have lower genetic variation than populations of surface balitorids, reflecting their isolation and reduced effective population sizes. Inter-populational variations among four populations of *Schisturaoedipus* from Mae Hong Son were also studied. Although the four cave systems are isolated from one another, the populations are genetically similar, suggesting gene flow among populations, perhaps through surface waters. The waterfall climbing cave leach, *Homaloptera thamicola,* is clearly different from *H. zollingeri* and *H. smithi* at the level of DNA fingerprint, and probably incorrectly placed in *Homaloptera*. In fact, it does not closely resemble any of the six genera examined. A new cave fish of uncertain relationship from Tham Phra Wang Daeng, near Phitsanoluk, was examined. It clusters more closely with *Schistura* rather than *Noemacheilus*.

Biospeleology as the Basis of Groundwater Management

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Current research using new techniques in microscopy and mass spectrometry have allowed an Ozark cave stream ecosystem (Cave Springs Cave, Arkansas) to be described fully for the first time, enabling better management practices for the recovery of the threatened Ozark cave fish (*Amblyopsis rosae*). The use of direct counts of microbial abundance by epifluourescence microscopy allows a good estimate to be made of total numbers of viable microbial cells in an aquatic ecosystem. Thus, the microbial community may be used as a bio-indicator of disturbance, especially in the form of organic loadings or intoxication. Furthermore, microbial biomass may be estimated from this technique, allowing a more complete carbon budget to be made or measurements of the bio-availability of organics present. The use of stable isotope assays allow a cave food web to be described completely, can determine which organic matter source (guano, agricultural waste, etc.) feeds the food web, and can identify pollution sources. Dye tracing, water-table contouring, photo-lineament studies, and other hydrogeologic methods have determined the recharge area for this cave stream, and the use of a geographical information system (GIS) has enabled a visual as well as statistical synthesis of the information relating to this spring complex. Once a groundwater ecosystem has been fully described, including energy and organic matter flux, trophic relationships, hydrogeologic characteristics, pollution threats, etc., it can be monitored and managed as an entire ecosystem.

Molecular Phylogenetic Characterization of Unusual Microbial Communities Associated with Corrosion Residues from Lechuguilla Cave

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In order to more fully characterize the microbial community associated with corrosion residues (CRs), we are utilizing molecular phylogenetic techniques to avoid sampling biases introduced by enrichment cultures. Using techniques developed at Los Alamos National Laboratory for soil, we have extracted DNA from CR samples from Lechuguilla Cave. Polymerase chain reaction (PCR) amplification of extracted DNA with primers specific for small subunit ribosomal RNA genes indicates the presence of bacteria, Archaea and Eucarya in both CRs. We have begun to analyze a clone library generated from these PCR products. A restriction fragment length polymorphism (RFLP) analysis of 16 clones from this extracted DNA demonstrated that 14 of 16 clones were unique, revealing the existence of a diverse microbial community. Preliminary results from the phylogenetic analysis of the small-subunit ribosomal RNA (rRNA) gene from two clones showed that the nearest relatives of one clone are *Crenarchaeota*. The existence of this type of low-temperature Archaea has only been discovered in the last five years. Little is known about the metabolic properties of these Archaea due to the present inability to culture them. The other sequenced clone's closest relatives are gram positive bacteria. Both sequences are very dissimilar (less than 0.5 similarity, 0-1.0 scale) to any other known 16S rDNA sequences.

Primary Productivity Estimates from a Chemoautotrophic Microbial Community in Movile Cave, Romania

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Since its inception, the Movile Cave Project has focused primarily on describing ecosystem energy and organic carbon sources. Previous research has documented microbial chemolithoautotrophy as the energetic base of the diverse and abundant invertebrate food web in Movile Cave. Preliminary studies show that the microbial community contains sulfide-oxidizing, sulfate-reducing, methanotrophic, and heterotrophic bacteria. Current research is based on constructing an ecosystem energy budget by quantifying energy flow within the food web. As a first approximation of energy flow, primary productivity of the microbial community was examined. To estimate primary productivity in Movile Cave, time-course incorporation experiments were conducted using [^{14}C] bicarbonate as a radiolabeled inorganic substrate. Preliminary results indicate that primary productivity in Movile Cave (~129.3 g C/m^2/yr) is similar to published values for the open ocean and mesotrophic lakes, but is an order of magnitude greater than values estimated for deep-sea hydrothermal vents. Productivity estimates will be used in constructing a complete carbon budget for the Movile Cave microbial community. Continuing experiments focus on estimating microbial respiration and excretion.

Cave Crickets at Mammoth Cave National Park: Source and Sink Population Dynamics

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Congruent increases in population size among nine entrances from 1995 to 1997 suggest that cave crickets inside Mammoth Cave National Park do not exist as a meta-population. Great differences in relative abundance of four size classes of crickets shows that there are both source and sink populations. In clear source entrances (3 out of 9 censused) small sizes are much more abundant than adults, so populations are increasing. But all other entrances (6 out of 9 censused) are sinks where adults outnumber or greatly out number small size classes. These populations are presumably maintained by immigration from sources. There was no correlation between population size and source entrances. The source entrances have some but not all of the following attributes: 1) close proximity of entrance roosts to reproductive areas; 2) ceiling pocket refuges from winter influxes of cold, dry air just inside the entrance; and 3) mesic summer microclimate with presumed better foraging opportunities in sinkholes and/or late successional forest outside the entrance.

Hawaii's Lava Tubes: Natural Laboratories for the Study of Evolution and Lineage Diversification in Troglobites

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This project utilizes molecular population genetics data coupled with behavioral and geological information to elucidate patterns of speciation and relationships between populations in the cave-adapted plant hopper species complex *Oliarus polyphemus*. This species complex on the island of Hawaii occupies lava tubes in volcanically active regions of the island. As a result of its volcanic habitat, *O. polyphemus* populations have undergone repeated expansion, contraction, and isolation events during their relatively short history on the island. Preliminary information has demonstrated significant differences in the mating calls of geographically close populations. While this behavioral information clearly demonstrates significant divergence between populations, it cannot distinguish the historical relationships of populations to one another. My work, therefore, uses genetic data to determine basic parameters of gene flow and to construct an intraspecific cladistic network in order to clarify the relationships of the populations. Genetic data (including sequence data and AFLP's) are being used to test the hypothesis that *O. polyphemus* is not limited to humanly accessible caves, but is distributed continuously throughout the millions of tiny voids in the lava substrate. This analysis will also help to better understand how habitat fragmentations have influenced the evolutionary history of *O. polyphemus*. Finally, this genetic information, when coupled with song data, can address basic issues of species status in the *O. polyphemus* complex. Because the identification of unique populations of *O. polyphemus* is likely to reflect similar patterns in other cave and surface organisms, conclusions of this study will identify crucial biological regions for conservation efforts.

SPATIAL AND TEMPORAL PATTERNS OF CARBON, NUTRIENT AND MICROBIAL TRANSPORT IN A KARST AQUIFER

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Aquifer physical structure and water flow patterns constrain energy input and distribution in karst groundwater ecosystems. Consequently, carbon availability and microbial biofilms may vary spatially by aquifer structural zone and temporally with hydrologic stage. To test this, we examined carbon and bacterial flux from aquifer input to output during two months in the Dorvan-Cleyzieu aquifer, France. Both months included low water followed by one or more floods. Dissolved organic carbon increased from input to output ($p<0.01$) but did not vary temporally ($p>0.05$). In contrast, microbial drift and activity (respiratory and hydrolytic) were not significantly different between structural zones ($p>0.05$), but changed significantly over time ($p<0.001$). In all zones, during initial floods total bacterial drift was high (86-130 x 10^3 bacteria/ml) then decreased during flood recession (24-32 x 10^3 bacteria/ml). Conversely, respiring bacterial drift was low at the peak of the first flood (5-17 x 10^3 bacteria/ml) then increased during flood recession (10-26 x 10^3 bacteria/ml). Although initial floods after low water caused consistent changes in microbial drift, the drift patterns differed between structural zones during subsequent floods.

SPECIAL BIOLOGY SYMPOSIUM: *Taxonomy and Systematics of Cave Organisms in the 21st Century: A Look Ahead*

PROGRESS IN CAVE COLLEMBOLAN TAXONOMY AND BIOGEOGRAPHY IN THE NEXT 30 YEARS

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Cave biogeography has a great need for more knowledge concerning the phylogeny of cave Collembola and the relationship between this and the microgeographic distribution of species. What will biospeleological Collembola taxonomy be like in the next 30 years? Various scenarios come to mind and I shall present two extremes. 1) General funding for taxonomy increases as the biological community realizes that this is the essential first step for any ecological or evolutionary analysis. This combined with relatively cheap and easily used molecular techniques, as well as increased facility in using computer scanning techniques for taxonomic analysis, results in a melding of genetic, morphological and behavioral information to develop a new sound and widely accepted picture of cave species as groups of evolutionarily and genetically united taxa. 2) Funding for taxonomy continues to focus more and more on genetic studies. Eventually this leads to a relatively static or diminishing knowledge of alpha and beta taxonomy of many groups such as Collembola. At the same time there is a much greater facility for genetic analyses and funding for such studies. The inability to match this information with troglomorphic features leads to a characterization of cave populations solely on the basis of genetic structure and the move towards abandoning of binomial nomenclature in favor of characterization of populations and eventually species as clusters of genetic formulae, stored and analyzed in computers. The result is a diminished interest in cave microarthropods such as Collembola as model systems for evolutionary and ecological study.

MAPPING BIODIVERSITY OF CAVE ORGANISMS

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Protection and education about cave organisms can best come about with a detailed understanding of their distribution. An ongoing project, in conjunction with The Nature Conservancy, aims to provide a list of cave-limited species, by county. Data on more than 1,000 species and subspecies are included in the database. Analysis of patterns suggests that the biggest gap in our knowledge is for non-cave subsurface habitats, especially small-cavity habitats such as the underflow of rivers. These species comprise less than 10% of the aquatic fauna. In Europe, they are often the majority. Most geographic areas are well covered, but data for the Ozarks, especially Arkansas, are not as complete as elsewhere. While counties are not a natural boundary, most data are listed by county, rather than by drainage basin. Lists by cave, while obviously more detailed, are more difficult to map.

SPECIES AND SPECIATION IN CAVE ANIMALS

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Animals with long evolutionary histories in caves share a morphological syndrome termed troglomorphy. The troglomorphic pattern includes reduced or lost features, such as eyes and pigmentation, and elaborated features, most notably enhanced extra-optic sensory structures and elongated appendages. The fact that the troglomorphic pattern is shared by distantly related taxa (e. g., cave-dwelling vertebrates and invertebrates) and by similar but geographically distant taxa (e. g., cave-dwelling carabid beetles of Europe and North America) suggests that troglomorphy is a consequence of a considerable amount of parallel and convergent evolution. Convergence and parallelism provide difficulties for systematists because features that have evolved in this manner do not reflect shared evolutionary history. In fact, phylogenetic studies using biochemical and molecular characters have shown that populations presumed to be conspecific on the basis of morphological features are actually much more distantly related. This raises the possibility that convergence and parallelism may be important processes even on very local geographic scales, and that many presumptive cave species may in fact be species complexes, despite being morphologically very similar. Genetic data on several cave inhabiting species, including the cave fish *Typhlichthys subterraneus*, the amphipod *Gammarus minus* and several species of trechine carabid beetles indicate substantial differentiation among populations deemed conspecific on morphological grounds. These data clearly indicate lack of gene flow among these populations and are at least consistent with the view that the evolution of troglomorphic features within these supposed species may be polyphyletic.

THE FUTURE FOR CAVE FISHES

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The first cave dwelling fish was discovered in the 1820s and the first named species(*Amblyopsis spelaea*) was described from Mammoth Cave in 1842. Since then, cave fishes have been discovered in 27 countries world wide and there are now 79 described species. What will happen to these in the next few decades and how might these numbers change? It seems certain that the number of known species will increase. In 1960 there were 27 species, 1970 (35), 1980 (39), and 1990 (59) and in 1998 (79). If this rate of discovery remains constant there will be 85 species by 2000, 125 by 2010 and 200 by 2020. At the same time, it is possible that known species will become extinct.

Three species (*Clarias cavernicola*, Namibia; *Speoplatyrhinus poulsoni*, USA; *Glossogobius ankaranensis*, Madagascar) are assessed as critically endangered by IUCN. Two are assessed as endangered (*Prietella phreatophila* and *Ophisternon infernale*, both in Mexico) and no less than 46 as vulnerable. This is 63% of all known species. One of the critical needs of the next few years, therefore, is for conservation assessments so that conservation effort is directed to the right places. A central plank of this must be accurate population assessment. A second will be an examination of the molecular genetics of demes.

Over 50% of all known species are from only five countries (China, Mexico, Brazil, USA and Thailand) and in all of these, human population pressure will continue to increase.

TAXONOMIC GAPS AMONG CAVE-DWELLING MILLIPEDS (SPEODESMUS) AND MITES (RHAGIDIIDAE), WITH NOTES ON THINGS THAT AREN'T

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The polydesmoid genus, *Speodesmus*, which is troglobitic, contains four described species from Texas, New Mexico, and Colorado. At least six new species in two species groups are known from Central Texas, and new populations have been found in West Texas and Utah. Numerous genera and species of cavernicolous rhagidiids are known from caves in the USA and Mexico. Some of the populations are relicts of arctic and boreal litter-dwelling ancestors, but there are unexplained gaps in Texas and other cave areas. Other arthropod groups are inexplicably scarce or absence from regional cave faunas in the USA; two examples are rhaphidophorid crickets in California and carabid beetles in Missouri.

A LIMITED INVENTORY OF INVERTEBRATE CAVE FAUNA OF COLORADO

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Finding little information on the cave fauna of Colorado, arrangements were made to inventory the invertebrate cave fauna in some Colorado caves before, during, and after the 1996 NSS Convention in Salida, CO. Collections were made in 6 of 7 caves visited in Williams Canyon in El Paso County, Canon City area of Fremont County, and the White River Plateau in Garfield and Rio Blanco Counties.

Taxa collected included amphipods, beetles, book lice, centipedes, copepods, diplurans, harvestmen, millipeds, mites, pseudoscorpions, spiders, and springtails. Preliminary identifications indicate that the collections included new species of amphipods, diplurans, millipeds, pseudoscorpions, springtails, and possibly a spider. The most significant discovery was two specimens of a minute, troglobitic chordeumatid milliped from Spring Cave, Rio Blanco County. Initially they were thought to represent a new family of milliped, until further study revealed critical anatomical details and they were assigned to the Family Tingupidae. *Blancosoma scaturgo* Shear and Hubbard, 1998 was described as a new genus and a new species. Results of this limited cave inventory indicate a diverse and significant invertebrate cave fauna exists in the caves of Colorado.

CONSERVATION AND RESTORATION SESSION

THE GOOD, THE BAD, AND THE UGLY: MICROBIAL LIFE IN CAVES

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Microbes. Who ARE these annoying, invisible little things? Why are we making such a fuss about them? How do they fit into the normal world of the caver? The admittedly complex answers to these questions can be simplified for, understood by, and dealt with by cavers armed with a little knowledge and a little caution.

First, we consider the Good Microbes, those fascinating tiny bits of life that can live in weird places and eat weird things. In their minuscule bodies, they contain the promise of an immense wealth of biological insight that has biologists enraptured.

Secondly, we will turn our attention to the Bad Microbes. These guys (known commonly as "germs") can and do make us sick. They have been the companions of humans for a very long time, and we bring them into caves ourselves. Who are they and what can we do about them?

Lastly, we will examine the murky realm of the Ugly Microbes. These organisms are native to caves and they MIGHT be able to make us VERY sick. Cavers already know about histoplasmosis. What about caves as a source of "new," really nasty emerging diseases like Ebola virus? Should we be alarmed? Should we ignore the whole issue?

THE USE OF INVENTORY DATA AS A TOOL FOR PLANNING CAVE RESTORATION PROJECTS

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Inventory is a useful tool for identifying and locating important features in a cave prior to commencing a restoration project. Inventory is used to catalog geological, mineralogical, paleontological, speleogenetic, biological and archeological information, as well as assessing the impacts of human use. Inventory data, coupled with photographic monitoring, can be collected at selected survey stations to keep track of changes to the cave caused by use over time.

The following steps may be required prior to commencing restoration. 1.) Survey the cave prior to gathering inventory information. This is true in caves that have never been surveyed, or where stations from previous surveys cannot be recognized. When conducting a survey prior to an inventory and restoration project, it is desirable to place unobtrusive permanent survey markers to facilitate later work. 2.) Collect a comprehensive list of important features during a scientific reconnaissance of the cave. 3.) Record a list of features by category on reproducible pages that will fit in a survey notebook. 4.) A team visits the area to be restored and uses the notebook pages to record all features near each survey station. 5.) Inventory data is plotted on a map of the area to be restored for use as a training and planning tool.

Inventory data should be archived. The use of computer database management software simplifies this process, particularly when the data can be coupled with cave mapping software. Using the computer simplifies the storage and manipulation of survey and inventory information, and provides a format for monitoring changes to the cave.

PROBLEMS WITH THE FCRPA IN UTAH AND NEVADA

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Lack of continuity and communication has recently caused the cave management successors to the Forest Service in Utah to reveal the nature and location of caves to people walking into the office from off the street. The cave information was given to the Forest Service only because of the Federal Cave Resource Protection Act (FCRPA).

In Nevada, one huge BLM district with many very significant caves has declined to implement any protection to the caves as provided by the FCRPA. The District has no cave management plan. Cave file information is not kept confidential. New, very sensitive discoveries desperately need attention by the land managers but cavers are reluctant to get involved with them under present circumstances.

EEEK!! I KILLED A MICROBE: CONFESSIONS OF A CAVE EXPLORER

Diana E. Northup, Biology Department, University of New Mexico

Recent studies of microbial populations in Lechuguilla Cave (New Mexico, USA) and Cueva de Villa Luz (Tabasco, Mexico) are demonstrating the rich potential for identifying new microbial species in caves. In both caves we find abundant microbial habitats, secondary mineral deposits of iron or manganese oxides, sulfur deposits, and, in Lechuguilla, pristine pools. When people enter caves, we introduce exotic organisms. More importantly, in caves lacking extensive organic nutrients, we leave behind organic matter in the form of skin, hair, urine, lint, and feces. Exotic microbes and organic carbons, plus physical damage such as soil compaction or introduction of contaminants from agriculture and other human activities, can compromise and damage microbial communities in caves. A case study of human impact in Lechuguilla Cave has shown that impact on microbial communities can be minimized.

IMPACT MAPPING: TECHNIQUE FOR IMPACT INVENTORY

Jerry Trout, USFS National Cave Coordinator

Impact mapping can be an effective means of documenting specific cave damage for inventory and monitoring purposes. Impact maps can be useful conservation tools for cave managers; they can provide valuable data for making decisions concerning acceptable limits of change, numbers of permits or visitors, areas in need of restoration, areas that might be defined as off-limits, and areas that show no appreciable change. Once accomplished, impact maps can be easily updated to record changes in the condition of the cave.

KARST HYDROLOGY IN CAVE PROTECTION AND RESTORATION

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Hydrologic protection of caves requires at least a basic understanding of how the caves in question have formed, and of the drainage area from which they capture water. Caves develop from a variety of processes and conditions such as in sinking streams, by backflooding, from rising hydrogen sulfide gases, and from rapidly-flowing to nearly-ponded waters. Knowledge of a cave's origin is critical in projecting its probable extent beyond the limits of exploration, and also into unexplorable micro-conduits and enlarged fractures. This insight in turn is critical to estimating the cave's drainage area. Dye tracing is a powerful tool in drainage basin delineation, yet it may not be feasible in some cases. Then the basin must be estimated based on the cave's hydrogeologic origin.

Cavers usually do a fine job protecting cave hydrologic systems from pollutants within the caves. Cavers clean trash from inside caves and entrance sinkholes. Feces and urine are often removed and low-impact methods are used to remove graffiti and algae. However, in many cases, caves are adversely impacted far more by outside activities in their drainage basins. Cavers must develop locally effective methods of protecting and restoring caves from rural impacts such as feedlot runoff, pesticides, fertilizers, and septic systems, and from urban impacts like roadway runoff, sewer leaks, leaking underground storage tanks, and sedimentation from construction projects. Close cooperation with land owners and regulatory agencies will often be needed.

EXPLORATION SESSION: UNITED STATES

HISTORY OF EXPLORATION AND SURVEY IN HURRICANE CAVE, DADE COUNTY, GEORGIA

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Hurricane Cave, Dade County, Georgia has a long history of exploration and survey. Since Hurricane Cave's first known exploration in 1964, there have always been indications that it had additional potential. Its name is derived from the rush of air that often issues from the Air Chute, a body sized hole that stopped the original explorers. Virgin passage had been left for years because of the grimness of the Air Chute and the passages beyond. During the late 1980s, some of the passages beyond the Air Chute were explored and mapped. But it wasn't until the mid-1990s, during a re-survey of the cave, that almost a third of the currently known passages in Hurricane Cave were discovered. Recent discoveries have helped better understand the relation of this cave to other smaller caves on the mountain. As of April 1998, the cave had 2,080 m of surveyed passage, with a vertical extent of 76 m making it one of the ten deepest caves in Georgia. The project is still in progress.

THE WIND CAVE PROJECT, WIND CAVE NATIONAL PARK, SOUTH DAKOTA

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The Wind Cave Project began in the Spring of 1990 when a new flagged-trail system had been instituted at the Park. This system allowed cavers to effectively help with the huge amount of survey and inventory work needed to be done. Since that time, project weekends have taken place on a monthly basis. In 1997, 3.1 km of new survey was completed, along with 2.8 km of inventoried passage. Presently, 58% of Wind Cave's 19,933 stations have been inventoried and recent work has led to the discovery of two significant areas: the Lunatic Fringe and Navidad. Both of these areas were discovered by cavers attempting to push through the present Western boundary of the cave.

BLACK HOUSE MOUNTAIN CAVE SYSTEM, FENTRESS COUNTY, TENNESSEE

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As of March 1998, the Black House Mountain Cave System consists of four multiple entrance caves: Cornstarch at 5.8 km, Alastor at 2.1 km, Red Bud at 1.6 km, and Temple Falls at 1.6 km, plus many associated smaller caves and karst features. During the past year our group continued to push the frontiers of the various caves, attempting to connect them. The dreaded Water World crawl in Red Bud finally opened up into a 27 m dome, with many leads in the area. We hope to span the 120 m gap between Red Bud and Temple Falls and possibly discover upper levels in Red Bud as well. The connection of the dry upper level April Fools entrance to Temple Falls through the Butt Crack avoids the dangerous Wet Wang water crawl. The 1.6 km wide tip of a major ridge of Black House Mountain tantalizes us with the potential of large passage between Walter World (not the same as Water World) in the south end of Cornstarch and the 30 m high multi-level breakdown trunk in April Fools / Temple Falls. Cornstarch has crossed under the creek separating it from Alastor, but differences in levels continue to frustrate a connection of these two caves. Finally, the 2.4 km of karst ridge between Alastor and the field house hints at a vast extension to the west.

THE CAVE IS SQUARE NO MORE: THE DISCOVERY OF SOUTHERN COMFORT IN WIND CAVE, WIND CAVE NATIONAL PARK, SOUTH DAKOTA

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Prior to 1991, the 96 km of Wind Cave, South Dakota were entirely underneath one almost perfectly square mile (1.6 km). On September 9, 1991, three cavers chased a tantalizing wind through an overlooked crawlway in the Silent Expressway, known since the early eighties. On that trip, they mapped 300 m of passage with a couple of small rooms. This new discovery was heading south, out of the square outline of the cave. On the next trip, cavers pushed through another 90 m of crawls into Southern Comfort, a room more than 150 m long, and averaging 15 m wide. The room trended almost due south and the cave was square no more. Over the next year, exploration continued. The Southern Comfort area of Wind was marked by large passages separated by long crawls, squeezes, and sharp breakdown, and had passed 8 km by November, 1992. Then Wind Cave slammed shut. Most of the side leads dwindled into squeezes, too tight to continue or into impenetrable breakdown. In October 1997, cavers returned to one of the tight passages at the end of Route 66, near the southwestern edge of Southern Comfort. After more than 100 m of squeezing, chipping, and shredding of clothes, the cave opened up into a 120 m long hand-and-knees crawl with airflow. On the next trip, they found a crawlway leading from the top of a tall canyon passage. The crawl broke into a series of canyons and decent-sized rooms where Southern Comfort continues.

1998 RIO ENCANTADO EXPEDITION, FLORIDA, PUERTO RICO

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The Rio Encantado Karst Basin remains a huge puzzle, with several world class caves and potential for much more exploration. Although the main system river passage is traversable for 15.9 km, a world record, there are surprisingly few side passages. This seems to be the result of both structural conditions and a series of complex stream piracies that have left major paleo-trunk and in-feeders to the system scattered throughout the mogote hills. Finding these missing pieces has proven productive and enlightening as a more complete picture of the past and present mega-system slowly emerges. Potential for major extensions and connections is high, but not without challenge. Typically, during the last days of the 1998 expedition, significant new caves were found and going surveys were left at several points. The project is also working to assist in land preservation efforts, as the development and deforestation of large areas of the karst is rapidly accelerating.

SEARCH FOR THE MISSING LINK: ONGOING EXPLORATION OF THE COBLESKILL PLATEAU, SCHOHARIE COUNTY, NEW YORK

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Approximately 7.2 km of cave theoretically lies between Howe Caverns and McFails Cave, based on dye tracing and water flow estimates. With the discovery in 1992 of Barrack Zourie slightly west of McFail's, yielding 5.1 km of passage, digging activity has stepped up. Several potential entrances to the fabled Missing Link have since been opened, including Pasture Cave, Chevy Cave and Peggys Hole.

ESPEY CAVE, CANNON COUNTY, TENNESSEE

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Espey Cave is one of the largest caves in Cannon County, Tennessee. Well-known to area residents, the cave was possibly visited as early as 1840 and was mined for saltpeter during the Civil War. Written records also mention that its cave stream was used to power a mill a few yards below its only entrance. Although several survey attempts were made over a 30-year time span by modern cavers (the first in 1956), none were ever completed. The Tennessee Cave Survey (TCS) officially listed the length of the cave as ~3.2 km, which was based on the results of previous survey attempts. After the discovery of a large extension in 1990, a new survey was begun by members of the TCS and the Tennessee Central Basin Grotto (TCBG). Surveying together in Espey, the members formed a new cave survey group that would eventually be called HR3, the purpose of which is to actively explore and survey Tennessee's Highland Rim caves. After a total of 66 survey trips from 1990 to 1996, the survey of the cave was completed at just over 9.7 km long, making the cave the second longest in Cannon County.

EXPLORATION AND SURVEY OF FOX HOLE, VAN BUREN COUNTY, TENNESSEE

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Fox Hole has been known locally and the entrance area of the cave visited for many years. The southern historic portion of the cave was first penetrated by NSS members Eric Morgan, Dave Van Fleet, and William Chambley in December 1962, when 520 m of cave was explored. The cave was re-discovered by Jim Hodson and Ron Tramel on January 12, 1974, and further exploration and survey began. On June 3, 1974, during a survey of the cave, Jean and John Smyre dug open a passage that led into the extensive north section. A grade-5 survey by Jean and John and many other Tennessee cavers was completed on September 29, 1984, with 3.1 km mapped. On May 6, 1995, during an exploration trip to the southern portion of the cave, Bill Walter and Hal Love discovered a small hole in the ceiling of an obscure crawlway with very good airflow. The following weekend, Hal, Joel Buckner, and Jason Wyatt enlarged the hole and broke into large passage. They were stopped by a 15 m sediment wall after 91 m. The following week, a large crew returned and tunneled through the sediment into more cave. A new survey project was started, with nearly 8 km mapped as of May, 1998. At least 3 km of cave remain to be mapped, with good potential for much more.

1998 ISLA DE MONA EXPEDITION

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Isla de Mona is a small uninhabited island 80 km off the coast of Puerto Rico. The island is entirely carbonate and is literally hollow with caves. To date little exploration or survey work has been done. The 1998 Isla de Mona expedition consisted of sixteen cavers from the US who spent fourteen days on the island. They concentrated their efforts on the survey and exploration of Cuervo Lirio and searching the north shore for new caves. Many kilometers of cave were surveyed and many new caves were discovered.

YELL CAVE, BEDFORD COUNTY, TENNESSEE

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Yell Caves Number 1 and 2 are located in Bedford County, Tennessee, and have recently been connected to yield a single cave that is the fourth longest in the county. Historically, this cave has been used for moonshine production and also as a source of local water which continues to this day. Although well known to locals, this cave had (until recently) been protected from visitation by its former owners. Three years ago, members of the Tennessee Highland Rim Survey gained permission to explore and survey the cave and, in the process, they established a good relationship with the owners. The cave has been the object of intense survey trips for the past three years. Since the discovery of a maternity colony of gray bats (*Myotis grisescens*) during the first winter of surveying, we have only been able to enter Yell Cave during the winter months. We are currently working with the landowners and the local authorities to protect the bat colony from future disturbances. Bat experts have estimated the colony size at 5,000 to 9,000 bats during one emergence count in the summer of 1997. In addition, possible extinct jaguar remains were found by Marbry Hardin during a survey trip at the cave's furthest extent. The cave has a surveyed length of over 2900 m consisting of mostly stream passage. When the survey is completed, we expect the total length of the cave to be approximately 3800 m. There have been 15 survey trips into the cave to date.

BURNS CAVE, BATH COUNTY, VIRGINIA

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A recent breakthrough in Burns Cave is one of the latest exciting discoveries in Burnsville, Virginia. After 30 years of hard pushing and digging, cavers have gained access to a long hypothesized lower level of the cave and have been given a glimpse of the main drainage for a large karst valley. The cave is one segment of a major cave system underlying Burnsville Cove. This system is complex in nature and not yet fully understood, even though several caves within this complex contain more than 60 km of passage. Burns Cave is a significant piece of this underground puzzle. The extreme nature of the entrance series has proven to be a major obstacle limiting not only the number of people who enter the cave, but also the frequency of the trips. An elusive wind and the possibility of further breakthroughs continue to draw a small group of cavers back to the cave's horror. At -240 m, Burns Cave is Virginia's deepest and possibly most difficult cave.

THE EXPLORATION AND MAPPING OF MONTAGUE CAVE AND RUSSELL CAVE, JACKSON COUNTY, ALABAMA

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Recent explorations from 1988 to present in Montague Cave and Russell Cave, Jackson County, Alabama, have yielded two new vertically extensive caves 124 m and 103 m deep respectively. The 1988 exploration of Montague Cave included repeating the aid climb of Thunderfalls, a 42 m tall dome first climbed by Don Davison, and rediscovering 915 m of passage. Revisiting Davison's exploration yielded an additional 3,659 m of passage and the 84 m tall "Storm Shaft." Stopped by overhanging chert, the original climb ended 49 m high on the wall. In 1994, a new route on the other side of the Storm Shaft, the "Rebelay Wall," was completed to the top of the dome in 4 pitches, but with no continuation. To date, 6,800 m) of passage has been surveyed. Continuing the work begun by Bill Torode, exploration of the upper level domes in Russell Cave began in 1995 and was finished in 1996. Domes of 38 m ("Guillotine Wall") and 11 m were climbed to reach a new high point in the cave at +103 m.

SNAKE DANCE ENTRANCE TO BULL CAVE, GREAT SMOKY MOUNTAINS NATIONAL PARK, TENNESSEE

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In the summer of 1996, cavers in east Tennessee discovered a cave entrance on Rich Mountain in the Great Smoky Mountains National Park. In the initial exploration by a group of five local cavers, the cave was surveyed down seven pits to a depth of 121 m below the entrance. This find was reported to the National Park and a cave exploration permit was obtained for the Tennessee Cave Survey to coordinate the continued exploration and survey during the 1997 caving season. During the summer of 1997, 25 different cavers from 5 states participated in the project. The cave was surveyed down another series of 6 pits to a horizontal borehole level at -180 m. The horizontal passage extended 200 m and ended with two more pits. A narrow passage then led 114 m to connect to the previously known lower stream passage of Bull Cave at a depth of 248 m. A re-survey of the lower stream passage showed the low point sump to be 282 m below the new entrance. This project surveyed 1.66 km of new cave, increased the cave length from 2.24 km to 3.66 km, and increased the cave depth from 226 m to 282 m. This route to the cave bottom requires negotiating 14 pits, the deepest of which is 43.6 m.

JEWEL CAVE EXPLORATION, JEWEL CAVE NATIONAL MONUMENT, SOUTH DAKOTA

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Jewel Cave is one of America's oldest national monuments, established by Theodore Roosevelt in 1908, and incorporated into the National Park Service in 1928. Although it has been known for about 100 years, most of its exploration has taken place since 1959, particularly as a result of the efforts of Herb and Jan Conn. Since then, exploration has progressed at a modest average of 4 km a year. This has been accomplished by volunteers working closely with the Park Service. Known for its barometric breezes, the cave's airflow has been the most valuable tool for discovering new passages. In late 1991, a strong breeze encouraged the excavation of "The Stopper," leading to the discovery of nearly 48.3 km of new cave, including larger rooms and passages than any previously known. Today, that breakthrough point is less than halfway to the end of the cave.

Exploration trips had always been done in a single long day. With trip times approaching 20 hours, and round trip distances as long as 16 km, it became apparent that camping would be necessary for continued exploration of the farthest reaches. A trial camp, conducted in June 1997, led to the development of a camping policy and the establishment of a permanent camp in November 1997. Since then, four-day trips have become common. Strong breezes recently led to a second breakthrough, and it is beyond the restriction known as "The End" that most of the cave is expected to be found.

EXPLORATION SESSION: INTERNATIONAL

Beyond the San Agustin Sump - Huautla

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In 1994, an international team of cavers mounted an expedition to explore beyond the San Agustín Sump in Sistema Huautla, in southern Mexico. A total of 44 people participated, including a dozen divers. After a month of assembling diving gear in the states, three months were spent in Huautla. Initial attempts were made on the sump resulting in the discovery of an airbell 425 m in. Another 180 m sump led from the southern extent of the airbell to dry borehole. Two people established Camp 6 beyond the second sump. During the following six days, 3.2 km of dry passage were explored and surveyed. At 2.4 km from Camp 6, the San Agustín river joined another river, presumably the Río Iglesia, quadrupling the downstream flow and forming the "Main Drain". About 800 m downstream from the Río Iglesia junction, the combined flow floods the passage in a 50 m wide by 25 m long sump. Exploration ended there, still 7 km from the resurgence at 1,475 m (now the deepest cave in the Americas). The resurgence is 1,639 m below the Nita Nanta entrance. However, in 1995 the resurgence was explored to a depth of 60 m below the spring level, and continuing down, at a distance of 1 km north of the mouth. This suggests a minimum overall depth potential of 1,700 m for Sistema Huautla.

1998 Vaca Plateau, Belize

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Since 1990, multidisciplinary research encompassing geology, hydrology, speleology and geoarchaeology has been conducted in a 25 km^2 portion of the northern Vaca Plateau in Western Belize. Dr. Philip Reeder, a geographer at the University of Nebraska at Omaha, manages the project. In March 1998, a team of 6 cavers spent 2 weeks at a remote jungle camp on the Mayan terraces of Ix Chel, a large temple complex in the study area. The team focused on geology, water and sediment collection and analysis, a small in-cave excavation, pottery assemblage and drawing, ridge walking for more caves and Mayan structures, and surface surveying. A detailed survey was completed of Macal Chasm with its 53 m entrance shaft located just east of Ix Chel's main plaza. Much time was spent completing a detailed survey of a significant burial cave. As a result of looting of the archaeological sites and caves in the area, valuable information about the Maya has been lost.

Speleological Potential of Egypt

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Egypt is located between Libya and the Arabian Peninsula, both of which have well-known caves and karst. The Underground Atlas dismisses its karst as "not considered of interest to speleologists." A National Geographic Society map shows caves of major archeological importance. As expected, Gezireh Grotto in Cairo is an artificial pleasure grotto but information obtained on limestone, gypsum and sandstone karst features warrants further investigation.

Recent Exploration In The Purificacion Karst

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Recent exploration in Mexico's Sistema Purificacion has added 5 km to the system, making it 90.5 kilometers long. In December 1996, a base camp in the World Beyond section produced 2.3 km of new survey, including the promising Batwing Boulevard, which may lead up to a higher entrance. In March 1997, another camp was put in via the Infiernillo entrance and added more survey. An aid climb up Napoleons Dome led to a new section of cave which pinched before a sump bypass could be realized. Above the system, a long term dig in Sótano de la Cuchilla broke through the grim Hurricane Crawl resulting in several hundred meters of new passage to yet another dig. Five kilometers to the west of the system, a promising new cave was explored in the Tinajas Valley. Sima Chupacable was pushed down a series of long pitches to a sump at -400 m. In the southern part of the area, the formerly sumped wet weather resurgence at Ojo Encantado was found to be open and was explored up several waterfall climbs and continues. This trip was part of an ongoing search across northern Mexico for blind catfish of the genus *Prietella*. While none were found here, the catfish team has had good success at other localities in Tamaulipas and Coahuila.

Ukrainian Caves; Geological Aspects and Exploration Techniques

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The Dnestr-Black Sea (DBS) and Crimea regions of Ukraine are two of the country's major caving areas. The DBS region is best known for its remarkable gypsum caves around Podoliya. The longest gypsum cave in the world, Optimisticheskaya (191.5 km), lies in close proximity to Ozernaya (111 km). The existence of a connection between these two caves has often been suggested, but results of recent work now indicate that a connection is most unlikely to exist. The gypsum cave of Zolushka currently has a length of 89.5 km. New exploration has also extended the mapped passages of Kristalnaya (22 km), Mlynki (23 km), and Slavka (8.2 km). The Black Sea's mountainous Crimean peninsula is home to many limestone caves. Krasnaya cave (13.7 km) remains the longest, while the Soldatskaya shaft is the deepest at 500 m. In recent years, new sections have been discovered in Emine-Bair-Cola (950 m) and Emine-Bair-Khosar (1,460 m) caves. In addition, the phreatic complex of the Chernaya (1,160 m), as well as Mramornay cave (2,055 m), has been surveyed to ever-increasing lengths. Deeper explorations include those of the Kaskadnay (-400 m), and Druzhba (-270 m) shaft systems.

GEOLOGY & GEOGRAPHY SESSION

Microbes in Carbonate Thermal Springs: Hot Springs National Park, Arkansas

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As part of a long-term study of possible terrestrial analogs to biogenic features in Martian meteorite ALH 84001, the authors are studying carbonate mineral deposits in subterranean hot springs located in Hot Springs National Park, Arkansas, USA. The hot springs, which are ~65°C at a nearly neutral pH of -7.3, precipitate aragonite and calcite at and below water surfaces. Although previous studies had termed the water "naturally sterile," bacteria are in fact commonly preserved in the carbonates, including 1-2 µm rods, and unusual filaments of 0.1 µm (or 100 nm) in diameter and up to 6 µm long. The waters also deposit orange films of amorphous Fe-Si-O material which is associated with a distinctive biota: spherical bacteria 5-15 µm in diameter, rod-shaped bacteria 0.5 - 1 µm long, and spherical shapes, interpreted as nanobacteria, less than 0.5 µm in diameter. The carbonates appear to be precipitated abiogenically, and early experiments indicate that the orange films, while clearly associated with biota, can be formed independently of biological action.

Bellefontaine Outlier, Ohio: Its Formation and Subsequent Cavern Development

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The Bellefontaine Outlier lies on the Cincinnati/Findlay Arch structure in the central half of Logan County, Ohio. The Outlier consists of middle Devonian limestone capped by the Ohio Black Shale. The Bellefontaine Outlier is surrounded by older Silurian limestones and shales. The nearest other Devonian outcrop begins 75 to 100 km to the east, and trends north-northeast. The whole Bellefontaine Outlier is a karst-dominated feature consisting of sinkholes being filled for the past 10-15 Ka by recent glacial till. Many of these sinkholes dot the landscape and need to be investigated. Zane Shawnee Caverns is developed in an east-west fissure with the south side opening down the stream valley. This allows the Black Shale to fill the top of the fissure, where it is cemented in place as a cap over the underlying chasm. The lower levels are dominated by a very small stream and passage system. They trend from the north and empty into the adjoining valley as small seeps. Presently, only Zanes and Ohio Caverns have been investigated, showing the upper levels are fracture controlled and the lower levels are vadose controlled.

Bell Hole Morphology: Speculations on Genesis

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Bell holes are conical to cylindrical dissolutional features in cave ceilings, displaying elongated vertical axes. The origin of bell holes is controversial with several mechanisms (phreatic and vadose) proposed for their origin. Phreatic mechanisms include floodwater, mixing-corrosion, and convection cells; vadose mechanisms are condensation corrosion and biogenic.

Few data on bell hole dimensions are available, and a quantitatively based definition of their morphometry is lacking. To evaluate proposed formational mechanisms, detailed morphological analysis was performed in Lighthouse Cave (30 bell holes) and Majors Cave (16) on San Salvador Island, Bahamas; Cueva de los Parajos (30) on Isla de Mona, Puerto Rico; and Roppel Cave (30) and Saltpetre Cave (16) in Kentucky; plus additional data from New York caves (8). Bell holes were profiled at 2 cm intervals along X and Y axes. Observations regarding rock texture, structure, and lithology were recorded along with a survey to determine bell hole relative positions.

Aggregate bell hole analysis indicates two major categories: cylinders, and cones. Height to width ratios range from 1.93 to 0.44. Bell holes with the greatest vertical development occur in the youngest caves, implying that vadose exposure does not correlate with bell hole development and making the vadose models unlikely. The uniformity of bell hole widths between various caves argues against mixing corrosion. The flank margin speleogenesis of the island caves eliminates floodwater hypothesis. As such, phreatic convection cells as a genetic mechanism appear favored.

A Method for Analyzing Morphological Variations of Cave Dissolutional Features

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Quantitative studies of cave dissolutional features (e.g., scallops, wall pockets) have yielded a wealth of speleogenetic information. However, analyses of other dissolutional features (e.g., bell holes, cusps, etc.) are mainly qualitative, making their speleogenetic implications mostly speculative. One difficulty in studying these features is developing a means of analysis that identifies morphological variations between populations. An ongoing study of bell hole morphology required development of such a method. The resulting methodology could easily be adapted to study other types of dissolutional features and similarly shaped non-cave features (e.g. stream potholes).

Data collection entailed profiling (2-4 cm interval) of the bell holes along two perpendicular axes normal to the vertical axis. These profiles are analogous to an inverted stream profile. A statistically significant sample (n = 15-30) was collected from each cave studied. A survey of bell hole locations facilitated analysis of packing distribution and spatial patterns of morphological variation.

Data analysis began with identification of inflection points in each profile to determine the boundary between the bell hole and ceiling. For each cave, measurements of percent height versus percent width for each bell hole were plotted. Comparison of these plots with ideal shape plots (e.g., cones, cylinders, hemispheres, etc.) identified patterns in bell hole morphology. Regression analysis of these data allowed creation of an aggregate shape plot using mean bell hole dimensions. The aggregate shape plots enable comparison of morphological variations between caves and geological settings.

Variation in Cave Temperatures on San Salvador Island, Bahamas: A Preliminary Analysis

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Horizontal and vertical temperature profiles between a non-tidal and tidal cave were recorded on San Salvador Island, Bahamas. Temperatures were measured and recorded approximately every 5 minutes for a 3-, and a 5-day period, using Hobo™ temperature data loggers. Temperature observations indicated that for the non-tidal cave, temperature increased from the entrance of the cave to the back (entrance mean temperature 22.0°C, back mean temperature 23.8°C). The variance in temperature observations decreased from the entrance of the cave to the back. For the vertical temperature profile in the non-tidal cave, temperature increased with height above the floor (floor mean temperature 22.5°C, ceiling mean temperature 24.1°C).

The thermal environment of the tidal cave is different from the non-tidal cave. Temperature increased from the entrance of the cave to the back along the horizontal profile (entrance mean temperature 25.0°C, back mean temperature 25.6°C), while variation of temperature observations decreased from the entrance to the back of the cave. Temperatures decreased from the floor of the cave to the top of the bell hole (tidal pool mean temperature 27.5°C, ceiling mean temperature 26.1°C). In addition, temperatures directly above and below the tidal water surface displayed a symmetrical, cyclical component that coincided with the tidal cycle. Temperatures rose at high tide, and decreased at low tide. These observations suggest tidal water inside a cave may enhance atmospheric instability. Such instability may support the dissolution process of condensation-corrosion.

CO_2 Measurements and Recent Flooding in the Mammoth Cave Karst Aquifer

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Interstitial fluids within the sediments beneath Charons Cascade in the River Styx area of Mammoth Cave were found to have CO_2 pressures an order of magnitude higher than the stream waters flowing on top of the sediments. Dissolution and downward cave growth thus might be occurring beneath these clastic deposits. This has generally been assumed to be negligible.

Intensive study of the Logsdon River, one of Mammoth Cave's and the Turnhole Spring Groundwater Basin's major underground streams, is also underway. There, results indicate the importance of both in-cave and external sources of CO_2, the major control on the water's ability to dissolve limestone. A single storm in March of 1997 (over 20 cm of precipitation in 12 hours), which caused the river level to rise over 28 m in less than 15 hours, has provided bounding conditions for the river's hydrologic and geochemical conditions, and their rates of change. Abandoned conduits within parts of the aquifer that rarely ever see water flooded rapidly, with a maximum rate of about 8 m per hour.

Phreatic and Vadose Features in Volcanic Caves in Kenya

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In Kenya, several extensive caves in unusual volcanic rocks present an interesting interface between karst and pseudokarst. Some of the caves have phreatic and vadose features like those of karstic caves. Located in tuff along one wall of a gorge, Gigglers Caves largely consist of an elongated multilevel network, rounded to elliptical in cross-section, with small rounded chambers. Local stream erosion is present, and some minimally developed karren. On Mt. Elgon, some voluminous caves appear to have a similar origin. These include Kitum Cave, Makningen Cave, and at least the upper Chepyanili Cave. Here the bedrock consists of a confusing complex of agglomerate, tuff, and lake bed deposits with extensive organic components and soluble salts. They are used as salt licks by wild and domestic animals. Makningen Cave is especially suitable for speleogenetic study. It is primarily a borehole passage 50-70 m wide and 10-20 m high. A large dome-shaped upper level is present, as are a small stream channel and a shallow breakdown dome. A vertical lava flow enters its borehole passage from the dome chamber. Depositional features are scant. Only superficial observations have been made in these caves, and intensive speleogenetic studies are needed.

Siderite Weathering, a Rare Source of CO_2 for Cave Genesis: The Eisenstein Stollen System and Adjacent Caves in the Iberg, Harz Mountains, Germany

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Genesis of limestone caves depends on how and in what amounts CO_2 is available. Probably >90% of cave-generating CO_2 is soil-derived and infiltrates the rock through seepage or river sinks. Internally either mixing-corrosion or, probably more important, the slow kinetics of carbonate dissolution near saturation carry the dissolution potential far into the rock. But other sources of acid anhydrites can be important also. Best known is the example of Carlsbad Cavern where oxidation of ascending H_2S provided dissolution potential.

The investigation of the Eisenstein Stollen System, a labyrinthic 5 km of irregular natural halls connected by short mine passages in isolated Middle Devonian reefal limestones in the southeast corner of Iberg Mountain, Harz Mountains, Germany, illustrates the importance of yet another CO_2-generating process: siderite weathering. When siderite ($FeCO_3$) is oxidized, CO_2 is liberated and the iron oxide mineral goethite forms. The limestone of the Iberg was infiltrated with Mg- and Fe-bearing solutions transforming the limestone partly into dolomite and siderite. The siderite started to weather when the groundwater level sank enough to allow oxygen into the ore body. Due to the *in situ* liberation of CO_2, isolated caves, partly filled with clayey geothite, started to form started to form around the ore bodies. The goethite was mined for iron until the end of the last century. Unconnected Frankenberg Höhle, Biese Schacht, Kernberg Schächte, and Iberger Tropfsteinhoehle, a show cave, add another 3 km of passages, halls and pits.

Dissolution Kinetics of Limestones and Dolomites from Isla de Mona, Puerto Rico, in Relation to Cave Development

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Isla de Mona is a 6 km diameter carbonate island located in the Mona Passage between Puerto Rico and the Dominican Republic. The island consists of an upland plateau with sea cliffs on three sides and an escarpment dropping down to small beach areas on the south side. Large flank margin caves have developed near the contact between the limestone and the dolomite. A laboratory investigation was initiated to interpret the distribution of Isla de Mona caves in terms of the dissolution kinetics of the carbonate rocks.

The relative dissolution kinetics of the Lirio Limestone and the Isla de Mona Dolomite were determined by dissolving discs of various samples in CO_2-saturated solutions. Uptake of dissolved carbonate was determined by monitoring pH and specific conductance as a function of time. Initial rates for limestones averaged 12.53 μmol m^{-2} sec^{-1} compared with 8.53 for dolomite. The rate curves had similar shapes. The limestone rates are comparable with those measured on single crystal calcite but the dolomite rates are higher than rates measured on Paleozoic dolomites.

Karstification of the Lirio Limestone takes place rapidly both because of the intrinsic chemistry of the rock and because of the large surface areas due to the porous character of the limestone. Because of the included calcite and perhaps also because of the porous surfaces, the Isla de Mona Dolomite dissolves substantially faster than the impermeable Paleozoic dolomites. Karstification within the Isla de Mona Dolomite would not be excluded from considerations of kinetics alone.

Delineation of Groundwater Spring Basins in Rutherford County, Tennessee: A First Step in Understanding Sinkhole Flooding

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Groundwater tracing was utilized in three spring drainage basins of Rutherford County, Tennessee, for the purpose of understanding present sinkhole flooding problems and planning for future growth. Ten successful dye traces were conducted. Seven traces went to Bushman Spring enabling the calculation of a drainage basin size of 26.4 km². One tracer traveled a distance of over 8 km in 3 days. Double Springs is a sub-basin within the larger Bushman Spring Basin. Two dye traces were conducted to Nice Mill Springs yielding a basin size of ~17.4 km². The tenth trace was to Compton Spring. More tracing is needed to this large spring to determine the recharge area. In all of the spring basins, groundwater moves through the Ridley Limestone perched above the Pierce Formation. Rapid movement of tracing agents suggests that subsurface cavities have not been clogged by human activities. Constructed geologic and topographic cross-sections, combined with two-foot contour map information, shows the karst water table is very close to the surface. As a result, natural constrictions associated with changes in cave passage size cause storm waters entering the subsurface to back up behind constrictions, resulting in flooding of upgradient sinkholes.

Geochemistry of Cueva de Villa Luz, Mexico, an Active H_2S Cave

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Cueva de Villa Luz, Tabasco, Mexico, is in deformed Cretaceous limestone at the foot of the Chiapas highlands. The cave is an outlet for H_2S-rich water interpreted to be from a nearby oil-rich sedimentary basin because of its high Mg, Na, Cl, and SO_4, and low silica. Two water types feed the cave through impassable inlets: (1) H_2S-rich, pH = 6.6, PCO_2 = 0.1 atm, depositing sulfur on adjacent walls, coating surfaces with white filaments of sulfur-oxidizing bacteria; and (2) oxygenated water exposed to aerated conditions upstream from the accessible passages, pH = 7.3, PCO_2 = 0.02 atm, no hydrogen sulfide,precipitating iron hydroxide which recrystallizes to goethite. Cave air around Type 1 inlets has up to 130 ppm H_2S. Suspended droplets of infiltrating water absorb H_2S and O_2, which react to form sulfur and sulfuric acid. Slow drips reach pH values as low as zero. Nearby limestone surfaces convert to gypsum by reaction with the acid. The redox reactions support a bacterial community that forms the base of a complex food chain. Folia of sulfur alternating with organic films may have formed by H_2S degassing below a former water surface. The main cave stream (28°C, 290 L/sec) is cloudy with colloidal sulfur and at saturation with calcite and dolomite, but undersaturated with gypsum. The cave enlarges as gypsum falls into the stream and dissolves. Acidic water also seeps through the gypsum crust into the limestone stream bed, creating rills. In places, the walls and floor are coated with organic-rich muck in which pyrite is forming.

By-Products of H_2S/H_2SO_4 Speleogenesis

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This paper discusses sulfuric acid indicator by-products of H_2S/H_2SO_4 speleogenesis found in major caves of the Guadalupe Mountains, New Mexico. Some of these speleogenetic materials are gypsum, hydrated halloysite (endellite), alunite, natroalunite, jarosite, quartz, hydrobasaluminite, todorokite, amorphous silica**,** and sulfurous alumina gel. They form as by-products of sulfuric acid reaction with bedrock and internal sediments **(**host rocks**)**. They are found in areas protected from flood or drip waters. Host rocks are limestone and dolostone (calcite and dolomite), and siltstone and internal sediments (quartz, illite, dickite, kaolinite, illite/smectite mixed-layers, montmorillonite-rich-clay, and mica). Montmorillonite-rich clay is common only in solution cavities of Carlsbad Cavern.

Gypsum is the most abundant by-product of H_2S/H_2SO_4 speleogenesis. It replaces dolostone or precipitates from solution both below and above the water table. Alunite, natroalunite, jarosite, and hydrobasaluminite**,** other sulfate by-products**,** formed by sulfuric acid reaction with clay. Sulfur stable isotope values of these sulfates are negative, indicating biogenic hydrogen sulfide derived from hydrocarbons. Silica released during the alteration of clays precipitated as quartz or opal. Todorokite is commonly found as black halos around pockets of altered bedrock. Late-stage secondary minerals, indirect indicators of H_2S/H_2SO_4 speleogenesis, include uranyl vanadates (tyuyamunite and metatyuyamunite), aluminite, gypsum, gibbsite, nordstrandite, amorphous silica, and sulfurous alumina gel. Study of the H_2S/H_2SO_4 speleogenesis of Guadalupe caves provides a general model for similar cave systems worldwide.

Revised Age for Xanadu Cave, Tennessee, and Implications for River Incision in the Cumberland Plateau Escarpment

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Xanadu Cave (Fentress County, Tennessee) is a 15 km long system on the Western Cumberland Plateau Escarpment. A minimum age of 0.91 Ma was previously assigned to upper levels of the cave based on paleomagnetic studies. To better constrain the age of the cave, we collected quartz sand for cosmogenic isotope dating, along with detailed paleomagnetic samples, at a site in the cave where a normal to reverse magnetic polarity change was found. Dating of the sand based on radioactive decay of ^{26}Al and ^{10}Be implies with 99% certainty that the sand was deposited prior to 2.7 Ma, and with 95% certainty that the sand was deposited prior to 3.3 Ma. The Obey River, presently 50 m below the sampling site in Xanadu Cave, is therefore downcutting at less than 20 m/Ma. This is comparable to rates obtained for the New River, Virginia, and the Kanawha River, West Virginia, but slower than rates of 30 m/Ma inferred for the Green River near Mammoth Cave, Kentucky, and 45 m/Ma for the Ohio River near Madison, Indiana. Assuming that the sediments were deposited near the river swallet, now 7.7 km upstream, the swallet is migrating upstream at more than an order of magnitude faster than river incision.

A Decade of Mud Movement

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In 1987, a peculiar mud slope in Shine Cave caught the attention of the authors. The slope has striations apparently carved by ceiling irregularities when moving mud squeezed under a step in the ceiling. Also where water drops fall from the ceiling onto the mud slope, a down-slope drip trench exists, rather than a typical drip hole. These circumstances suggested a measurement of the mud movement rate could be made. With that objective, simple plumb bobs were hung from a few points on the ceiling above the slope. Under the point of each bob, where it almost reaches the mud, a stiff vertical wire was pushed into the mud so that the wire initially aligned with the bob. After the mud moves, the wire no longer aligns with the bob and the displacement can be measured. After 4 years, the initial results of periodic measurements were reported in 1991. Measurements have continued through 1997. This decadlong data series shows a higher than typical rate during winter and spring 1991, correlating with an anomalous high rainfall period. From examination of the decade data set, the average rates are: 3 mm/yr from late 1987 through 1990; 40 mm/yr in the first half of 1991; and 3.5 mm/yr from 1992 through 1997. Measurements of the elongation of drip trenches, while not as accurate, confirm the rates from the plumb bob installations.

Cave Morphology and Hydrology as Measures of Karst Aquifer Evolution

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Caves increase in length, volume, vertical extent, and general complexity with time, and thus become better integrated components of their aquifers. These attributes can be regionally examined to determine the evolution of karst aquifers. Two aquifers in south-central Texas were studied. The Lower Glen Rose (LGR) Aquifer is shallow, and mostly gravity drained to the Guadalupe River, with a deeper component that joins the artesian flow of the Edwards (Balcones Fault Zone) Aquifer. Caves are best developed in the central portion of the LGR aquifer where groundwater circulation was first initiated. Groundwater has flowed through that aquifer's eastern and western sections for about the same amount of time, but few significant caves and springs are known in the east, where the water table has been relatively higher and groundwater circulation probably slower. In the Edwards Aquifer, caves change from dendritic conduit networks to isolated chambers from west to east, suggesting the aquifer has grown eastward, accreting major fault blocks as incising streams allow discharge from progressively lower elevations.

The degree of cave extent and complexity in assessing aquifer evolution must be determined relative to the caves in each given area. Hydrologically mature aquifers can sometimes be difficult to assess if a high degree of uniformity exists among the caves, and the nature of conduits related to groundwater piracy or other key hydrologic events is obscured. Conceptual understanding of aquifer development can be useful to groundwater modeling, management, and cave exploration.

HAWAII SESSION

A Summary of Survey Activities in Lava Tubes to the North of the Northeast Rift Zone of Mauna Loa, Hawaii

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On the north side of the Northeast Rift zone on Mauna Loa (elev. 4171 m) on the island of Hawaii, lava flows, ranging in age from historical to about 4 Ka BP, cover an area of about 570 km^2. To date, over 21 km of survey has been conducted in about 50 tubes in 12 flows below and to the north of the NE rift zone. The most productive of these are three historic flows: the 1855 flow (6830 m surveyed in 18 tubes), the 1859 flow (4600 m surveyed in one tube) and the 1935 flow (4200 m surveyed in 5 tubes). The tubes surveyed have ranged in depth from 1.5 to > 15 m below the local surface, and in complexity, from simple unitary conduits to multiple level, braided passages.

Cultural Resources In Caves At Hawaii Volcanoes National Park

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At various times during the last 2000 years, Polynesians from the Marquesas and Tahiti sailed to Hawaii and settled, eventually becoming today's Native Hawaiians. Caves were, and are, viewed by them as part of the resource base of Hawaii, and were extensively used by the people of old. Caves served as temporary or permanent habitation sites and were used for religious purposes, shelters in time of war, and storage places for food, as well as work areas. Water dripping from cave ceilings was collected in gourds or other containers, especially in desert areas. Some caves are paleontologically important, containing the bones of several species of extinct flightless birds endemic to Hawaii. Important caves were named, and political land boundaries often followed the course of large caves. Nearly every large lava tube in Hawaii Volcanoes National Park older than 200 years contains archeologically important cultural remains. These may range from charcoal deposits, to simple arrangements of pebbles used to prop gourds upright, to caves containing hundreds of petroglyphs, to habitation caves with their complement of features.

The Highcastle Lava Tube - Hawaii Volcanoes National Park

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The volcanic nature of Hawaii and the kind of lava erupted allows for the formation of sometimes extensive lava tube systems. Lava tubes are more commonly found on the younger, less weathered volcanoes, such as Mauna Loa and Kilauea on the island of Hawaii. The lands that comprise the 97,000 hectares of Hawaii Volcanoes National Park were formed by lava flows from the summits and rift zones of both volcanoes. We have been able to observe and gain some insight as to the formation and evolution of lava tube systems during an ongoing eruption on the east rift zone of Kilauea. A three year old lava tube was entered, mapped, and its features inventoried in the winter of 1997. A suite of unusual secondary minerals was collected and analyzed, and lava features in the cave were described and analyzed. An attempt was made to correlate observations made while the tube was active, and those made during exploration. Location(s) of skylights, size and shape of the tube, locations of mineral deposits and lava features, as well as surface features, were all examined to ascertain if patterns existed which would account for our observations. The youth of Highcastle offered a unique opportunity to focus on the apparently transient features only found in recently formed lava tubes.

Hawaii Caves 1958-1998

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Systematic speleology began in Hawaii in 1958, with publication of an initial report in the *NSS Bulletin*. The ill-fated fallout shelter program of the 1960s identified and published the locations of numerous caves. In 1970, Frank Howarth and Fred Stone initiated biological studies that radically changed scientific understanding of insect evolution. Later in the 1970s, studies by mainland and overseas speleologists began to accelerate. Most of the body of knowledge comprising today's mainstream of Hawaiian speleology accumulated following formation of the Hawaii Speleological Survey in 1989. The number of known caves has increased to more than 1,200, including the world's longest lava tube cave (Kazumura Cave, with 60.2 km mapped). More than 100 km of cave passages has been mapped. Collaboration with planetary geologists led to discovery and investigation of a new type of cave at vents for nodules of ultramafic xenoliths. New types of sheet flow caves have been found in Kilauea Caldera, and numerous hollow lava tumuli of several types. The deepest pit in the United States is either on Hualalai Volcano or on Molokai Island (the latter pit is mostly water-filled and re-measurement is needed).

Lava Rise Caves in Kilauea Caldera, Hawaii

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A lava rise is a large lava tumulus found on some flow fields of basalt, such as the Kilauea Caldera, Hawaii. Like other tumuli, they result from injection of very fluid lava beneath a deformable plastic crust. Many undergo partial deflation after their margins have solidified, resulting in a central depression or collapse surrounded by a boundary ridge one to several meters high. In some cases, a cavernous space persists within the boundary ridge and between it and the central depression. It can extend several meters outward from the high point of the boundary ridge. Sometimes extensive, complex feeder and/or drain tubes are present. The classical case approximates the shape of a hollow donut, but commonly, only segments of the ring are present. A few of these unusual caves have been investigated and the consistency of their internal structures is not clear. They appear to be more closely related to flow lobe caves than to "ordinary" hollow tumuli, but a deep fissure cave thinly lined with accreted lava in the middle of one central depression raises a question about the route of the lava injection. One of the boundary ridge caves has been mapped to the margin of an unrelated adjoining conical tumulus.

Cultural Resources in North Kona Lava Tubes

Doug & Hazel Medville, Hawaii Speleological Survey

A variety of structures and artifacts found in lava tubes in the North Kona district, Hawaii are evidence of former and ongoing use by native Hawaiians. These include walls, steps into pukas, rock rings, platforms, and other structures. Tube use is evidenced by offerings placed at entrances, as well as twigs and shells found inside the tubes. Although several of the features observed while surveying in the tubes have been described in the archeological literature, other features, so described, are no longer to be found as a result of their removal from the tubes by unknown persons. As development continues in the North Kona district, cultural features found in the lava tubes are expected to continue to diminish.

HISTORY SESSION

Lost Caves of Harrison and Crawford Counties, Indiana

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Harrison and Crawford Counties, bordering the Ohio River in southern Indiana, have long been known to cavers. Some 800+ caves for the side-by-side counties are listed in the Indiana Cave Survey database. Famous show caves, such as Wyandotte and Marengo Cave, are here, as well as the 30+ km Binkley Cave System. At least 18 caves in these counties have been physically closed or "lost" so that present entry by cavers is not possible because of natural cave-in, sealing during highway construction, being bulldozed shut by owners, flooding, quarrying, or inadequate knowledge about the location of the entrance. The existence of these once open caves is documented with newspaper articles, photos, and word of mouth and hand-me-down stories. These caves await rediscovery by persistent cavers. From the known clues, some of the lost caves may prove to be quite extensive and/or very beautiful.

Ralph Waldo Emerson and Mammoth Cave

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Although speleohistorians have long known that Ralph Waldo Emerson visited Mammoth Cave sometime in the 1850s, recent research in his journals and letters has yielded additional information about his trip to Kentucky and the cave. Of particular interest is Emerson's lengthy letter to his wife, Lydian, which details his two tours into Mammoth Cave in June 1850. Emerson was impressed by the natural features of the cave as well as the theatrics and other elements of the tour. The Mammoth Cave experience made a lasting impression upon Emerson and provided the seeds of ideas which later emerged in his essay "Illusions."

Historic Caves of the Matterhorn Revisited

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Following the 1997 International Congress of Speleology in Switzerland, the author spent some time in Zermatt, climbing and investigating local historic caves.

During an ascent of the Matterhorn, a shallow cave was visited on the east face near the Hornli Ridge, at an elevation of 3,811 m msl. Due to its strategic location, this grotto has been used as a bivouac on numerous occasions by climbers. In 1868, three years after the first ascent of the Matterhorn, a small wooden hut, protected by dry stone walls, was constructed out from the cave mouth to increase the shelter's capacity to accommodate 7 or 8 stranded climbers. Over time, the hut fell into progressive stages of disrepair, and by the turn of the century it was all but gone. In 1915 the Solvay Hut was established 192 m above the cave. This is still the mountain's highest emergency shelter.

A second historic cave, the Gouffre Des Busserailles, a few kilometers south of the mountain across the Italian border, can still be seen for a small fee. It has an impressive narrow, sinuous glacial gorge, and is about 100 m long and 33 m deep. It was first entered in November 1865 by the Alpine guide, Jean-Antoine Carrell, who was lowered by others into the chasm. They soon built a plank walkway so everyone could explore the cave. Edward Whymper was also impressed and referred to the cave in his classic treatise, *Scrambles Amongst the Alps in the Years 1865-69*.

The Saltpeter Mining History of Virginia Caves: An Inventory and Compendium in Progress

David A. Hubbard, Jr., P O Box 3667, Charlottesville, VA 22903

From the mid-18th century until 1865, many Virginia caves were used for the extraction of saltpeter, with the most intense mining occurring during the Revolution, the War of 1812, and the Civil War. During recent years an active inventory of these caves and their contents has been in progress, using historic documents, oral tradition, and artifacts to rediscover sites. Aspects of the physical remains were recorded, which reveal a wide array of variation in tools used, sediment types exploited, where leaching took place, where water was collected, types of vats used, and sometimes when a passage was worked and by whom. Ongoing research indicates that 94 caves were mined for saltpeter within the present geographic limits of Virginia. This inventory also entails the compilation of previous documentation. Older photographs and slides of mining evidence are sought for duplication and inclusion in the compendium. All saltpeter mining remnants and artifacts are protected by the Code of Virginia.

The Tombigbee Railroad Survey Visits Saltpeter Cave

Charles A. Lindquist, 214 Jones Valley Drive SW, Huntsville, AL 35802-1724;
William W. Varnedoe, Jr., 5000 Ketova Way SE, Huntsville, AL 35803-3702

Inscriptions scratched on a rock in Saltpeter Cave, Lawrence County, Alabama, record a June 8, 1887, visit by the "Tombigbee R. R. Survey". Perhaps drawn by curiosity or a cool escape, this survey party apparently departed from its assigned tasks to view the wonders of this cave with its large entrance. In doing so, the group left a lasting record of its membership on that day. It also marked an event in the fascinating history of transportation problems and opportunities in the corner of Alabama, Mississippi, and Tennessee where the headwaters of the Tombigbee River approach the northward bend in the Tennessee River. Probable identifications for four of the six survey members were made.

The Demise of Shelah Waters

Larry E. Matthews, 8514 Sawyer Brown Road, Nashville, TN 37221-2403

In 1869, Shelah Waters explored extensively in Higginbotham Cave (now known as Cumberland Caverns) in Warren County, Tennessee. Tom Barr's *Caves of Tennessee* (1961) reported the local folklore that Waters was ambushed and killed in 1870. In 1990, the McGarr-Waters Papers at the

Tennessee State Library and Archives were consulted, which contained documents which clearly proved that Waters was still alive as late as December 9, 1887. Subsequent research by Marion O. Smith resulted in the discovery of Waters' obituary in the February 4, 1894, issue of the *Nashville Daily American*. Based upon this new information, the author located Waters' grave in the Nashville National Cemetery. Waters' house at 407 Fatherland Street in east Nashville is no longer in existence. This past year Shelah Waters' name was found by Joseph C. Douglas in another Warren County grotto, Hubbards Cave.

Spelunking Socialists and Students

Annette M. Oeser and James K. Oeser, 111 Orchard Valley Circle, Hendersonville, TN 37075-2415

Ruskin Cave, Dickson County, Tennessee, has been noted at least since 1808 and 1810, when deeds listed a "great cave" as a landmark of the property. Ruskin was home to a socialist commune in the late 1890s and to Ruskin Cave College (RCC) from 1904 to 1918. Graffiti in the cave shows that it has been visited by numerous people, including some adventurous individuals who belly crawled over 60 m to reach the back portion of the cave. One hundred students and two faculty members from RCC have been identified as traversing the crawl, since their names and/or initials are found past that point. Ten identifiable trips are noted that contain names or initials and a date. Two trips were led by faculty members R. J. Kelly and Virgil B. Hatley. Kelly's group (1 faculty member, 6 students) contained at least 4 females while Hatley's group (1 faculty member, 7 students) consisted of at least 5 females. The socialist commune found its home at Ruskin from 1896 until 1899. The cave was named after the noted British socialist John Ruskin, who never visited the colony. The socialists used the cave entrance extensively for canning, food storage, and dances. Several socialist names appear before and after the crawl. C. W. Broeg, the stonecutter for the commune, chiseled his name before the start of the crawl. Other socialists entered the back of the cave on September 9, 1899, before the colony dissolved and the cave property was sold.

Caves and Civil War Armies in the Chattanooga Region

Marion O. Smith, P O Box 8276, U T Station, Knoxville, TN 37996-0001

Some caves in southern Tennessee, northeastern Alabama, and northwestern Georgia relate to movements of Civil War armies. On or near the routes the armies traveled were caves worked by the Confederates for saltpeter or springs with associated passages. Over a dozen of these caves were visited by Union troops during the last half of the war. Some were entered during the Chickamauga-Chattanooga campaign while others were subsequently toured by railroad guards or transient soldiers. Two of the caves, Lookout and Nickajack, received heavy visitation by men from both sides. Many of these military tourists have been identified.

PALEONTOLOGY SESSION

A Modern and Holocene Bone Site in White Cross Bone Cave, Tennessee

Frederick Grady, Department of Paleobiology, MRC 121 NHB, Smithsonian Institution, Washington, D.C. 20560; Laurie Adams, 76 Lavale Avenue, Asheville, NC 28806

The surficial deposits in White Cross Bone Cave, Cocke County, Tennessee include 10 species of mammals and several birds. The well preserved nature of the material is suggestive of an owl roost or natural trap. An owl roost is suggested by the dominance of several species including *Sigmodon hispidus* [Hispid cotton rat], *Microtus pinetorum* [pine vole], and *Blarina brevicaduda* [short-tailed shrew], and the shallow depth of the cave such that small animals would likely survive a fall and be able to climb out of the cave. A test pit 30 cm deep reveals a similar fauna though less well preserved. None of the species in White Cross Bone Cave are extinct and all are found in the local area today.

New Finds of Pleistocene Tapirs from Tennessee, Virginia, and North Carolina

Frederick Grady, Department of Paleobiology, MRC 121 NHB, Smithsonian Institution, Washington, D.C. 20560; David A Hubbard, Jr., Virginia Cave Board, PO Box 3667, Charlottesville, VA 22903; Cato Holler, Jr., O Box 100, Old Fort, NC 28762

Six new discoveries of Pleistocene tapirs are all referred to as *Tapirus veroensis* based on size. The Tennessee specimens consist of an upper second molar from Blue Spring Cave, White County, a lower first molar from an unnamed cave in Montgomery County, and the diaphysis of a femur from Upper Buffalo Mountain Cave, Washington County. All are new county records of *Tapirus* in Tennessee. The Virginia specimens consist of an upper fourth premolar or first molar from Slip Sliding Away Cave, Scott County, and an upper first or second molar from Lost Lake Cave also of Scott County. Both Virginia specimens are from newly discovered caves. The North Carolina specimen is a partial upper molar from Blowing Springs Cave, Swain County and is the first cave record of *Tapirus* from the western part of the state. All 5 teeth have had their roots chewed off by rodents, probably *Neotoma magister* [eastern woodrat], and the femur also exhibits evidence of rodent gnawing.

New Paleontological Cave Resource Finds In Virginia

David A. Hubbard, Jr., PO Box 3667, Charlottesville, VA 22903
Frederick Grady, Department of Paleobiology, MRC 121 NHB, Smithsonian Institution, Washington, D.C. 20560

A new inventory of paleontological resources in Virginia caves has yielded significant new records. Records include additional fauna at known paleontological sites and new sites. New sites appear to represent accumulations by wash-in, pit-fall, pack-rat hoarding and visitation. New records of extinct fauna include: *Arctodus simus* [short-faced bear], *Mammut americanum* [mastodon], *Mammuthus primigenius* [woolly mammoth], *Tapirus veroensis* [vero tapir], *Platygonus compressus* [flat-headed peccary], and *Bootherium bombifrons* [musk ox]. Goals of the Paleontological Resource Inventory Of Virginia Caves (PRIOVAC) include: 1) determining the context of deposits; 2) taxa inventory; 3) communicating with fellow cavers about the importance of paleontological resources and appropriate protocols when suspected paleontological resources are discovered. The paleontological resources of Virginia caves are protected by the Code of Virginia.

RESCUE SESSION

The USAR stretcher: A New Litter For Cave Rescue

Jay Kennedy, 408 Mason Street, Marshall, MN 56258

The USAR - Urban Search and Rescue Stretcher- was developed from the Neills-Robertson stretcher. The self-contained unit includes a detachable semi-rigid plastic drag plate, Cordura nylon fabric-covered foam and plastic stretcher body, integral fiber pile exposure bag, removable head support and attached rigging straps for both horizontal and vertical lift of a casualty. It is adjustable to fit a wide range of patient sizes, from children to large adults. It is lightweight (9.9 kg) and compact, rolling down to 25 cm x 76 cm. Placement of a patient in the USAR can be done without rolling the casualty, using as few as two rescuers. The USAR encircles the patient, acting as a full-body splint. It has a very low profile for tight cave passages and can be dragged through mud or over rock and gravel, protected by the plastic drag plate. Vital signs are easily assessed with minimal manipulation of the litter straps. The USAR is x-ray translucent and contains no metal. The USAR is an excellent evacuation aid for caving groups exploring remote cave systems or for rescue caches.

A Self Rescue Technique for Dealing with the Edge of a Drop

Cindy K. Heazlit, 5672 Bluegrass Lane, San Jose, CA 95118-3513, cheazlit@ix.netcom.com

One of the challenges of vertical caving is negotiating the edge of a drop. The caver must deal with loose rock, overhangs, and excess friction when the rope touches the rock. These hazards are increased in a self rescue situation. Some of the rescue hazards can be mitigated through proper patient preparation and a special edge technique. In the first phase of the technique, the rescuer prepares the patient by placing them in a chest harness. A quick attachment safety and an ascender are clipped to the patient's seat harness. A carabiner or pulley is clipped to the leg loop of the harness. The main line runs through this entire system. The rescuer also attaches a safety ascender and an ascender to their own harness. In the second phase of the technique, the main line and patient are hauled to the top of the drop. In the third phase, the rescuer clips into the main line with the safety and runs the tail of the line through the harness ascender. The rescuer squats at the edge of the drop, and pulls in as much of the tail as possible. The rescuer then stands up, hauling the patient up.

The patient's seat ascender will capture the upward progress. This procedure is repeated until there is no rope left. At this point the patient should be a least a foot above the edge of the lip. The rescuer can then drag the patient across the lip into a safe area.

SURVEY AND CARTOGRAPHY SESSION

A Versatile Rangefinder

Dale J. Green, 4230 Sovereign Way, Salt Lake City, UT 84124

Optical range finders based on the parallax method are almost totally worthless in the cave environment because of low light levels. Even with powerful (heavy and bulky) lights, converging the illuminated images does not produce satisfactory results. However, if an object at the distance being measured is illuminated with a spot from a laser beam, the result is astonishingly accurate. Using an instrument with a lens separation of 10 cm, repeatable accuracy of 3 cm is possible up to about 6 m. Accuracy degrades to 5 cm at 9 m, 15 cm to 15 m, 30 cm to 30 m, and about 1.5 m up to 45 m (if you can see the spot). Using this instrument it is possible to make accurate, non-invasive measurements to inaccessible or environmentally sensitive areas.

SpeleoMeshing: A Technique for High Definition Cave Surveys

Greg Passmore, 3D Pipeline Corp., 599 Mathilda Ave., Suite 39, Sunnyvale, CA 94086

This paper describes a set of novel computer techniques for cave and mine mapping which are collectively referred to as SpeleoMeshing. The process yields detailed volumetrics, dense meshes for structural finite element analysis, and photo-realistic rendering. The techniques are low cost, high in accuracy and suitable for use on personal computers.

The process is composed of three steps: collection of passageway profiles, conversion of the profiles into 3-dimensional models and, optionally, collection and application of texture maps on passageway walls for photo-realistic rendering.

The first step of the process uses a simple pocket laser to outline each passage profile along survey lines for photographic capture. The photograph is subsequently digitized and used to calculate passage profile axiometric distances. In the second step, the resulting axiometric passage profile data is extruded between profiles into a 3-dimensional wire frame mesh. This wire frame mesh data is suitable for high accuracy volumetric analysis and for structural finite element analysis. In a third step, for high quality rendering, the photographs of passageway walls are taken for color and texture definition. The resulting photographs are then texture mapped onto the 3-dimensional model, and computer rendering techniques are used to produce near photo-realistic renditions of the cave.

Automatic Underwater Surveying and Mapping

Fred Wefer, P.O. Box 47, McDowell, VA 24458; Barbara am Ende & William C. Stone, 18912 Glendower Rd., Gaithersburg, MD 20879

In October 1998, the U. S. Deep Caving Team will field an expedition to Wakulla Springs, a show cave in The Edward Ball Wakulla Springs State Park south of Tallahassee, Florida. The objectives are to continue the exploration, survey, mapping, and scientific study begun in 1987 by The Wakulla Springs Project and continued by the Woodville Karst Plain Project. Wakulla Springs is an underwater cave exceeding 5 km in length and 100 m in depth.

Surveying will be done automatically by a Digital Wall Mapper (DWM) mounted on a Diver Propulsion Vehicle (DPV). The DWM uses an inertial navigation system for determining the position and orientation of the DPV and a sonar device that simultaneously measures thirty-two wall distances for determining cross sections. Data are gathered several times per second, the resulting spacing of wall points being a fraction of a meter.

Within the DWM, the data from the inertial navigation system, the sonar device, three pressure sensors, and a thermometer are stored in an on-board computer. When the DPV returns to the surface the data are downloaded to a Personal Computer (PC). The PC reformats and writes the data to a zip disk that is then transferred to a Silicon Graphics workstation. Nine separate programs, written in ANSI C and using OpenGL for graphics support, comprise the software suite. A three-dimensional interactive cave map is produced with minimal human intervention.

INDEX TO VOLUME 60 OF THE JOURNAL OF CAVE AND KARST STUDIES

IRA D. SASOWSKY AND KEENA L. TOMKO

Department of Geology, University of Akron, Akron, OH 44325-4101, USA

This index covers all articles and abstracts published in volume 60 parts 1, 2, and 3, including the selected abstracts from the 1998 Society meeting in Sewannee, Tennessee.

The index consists of three sections. The first is a **Keyword** index, containing general and specific terms from the title and body of an article. This includes cave names, geographic names, etc. The second section is a **Biologic** names index. These terms are Latin names of organisms discussed in articles. The third section is an alphabetical **Author** index. Articles with multiple authors are indexed for each author, and each author's name was cited as given.

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

Construction of the index was greatly aided by use of the KWIX indexing program, and thanks are extended to Keith D. Wheeland, the author of that software.

KEYWORD INDEX

BIOLOGIC NAMES INDEX

AUTHOR INDEX

CAVE SCIENCE NEWS

EXPLORATION EDITOR NEEDED BY JOURNAL

The *Journal of Cave and Karst Studies* is looking for a new Associate Editor of Exploration. The present Exploration Editor, Doug Medville, now serves as the NSS Administrative Vice-President and would like to step down as soon as a replacement is identified. The responsibilities of the Associate Editors are to solicit articles, arrange for appropriate reviews of papers in their fields of expertise, work with authors to prepare their manuscripts for publication, make recommendations concerning acceptance and rejection of submitted paper, and assist the Editor in gathering material for the non-refereed section of the Journal. Advice from the Associate Editors, along with the *Journal's* Advisory Board, is commonly solicited on editorial policy decisions, making an Internet address highly desirable.

The *Journal* seeks to strengthen its exploration department and is looking for a pro-active caver with contacts in the exploration community and experience in scholarly publishing. Interested candidates are asked to send a letter of interest by February 15, 1999 to the editor at: HoseL@jaynet.wcmo.edu.

POSITION AVAILABLE - CHAIRMAN OF THE NSS INTERNATIONAL EXPLORATION COMMITTEE

The International Exploration Committee is in the office of the Executive Vice President . The duties include serving as one of the points of contact for those wishing to use the NSS name in a list of sponsors for an activity or event outside of the United States. The Committee presents applications for official NSS expedition status to the Board of Governors. This committee also administers the International Exploration Fund Grant Program and assists the Fund Raising Committee in soliciting donations for this fund. Members interested in this position should contact the NSS Executive Vice President, Ray Keeler,via email rkeeler@pcslink.com or call h/602-561-2917, w/602-436-6585.

SEVENTH MULTIDISCIPLINARY CONFERENCE ON SINKHOLES AND THE ENGINEERING AND ENVIRONMENTAL IMPACTS OF KARST with an Introductory Course on Applied Karst Geology and Hydrology April 10-14, 1999 Harrisburg/Hershey, Pennsylvania

Presented by: U.S. Environmental Protection Agency; U.S. Dept. of Transportation/Federal Highway Administration; Pennsylvania Geological Survey; Association of Groundwater Scientists & Engineers of the National Ground; Water Association; Geo-Institute of the American Society of Civil Engineers; Assoc. of Engineering Geologists; Virginia Water Resources Research Center; Mid-Atlantic Karst Consortium; Karst Waters Institute; P.E. LaMoreaux & Associates, Inc.

The Seventh Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst will be held April 10-14, 1999, in Harrisburg/Hershey, Pennsylvania.

Geologists, geographers, engineers and others will share knowledge among the various disciplines with an emphasis on practical applications and case studies. Civil and environmental engineers, geologists, biologists, planners, and regulatory officials who deal with water resources, waste disposal, foundation stability, and other geotechnical issues will benefit from attending the Seventh Conference.

Due to popular demand, the Seventh Conference will include an optional one-day Introductory Short Course on Applied Karst Geology and Hydrology. This course is intended to provide a basic understanding of the fundamental principals of karst as they relate to real-world applications. The Short Course will be of particular benefit to local, state, and federal government officials; consultants; students; and others tasked with decision making and project management involving karst.

Conference web site: http://www.uakron.edu/geology/karstwaters/7th.html.

Please direct any questions concerning papers, registration, or attendance to Barry F. Beck, J. Gayle Herring, or J. Brad Stephenson.

NEW WORLD DEPTH RECORD IN POLAND REPORTED

Zbigniew Zwolinski recently reported on the *Cavers Digest* that a Polish expedition linked the cave labeled Pl-2 to Lamprechtsofen (the Leoganger Steinberge massif, the Northern Calcareous Alps, Austria) on August 19, 1998. The new depth of Lamprechtsofen reached 1632 m. If the report is confirmed, Lamprechtsofen became the deepest explored cave in the world..

MULTILINGUAL DICTIONARY FOR SPELEOLOGISTS

The International Union of Speleology has an online dictionary of interest to cavers and karst researcher. It can be found at: http://rubens.its.unimelb.edu.au/~pgm/uisic/lexintro.html

FRIENDS OF KARST MEETING BOWLING GREEN, KENTUCKY, SEPT. 23-25, 1998

The Friends of Karst held a joint meeting with UNESCO's International Geological Correlation Program, Project 379: "Karst Processes and the Global Carbon Cycle", September 23-25, 1998, in Bowling Green, Kentucky. The meeting was organized by Chris Groves (Department of Geography and Geology, Western Kentucky University) and Joe Meiman (National Park Service, Mammoth Cave) with the help of Ken Kuehn of Western Kentucky University, and Nick and Whit Crawford of Crawford & Associates. Talks were interspersed with refreshments, meeting karst people from all over the world, trips to Mammoth Cave, and a gala banquet at Lost River Cave. It was one of the most memorable meetings we've been to, with more than 100 participants from all over the United States and the world, including China, Japan, Hungary, Poland, Romania, Belgium, United Kingdom, and Canada.

Each morning was devoted to talks covering broad topics such as the Mammoth Cave region and the CO_2 cycle in karst systems. On the first morning, geologic and hydrologic research in the Mammoth Cave area was reviewed by Art Palmer, Will and Bette White, and Ralph Ewers, followed by a report of a new dating technique that makes it possible to establish the very old age of the upper-level sediment in Mammoth by Darryl Granger and Derek Fabel of Purdue University. Nick Crawford reviewed the spectacular environmental karst problems in the Bowling Green area, and Joe Meiman and Chris Groves summarized current research in Mammoth Cave. This was followed by two sessions in the afternoon by individuals presenting their current research. Topics ranged from specific cave studies to regional geomorphic investigations in one session and CO_2 geochemistry in karst systems in the other. That evening people were bused to the Park Mammoth resort for a meal and then to Mammoth for the Half-Day Tour led by long-time karst researchers Derek Ford, Will White, Ralph Ewers, and Art Palmer.

On the second morning, representatives from the Institute of Karst Geology in Guilin, China, introduced the theme of the role of karst in the CO_2 cycle. Camille Ek, Julia James and Will White gave examples of CO_2 flux in caves, both in the atmosphere and the water. This was followed by general-interest talks by some of the well-known overseas participants. The afternoon again featured two sessions. One covered practical karst hydrologic problems and their solutions, while the other covered geochemical and isotopic studies in karst water. Several posters were on exhibit. Of note was the new atlas of Karst Ground-Water Basins in Kentucky developed by Joe Ray and James Currens. After the talks, everyone was bused to a scrumptious catered banquet at Lost River Cave in Bowling Green, which included boat tours in the cave, which is now owned by Western Kentucky University. No one returned early.

The last day featured a variety of field trips. These featured local environmental problems, a visit to the laboratory of Crawford and Associates, surface karst, and cave trips illustrating speleogenesis and geology in the Mammoth Cave system. This culminated three action-packed days in which people had the opportunity to meet many engaging foreign karst workers and to see old friends. The great effort to assemble all these people really paid off and we are all grateful to Chris and Joe for their vision and to Western Kentucky University for organization, van transportation, and classroom space.

ENDANGERED CAVE AND KARST SPECIES

The list of Endangered and threatened cave and karst species of North America from the U.S. Fish and Wildlife Service is available at: http://www.fws.gov/~r9endspp/endspp.html.

ILLINOIS CAVE AMPHIPOD LISTED AS ENDANGERED

An article about the U.S. Fish and Wildlife Service adding the Illinois Cave Amphipod to the endangered list appeared in the Sunday, September 6 St. Louis Post-Dispatch in the MetroWatch section on page C2 under the headline "Monroe County Cave Critter is now on U.S. endangered list". In a few days the text should be available in the archives accessible via www.stlnet.com. (Philip W. Newell)

INTERNATIONAL SYMPOSIUM OF BIOSPELEOLOGY TO BE HELD IN CROATIA

We would like to invite you to participate in the work of The XIVth International Symposium of Biospeleology which will be held in 1999 in Makarska, Croatia. The first announcement for The XIVth International Symposium of Biospeleology and all the preliminary information can be found at http://www.hpm.hr/biospel.

Submitted by the Drasko Holcer for the Organizing Committee of The XIVth International Symposium of Biospeleology; Croatian Biospeleological Society; c/o Croatian Natural History Museum; Demetrova 1, HR - 10000 Zagreb, Croatia; tel +385 1 424995 fax 385 1 424998; e-mail biospel@hpm.hr.

SPELEOLOGICAL CONFERENCE IN CUBA SCHEDULED FOR APRIL 2000

The Speleological Society of Cuba (La Sociedad Espeleológica de Cuba) will celebrate its 60th anniversary during a congress in the city of Camagüey, which is served by an international airport. "Speleology for the New Millenium" will be the theme of the meeting between April 16 - 22, 2000. The registration cost is $100 U.S. Abstracts (<250 words) from presenters are due by December 15, 1999.

They Cubans are offering a package deal including 7 nights lodging (double occupancy), breakfast, lunch, dinner, transportation in Camagüey, and some activities for $270 U.S.

More information on the conference may be obtained from: Angel Graña González; Secretario del Congreso; Sta B. No. 6611 Entre 66 y 70; Miramar, Playa, Ciudad de La Habana; HYPERLINK mailto:Funat@artsoft.cult.cu; Tel.29-2885/Fax24-0438 or Abel Perez Gonzalez; Biokarst@cidea.unepnet.inf.cu.

Kevin and Carlene Allred met inside a Utah cave in the mid-1970s. Since then, they have studied and documented hundreds of caves in the western United States, Alaska, and Hawaii. They reside with their four children in a semi-remote, self-built log house in southeastern Alaska.

William R. Halliday recently retired as Chairman of the NSS's Hawaii Speleological Survey and as President of the Commission on Volcanic Caves of the International Union of Speleology. A graduate of Swarthmore College and of George Washington University School of Medicine, he has published many papers in vulcanospeleology, calcareospeleology, glaciospeleology, and spelean history.

Dr. Vladimir Maltsev mostly works in the fields of applied geostatistics, software design, and ore estimation methodology. In these fields, he has written about 20 articles, 3 books, and 3 programs with circulation above 500 copies. His avocational interest in mineralogy, including mineralogy of caves, has led to about 40 published articles. Dr. Maltsev is a widely recognized photographer with 400 photos published on calendars and magazine covers. His films have won awards at several nature film

Stewart B. Peck is professor of biology at Carleton University. He has long been interested in the ecology and evolution of cave insects in both North America, the West Indies, and throughout Latin America.

Amador E. Ruiz-Baliu was a research biologist at the cave research laboratory of the Cuban Academy of Sciences at Siboney, Cuba. He is now chair of the Biology Department at the Eastern University, Santiago de Cuba. His present research is on the crickets of Cuba, especialy the rich faunas of cave crickets.

Gabriel F. Garces Gonzales was a research biologist at the cave research laboratory of the Cuban Academy of Sciences at Siboney, Cuba. He is now employed as a research scientist at the Eastern Center of Ecosystems and Biodiversity, at the Tomas Romay Museum, Santiato de Cuba. He presently works on the taxonomy of Cuban flies, especially the plant-feeding Agromyzidae.

Veronica A. Toth, MSc (McMaster University) is a geologist and remote sensing specialist at Universal Systems, Fredericton, New Brunswick. Derek C. Ford (Professor of Geography and Geology, McMaster University, Canada) is a leading innovator in cave genetic studies and dating of cave deposits. Henry Schwarcz (Professor of Geology, McMaster University, Canada) has contributed directly to geology, archaeology, and anthropology through his stable isotope research studies.

Dr. Donald W. Webb is an insect systematist. His research focuses on the systematics and ecology of the Diptera families Rhagionidae and Therevidae for the world. Currently, he is developing a database on the macroinvertebrate biodiversity in Illinois caves and springs and examining the effects of water quality on this biodiversity.

GUIDE TO AUTHORS

The *Journal of Cave and Karst Studies* is a multidisciplinary journal devoted to cave and karst research. The *Journal* is seeking original, unpublished manuscripts concerning the scientific study of caves or other karst features. Authors do not need to be members of the National Speleological Society but priority is given to manuscripts of importance to North American speleology.

LANGUAGES: Manuscripts must be in English with an abstract, conclusions, and references. An additional abstract in another language may be accepted. Authors are encouraged to write for our combined professsional and amateur readership

CONTENT: Each paper will contain a title with the authors' names and addresses, an abstract, and the text of the paper. Acknowledgments and references follow the text.

ABSTRACTS: An abstract stating the essential points and results must accompany all articles. An abstract is a summary, not a promise of what topics are covered in the paper.

REFERENCES: In the text, references to previously published work should be followed by the relevant author's name and date (and page number, when appropriate) in brackets. All cited references are alphabetical at the end of the manuscript with senior author's last name first, followed by date of publication, title, publisher, volume, and page numbers. See the current issue for examples. Please do not abbreviate periodical titles.

SUBMISSION: Authors should submit three copies of their manuscript (include only copies of the illustrations) to the appropriate specialty editor or the senior editor. Manuscript must be typed, double spaced, and single-sided. Electronic mail submissions require prior permission of the Associate Editor, and is only encouraged from countries where timely transmission of air mail is a problem. Authors submitting manuscripts longer than 15 typed pages may be asked to shorten them. Authors will be requested to submit an electronic copy of the text, a photograph, and brief biography upon acceptance of the paper.

DISCUSSIONS: Critical discussions of papers previously published in the *Journal* are welcome. Authors will be given an opportunity to reply. Discussions and replies must be limited to a maximum of 1000 words and discussions will be subject to review before publication. Discussions must be within 45 days after the original article appears.

MEASUREMENTS: All measurements will be in *Systeme Internationale* (metric) except when quoting historical references. Other units will be allowed where necessary if placed in parentheses and following the *SI* units.

FIGURES: Figures and lettering must be neat and legible. Figure captions should be on a separate sheet of paper and not within the figure. Figures should be numbered in sequence and referred to in the text by inserting (Fig. x). Most figures will be reduced, hence the lettering should be large. Once the paper has been accepted for publication, the original drawing (with corrections where necessary) must be submitted to the editor. Photographs must be sharp and high contrast. Color will be printed at author's expense only.

COPYRIGHT AND AUTHOR'S RESPONSIBILITIES: It is the author's responsibility to clear any copyright or acknowledgement matters concerning text, tables, or figures used. Authors should also ensure adequate attention to sensitive issues such as land owner and land manager concerns.

PROCESS: All submitted manuscripts are sent out to at least two experts in the field. Reviewed manuscripts are then returned to the author for consideration of the referees' remarks and revision, where appropriate. Revised manuscripts are returned to the appropriate associate editor who then recommends acceptance or rejection. The Senior Editor makes final decisions regarding publication. Upon acceptance, the author should submit all photographs, original drawings, and an electronic copy of the text to the editor.

The senior author will be sent one set of proofs for review. Examine the current issue for more information of the format used.

National Speleological Society
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