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Cantharid Beetle Larvae in American Caves

Stewart B. Peck *

ABSTRACT

Records are given for larval Cantharid beetles (probably *Cantharis*) from eastern North American caves. These larvae, which should be classed as troglonexes, are important predators in terrestrial cave communities.

Larval, but not adult, Cantharid beetles have been known from European caves for some time (Jeannel, 1926; Vandel, 1965). In the literature on North American cave faunas, Packard (1888, Plate 20 and Fig. 14), Reddell (1970), and Holsinger and Peck (1971) record larval Cantharid beetles from caves in Kentucky, Texas, and Georgia, respectively. The purpose of this note is to give additional records of cantharid beetle larvae collected from caves, to show that they should be categorized as troglonexes, and to point out that they may be significant predators in cave communities.

Adult cantharid beetles, commonly called soldier beetles, are found flying in fields in the spring, summer, and fall seasons. Their bodies are elongate and they look somewhat like fireflies, but lack light organs. They are often found on the foliage and flowers of milkweed, goldenrod, etc., where they may feed on nectar and pollen.

The larvae of these beetles generally live in leaf litter and in the soil. Some are predaceous and others are omnivorous. Pupation occurs in cells in the soil. About 320 species of these beetles occur in the United States. The genera *Malthodes*, *Poda-brus*, and *Cantharis* respectively contain about 100, 97, and 56 species in the United States and Canada. There are 13 other, smaller, genera in the same region.

The cave-collected larvae from Europe have been classified in the genus *Rhagonycha*, which is considered as a subgenus of the genus *Cantharis* by North American specialists on these beetles. The one specimen reported by Reddell (1970) was identified as the genus *Cantharis*. Generic determinations were not given by Packard (1888) or by Holsinger and Peck (1971).

Cantharid larvae from caves generally have red-brown heads and whitish bodies. The bodies usually have darker regions on both sides of each of the three thoracic segments. They are elongate, dorso-ventrally flattened (Fig. 1), and about 20 mm in length. To the casual observer, they may be mistaken for the larvae of carabid beetles or staphylinid beetles, which also occur in caves. However, cantharid larvae have four leg segments and one claw, being thus easily distinguished from carabid larvae, which have five leg segments and two claws. Their shape and coloration should usually permit one to separate cantharid from staphylinid larvae. Other technical characteristics can be found in references on insect larvae.

During the course of surveys and work with the invertebrate cave faunas of several eastern states, I became aware of the relative frequency with which cantharid larvae were found in caves. They were usually found under rocks, often near piles of guano or organic debris. Many were taken at carrion bait or in carrion-baited traps. A transcript of my records follows (these specimens are deposited in the Entomology collections of the United States National Museum, Washington, D. C.):

Canada

Ontario. MOIRA, Moira Cave, 11.vi.71, 1, G. Muller. PLANTAGENET, Plantagenet Cave, 13.vii.71, 1, G. Muller. TOBERMORY, Museum Cave, 23.v.71, 1, G. Muller; 16.vi.72, 1, SBP; 5.viii.71, 1, G. Muller.

United States

Alabama. JACKSON COUNTY. Indian Rocks Cave, 7.viii.67, 1, SBP and A. Fiske. Trenton Cave, 27.viii.71, 1, SBP. LIME-STONE COUNTY. Indian Cave, 19.viii.65, 1, SBP. MADISON COUNTY. Barclay Cave, 10.viii.65, 1 in trap, SBP; 17.viii.65, 3 in traps, SBP; 1.ix.65, 5 in traps, SBP. Cave Spring Cave, New Hope, 25.viii, 11.ix.68, 1, SBP, A. Dobson, R. Graham. Moring Spring Cave, 11.ix.68, 1, SBP. MARSHALL COUNTY. Warrenton Cave, 11.vii.73, 1, SBP. Georgia. CHATTOOGA COUNTY. Parker Cave, 12-20.vi.67, 3 in traps, SBP and A. Fiske. WALKER COUNTY. Harrisburg Cave, 12.vii.67, 2, SBP and A. Fiske. Mt. Cove Farm Cave, 20.vi.67, 1, SBP and A. Fiske; 11-20.vi.67, 2 in trap, SBP and A. Fiske. Pettijohn Cave, 10-21.67, 8 in trap, SBP and A. Fiske. Illinois. JERSEY COUNTY. Grafton Cave, 4.iii.48,



Figure 1. Cantharid beetle larva on rotting wood.

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1, H.B. Mills (Illinois Natural History Survey Collections). Kentucky. EDMONSON COUNTY. Whites Cave, 25.vi.73, 1 on rotting board, SBP. WOODFORD COUNTY. Clifton Cave, 8.ix.64, 1, SBP. Tennessee. BEDFORD COUNTY. Reese Cave, 23.viii.65, 3, S. & J. Peck; 12.iii.66, 1, SBP. CANNON COUNTY. Connell Creek Cave, 4.16.vii.73, 5, SBP. Doolittle Cave, 1.15.vii.73, 1, SBP and C. Laing. DEKALB COUNTY. Overall Cave, 4.vii.73, 2, SBP and C. Laing. West Virginia. POCAHONTAS COUNTY. Blue Spring Cave, 23.vi.68, 1, SBP.

The records tend to understate the commonness of these larvae in caves. I initially assumed these larvae to be accidentals in the caves and of little importance to cave communities, so I did not keep records of many of my earlier encounters with them. I now think that the larvae are too frequently encountered in caves to be dismissed as accidentals. Since no adult beetles have been found in the caves (their ecological needs suggest that they would not survive in caves, anyway), it becomes obvious that the beetles use caves for only part of their life cycle and are unable to complete a full life cycle in caves. Consequently, they should be considered as troglonexes.

The lack of adult beetles makes generic determinations of the cave cantharids difficult. In an attempt to obtain adults, I tried to raise larvae through to the adult stage. Several larvae from several caves were easily kept in separate, covered plastic boxes of moist soil in a refrigerator at 60°F (15°C). The larvae crawled over the soil surface or, usually, sat in a system of burrows and tunnels which they dug. They fed readily on bits of fresh hamburger, or freshly killed fruit flies, especially when these were placed between the larval mandibles. These larvae lived for over a year, with one undergoing a moult, but all died before pupation.

The successful rearing of larvae to adults, for purposes of

positive identification, yet remains as a project to be pursued by an interested student of biospeleology. In the meantime, it appears that the larvae belong to the genus *Cantharis*, but it is not known if more than one species is represented in the cave records presented above.

What is the importance of these larvae in cave communities? Most of my collections were within a few hundred feet of the cave entrance and, usually, just inside the dark zone. The larvae, accidentally or intentionally, may come this far into the caves in the course of their larval wanderings. All specimens were plump, suggesting that, even if they arrived by accident, they are successful cave occupants and are by no means starving in the caves. Without regard to how the larvae enter the caves, once in, these large, active, predacious larvae certainly become a very important carnivore in the terrestrial invertebrate cave community. Whether or not the larvae pupate in the caves is not known. If so, and if within a few hundred feet of the cave entrance, most likely the adults soon make their way to the entrance and the outer world in order to complete their life cycle.

I wish to thank the numerous people who have helped me in the field in my studies of the cave faunas of eastern North America. Drs. H. F. Howden (Carleton University) and E. C. Becker (Canadian Biosystematics Research Institute) critically read the manuscript. Dr. Becker and Dr. D. M. Anderson (USNM) confirmed the idea that the larvae are most likely in the genus *Cantharis*. Mr. Kenneth Fender (McMinnville, Oregon) corresponded with me on the problem of the identity of the cantharid larvae. Dr. M. W. Sanderson, Illinois Natural History Survey, is thanked for providing aid to this and to other cave faunal studies and for supplying material from the collections under his care.

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Additional Data on the Mineralogy of the New River Cave

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ABSTRACT

The concentrations of several metallic elements in some speleothems of calcite and of aragonite and the associated waters and, also, in the calcite and aragonite parts of the same speleothems have been determined. The results give no indication that the concentration of Sr is the controlling factor favoring the growth of aragonite under the conditions in New River Cave. In all but one instance, the minor elements are excluded to some extent in the growth of speleothems of calcite and aragonite.

INTRODUCTION

New River Cave, in Giles County, Virginia, is of great interest in the study of the relationships of the polymorphic calcium carbonate minerals, calcite and aragonite, as both minerals are common there and occur in several types of speleothems. New River Cave runs parallel to the axis of Spruce Run Mountain, along the Saltville fault. According to barometric measurements made by Holden, Price and Stephenson in 1942, the entrance is at an elevation of about 2015 ft (614 m). The samples analysed in this study, except No. 78, were taken in the Attic Room, which is about 300 to 350 m from the cave entrance. The room is situated about 40 m above the main passage. An air stream blows into the main passage in winter and out in summer, but there is no perceptible air movement in the Attic Room. The relative humidity is very high, as shown by an experiment in which a weighed sample of water in a polyethylene dish 47.2 cm² in area and 2 cm deep showed a gain in weight of 0.17 gram over a period of 121 days. The CO₂ content of the air in the Attic Room is about 0.67%. This is about 18 times the concentration in the outside air. As the elevation of this part of the cave is about 650 m and the average barometric pressure about 0.93 atmospheres, the partial pressure of CO₂ in the Attic Room air is about 0.0062 atm. The temperature in the Attic Room is nearly constant, showing an annual variation from 11.4° to 12.0°C (Murray, 1954a). The constancy of conditions and the variety of actively growing speleothems of both calcite and aragonite makes the Attic Room a useful laboratory for the study of calcite-aragonite relationships.

In earlier papers (Murray, 1951, 1954a and 1954b), data on the chemical composition of calcite and aragonite speleothems and of the waters associated with them has been given. The development of Atomic Absorption Spectrometry has made it feasible to extend these studies to some elements occurring in these minerals and waters in lower concentrations.

Some of the samples selected for this study were speleothems, found broken on the cave floor, in which both minerals are present in separate layers or patches in contact, indicating a change in the conditions of deposition or the transformation of one mineral into the other. Calcite is thermodynamically stable relative to aragonite, but the change is usually very slow, as shown by the occurrence of aragonite in the interior of large stalagmites.

The other samples were speleothems in contact with water,

either in pools or dripping, so that analyses of both solid and water would reveal the extent to which the accessory metallic elements are co-precipitated with the calcium as the mineral is deposited. It should be realized, in interpreting the data, that the solid was deposited over a much longer period than that involved in collecting the water and that changes may have taken place during that time. The amount of data obtained has been limited, in many cases, by the small size of the sample (for example, 2.8 grams of water in 98 days or 21 grams in 570 days).

EXPERIMENTAL

Samples of still or of rapidly dripping water (No. 78) were collected in clean polyethylene bottles. Samples of slowly dripping water were collected in the borosilicate glass sampling tubes described in an earlier paper (Murray, 1954a). Small samples were taken of the tips of stalactites from which water samples had been collected and clean material was selected for analysis under a binocular microscope. The solid samples were ground in a clean agate mortar and pestle. A weighed portion was dissolved in dilute HCl, centrifuged, and transferred to a clean volumetric flask. Where the sample size permitted, water samples were concentrated for determination of Sr, Mn and Zn by evaporation in platinum or by ion exchange on Dowex-50 resin.

Ca, Mg, Sr, Mn and Zn were determined with a Perkin-Elmer Model 303 Atomic Absorption Spectrometer. Na and K were determined by Flame Emission Spectrometry. Al was determined by the fluorescence of the Al complex with Pontachrome Blue Black R in a solution buffered at pH 4.6.

The minerals were identified with a petrographic microscope using refractive indices, cleavage and extinction angles. The CO₂ content of the air in the Attic Room was determined by Dr. Harold McNair and Miss Robin Kinser, using a Gas Chromatograph with a Porapak Q column.

DISCUSSION

The data given in Table 1 agree with the earlier work on New River Cave (Murray, 1954b) in showing that the Mg content of calcite is generally much greater than that of aragonite. This is also evident from a comparison of the solid samples of Table 3 (aragonite) with those of tables 2 and 4 (calcite). In most cases, the Sr content of aragonite is greater than that of calcite. The aragonite unit cell is of the same structure and nearly the same

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size as is that of strontianite (SrCO_3) and, therefore, Sr should be expected to substitute for Ca in aragonite more readily than the smaller Mg^{++} ion. The carbonates of the larger alkaline earth ions crystallize with the orthorhombic aragonite structure type whereas the smaller Ca^{++} and Mg^{++} ions crystallize with the rhombohedral calcite structure. Ca is the only member of the family whose carbonate is known with both types. BeCO_3 is not known. No significant differences are apparent from this data between calcite and aragonite in their content of Na, K, Mn, or Zn. It will be noted that the pairs D and G in Table 1 have much less Mg than have the pairs A and K and that the percentages of Sr in the calcite and aragonite phases are very similar in D and G, whereas in A and K there is much more Sr in the aragonite. This suggests that the calcite parts of D and G were originally precipitated as aragonite, which subsequently was transformed to the more stable calcite.

In tables 2 and 3, the metal ion content of several stalactites of calcite and of aragonite is given together with the corresponding data for the water associated with each. In Table 4, similar data are given for 3 samples of cave coral from pools and for the associated pool waters. The data for solids is expressed as percentage and that for water as milligrams per liter (ppm).

Holland and others (1964) have shown that, when aragonite is precipitated in the laboratory at 90° to 100°C ., the ratio of Sr to Ca in the aragonite phase is related to that in the solution phase by:

$$\left(\frac{m_{\text{Sr}^{++}}^{\text{A}}}{m_{\text{Ca}^{++}}^{\text{A}}} \right) = k_{\text{Sr}^{++}}^{\text{A}} \left(\frac{m_{\text{Sr}^{++}}^{\text{L}}}{m_{\text{Ca}^{++}}^{\text{L}}} \right)$$

TABLE 1. Percentage of Minor Elements in the Calcite and Aragonite Parts of Speleothems in which Both are Present.

Sample*		Mg	Sr	Na	K	Mn	Zn
A	Calc.	0.74	0.0040	0.026	0.042	0.0013	-
	Arag.	0.12	0.026	0.023	0.044	0.0013	-
D	Calc.	0.031	0.018	-	-	0.0010	0.0005
	Arag.	0.0073	0.017	-	-	0.0010	0.0004
G	Calc.	0.026	0.036	0.013	-	0.0008	-
	Arag.	0.0028	0.033	0.014	-	0.0007	-
K	Calc.	0.72	0.0064	0.019	0.029	0.0014	-
	Arag.	0.040	0.038	0.021	0.039	0.0014	-

* Descriptions of samples in Table 1.

A Stalagmite of fine grained, acicular aragonite, 72 mm in diameter, with irregularly shaped patches of coarsely granular calcite.

D Stalagmite, 60 mm in diameter, with center of equant calcite crystals up to 10 mm and an outer layer of medium-fine aragonite crystals oriented radially and up to 6 mm long.

G Eccentric stalactite of coarse, radially oriented aragonite crystals, with minor diameter of 50 mm. The central tube is lined with equant calcite crystals up to 2 mm in diameter.

K Ribbon-type stalactite with older part of fine, acicular aragonite and newer part of moderately coarse calcite.

where k_{Sr}^{A} is the distribution coefficient for Sr between solution

and aragonite. The value of k_{Sr}^{A} would be greater than unity if the Sr were concentrated in the aragonite phase during precipitation and vice versa. The value of k is temperature dependant and decreases with rising temperature. Holland, *et al.* give the value 1.0 for k_{Sr} for aragonite at 25°C . and 0.14 for k_{Sr} for calcite. Their findings for Luray Caverns are in rather good agreement with these values.

The values of k_{Sr} and also of k_{Mg} have been calculated for the solid-liquid pairs from New River Cave and are shown in tables 2, 3 and 4. The k_{Sr} values show considerable variation and are somewhat smaller than those obtained by Holland, *et al.* They show that Sr is excluded in the precipitation of aragonite under these conditions, but not as strongly as in the precipitation of calcite. The k_{Mg} values show less variation and show that Mg is excluded more strongly by aragonite than by calcite. Na, K, and Zn were found to be excluded by both calcite and aragonite in all cases where the data was obtained. Mn was excluded in most cases, the sole exception being Pool sample No. 75, where a k_{Mn}^{C} value of 1.74 was found.

The distribution coefficient may be derived theoretically. It depends on the solubility products of the two carbonates (e.g. aragonite and strontianite for k_{Sr}^{A}), the activity coefficients of the two solid carbonates, and the activity coefficients of the two ions in solution. In the present case, these quantities are nearly constant and k_{Sr}^{A} would, thus, be expected to be constant. The conditions for which this should be true involve the slow growth of a very small crystal in equilibrium with a solution of constant composition at a constant temperature. In the case of a stalactite growing in contact with the water phase, the water phase will be supersaturated with respect to calcite or to both calcite and aragonite, not at equilibrium. If the water phase were in equilibrium with calcite, it would be undersaturated with respect to the more soluble aragonite. The composition of the water phase may be expected to change in response to changes in the temperature and humus content of the soil and in the amount of rainfall. There may also be changes in the path the water follows in moving from the soil to the stalactite and, thus, in the kind of rock that it dissolves. In the final stage of the evolution of the water, the rate of dripping from the stalactite, the rate of loss of CO_2 to the air, the rate of precipitation on the stalactite, the rate of evaporation, and the identity of the mineral being deposited may all affect the composition of the water phase. From the fact that stalactites often contain both aragonite and calcite, it is clear that changes may occur during the time required for deposition of the solid samples taken for analysis, if not during the shorter time required to collect the water sample.

It is known (Cornu, 1907) that high concentration of Sr favors the precipitation of aragonite in the laboratory. Comparison of Sr concentrations of the water samples reported in tables 2 and 3 gives no indication that Sr concentration is the controlling factor in the cases studied from New River Cave. Several other factors are known to favor the precipitation of aragonite, including Mg concentration, temperature, degree of supersaturation, and the kind of nuclei present. The temperature in New River Cave is in the region that generally favors calcite in laboratory precipitation and, at least in the Attic Room, shows little variation. Mg concentration, supersaturation, and the kind of nuclei present appear to be plausible as controlling factors. These, in turn, are probably influenced by the past history of the water phase, the rate of water flow, and the rate of growth of the stalactite.

Curl (1962) has discussed the role of Mg and Sr in favoring the precipitation of aragonite. He presents strong arguments that the mode of their action concerns the kinetics of the crystal growth, rather than the thermodynamic stability of the solid

TABLE 2. Analyses of Calcite Stalactites and Associated Water.

Sample Number	Collection Rate (ml/days)	Ca	Mg	k_{Mg}	Sr	k_{Sr}	Na	K	Mn	Zn	Al
78	500/0.1	18.3ppm	16.0		0.17		1.1	0.9	0.004	0.07	0.004
78-solid		37.0 %	0.48	0.015	0.013	0.038	0.012	0.023	0.0011	0.003	0.0025
79	50/98	12.1	14.0		0.037		1.1	-	0.007	-	-
79-solid		37.5	0.74	0.017	0.0056	0.049	0.012	0.019	0.0008	-	-
80	111/98	16.8	20.7		0.048		1.1	1.1	0.010	0.4	-
80-solid		38.0	0.65	0.014	0.0089	0.082	0.013	0.020	0.0010	0.003	-
86	16/121	13.4	20.5		0.034		-	-	-	-	-
86-solid		38.8	0.79	0.013	0.0074	0.075	-	-	0.0008	-	-
89	21/570	20.1	16.0		0.060		-	-	0.003	-	-
89-solid		37.6	0.44	0.015	0.019	0.017	-	-	0.0005	-	-

TABLE 3. Analyses of Aragonite Stalactites and Associated Water.

Sample Number	Collection Rate (ml/days)	Ca	Mg	k_{Mg}^A	Sr	k_{Sr}^A	Na	K	Mn
81	2.8/98	12.9 ppm	22.2		0.02		-	-	0.02
81-solid		39.5 %	0.10	0.0015	0.059	-	0.013	0.021	0.0011
82	56/98	14.1	20.7		0.029		-	-	-
82-solid		38.6	0.12	0.0021	0.051	0.64	-	-	0.0009
84	6.2/121	14.5	16.3		0.023		-	-	-
84-solid		40.1	0.043	0.00095	0.031	0.49	-	-	0.0008
85	21/121	12.5	20.0		0.033		-	-	-
85-solid		40.0	0.032	0.00050	0.036	0.34	-	-	0.0007

TABLE 4. Analyses of Calcite Cave Coral and Associated Pool Water.

Sample Number	Ca	Mg	k_{Mg}	Sr	k_{Sr}	Na	K	Mn	Zn	Al
75	13.5 ppm	19.0		0.038		1.0	0.8	0.0015	-	0.008
75-solid	37.7%	0.95	0.018	0.0070	0.066	0.023	-	0.0075	-	-
77	13.3	18.4		0.024		1.0	0.8	0.0078	-	-
77-solid	37.5	0.93	0.018	0.0052	0.077	0.011	0.021	0.0011	0.0005	-
83	13.2	14.3		0.022		-	-	-	-	-
83-solid	38.6	0.90	0.022	0.0026	0.040	-	-	0.0018	-	-

phases. Sr is thought to act by forming strontianite nuclei upon which the growth of aragonite can start. Mg, on the other hand, is thought to act by becoming adsorbed at the boundaries of growth steps and inhibiting the growth of calcite. It has long been a puzzle as to how Mg, which is strongly excluded from the aragonite structure, can act to promote the growth of aragonite.

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Extinct Peccary (*Platygonus compressus* LeConte) from a Central Kentucky Cave

Ronald C. Wilson *, John E. Guilday †, and John A. Branstetter *

ABSTRACT

Recent exploration of Lone Star Peccary Cave, Kentucky revealed a well preserved partial skeleton of a young adult flat-headed peccary (*Platygonus compressus*). The Lone Star Skeleton is compared with other Pleistocene peccaries from Kentucky and is found to be very similar. The probable Wisconsinan age of the skeleton is discussed.

INTRODUCTION

Lone Star Peccary Cave, Hart County, Kentucky (Fig. 1), a solution feature in the Mammoth Cave (Ste Geneviève, Beaver Bend, and Paoli) limestones of Mississippian age (Moore, 1972), is located in south-central Kentucky. It opens in a karst valley on the western flank of the Chester cuesta near its easternmost extension, just north of the Central Kentucky Karst (as delineated by Quinlan, 1970). A partial survey indicates that over a mile of passageways exist in the cave. The owner, Mr. Roy Butler, Jr., Route 2, Bonnieville, Kentucky, has asked that we not divulge the exact location of the cave. We respect his privacy and congratulate his efforts to conserve the cave! The location may be obtained from the T.H. Morgan School of Biological Sciences, University of Kentucky, with the understanding that the owner must be consulted before any scientific work is begun in the cave.

The cave was virtually unknown until a partial skeleton of the extinct flat-headed peccary was discovered there in March, 1973.

THE LONE STAR PECCARY CAVE SKELETON

Catalogue number: Carnegie Museum of Natural History, Section of Vertebrate Fossils No. 24589.

Species

Platygonus compressus LeConte. Flat-headed peccary. Material: (Figures in parentheses are field-plot numbers; see Fig. 2.) Cranial: partial right mandible with full dentition (23); right upper third premolar (14); right upper first incisor (10); right upper second molar, posterior loph (10). Post cranial: left femur (1); right femur (12); left patella (2); left tibia (5); left fibula (6); right metatarsus (7); fragments of left innominate—acetabulum, ischium, tuber ischii (9, 13, 15, 17); rib fragments (3, 4, 8, 11, 19); fragment of left scapula (14); right humerus (21); left radius/ulna (22); right radius/ulna (18); right metacarpal IV (16); left metacarpal IV (20).

Circumstances

Bones were found, either on the surface or superficially buried in yellow-brown sterile silt, scattered over an area approximately 5 by 25 ft in size. This area is adjacent to and downslope from a small talus mound directly beneath a hole in the ceiling that at one time may have been open to the surface. The site lies

about 1000 ft from the present cave entrance, in a small gallery perched approximately 15 ft above stream level, in the central area of the cave (Fig. 1, inset); the floor of this gallery is 25 ft below the hole in the ceiling and 12 ft below the entrance to the upper level. Part of the site is in a low crawlway to the east of, and downslope from, the talus pile (Fig. 3).

The peccary arrived at the site by one of two routes. One possibility is that it entered the upper level passage that contained a partial right radius of a small bear (*Ursus*, ? sp.), through an entrance that is now closed, at a time before the present sediments and flowstone were deposited (the ceiling height being now much too low). It then wandered about until it fell 12 ft into the passage where the bones were found. The other possibility is that it entered, by a now-closed entrance, into an hypothesized upper level passage that lead to the hole in the ceiling above the site. It then fell through the hole 25 ft to the floor. In either case, injuries were apparently sufficient to prevent further wandering. Because the known upper level passage is narrow and constricted and would be difficult for a full-sized peccary to negotiate, we tend to favor the latter possibility. In addition to the fact that a 25-ft fall probably would have been more incapacitating than a 12-ft fall, the route between the bear bone and the peccary site contains three possible pitfalls, two of which would have been more easily encountered than the one terminating in the peccary passage. The existence of several other holes in the ceiling to the south of the peccary site supports the hypothesis and suggests that, if the peccary did enter via the hole in the ceiling, it came from the north. Numerous sinkholes occur to the north of the site, any one of which may have been open in the past and used as an entrance by the peccary. At the peccary site, remains of woodchuck (*Marmota monax*), deer mouse (*Peromyscus*), and one terrestrial gastropod (*Triodopsis albolabris*) were also present.

Preservation

Those elements that were preserved were in excellent condition, but fragile and brittle due to loss of organic matter. All bones appear to have been complete *in situ*, i.e., all breaks were fresh ones, with the exception of those in the left hip bone (the right was missing). This had been broken into at least four pieces prior to excavation (by the initial fall?), judging from the dirt-stained break surfaces, most fresh breaks were due to cavers having disturbed the superficially buried bones prior to their discovery (Fig. 4); additional breaks were incurred during excavation. The bones appeared chemically unaltered. They were chalk-white on freshly broken surfaces and lightly stained by the yellow-brown matrix on unbroken surfaces. Marrow cavities

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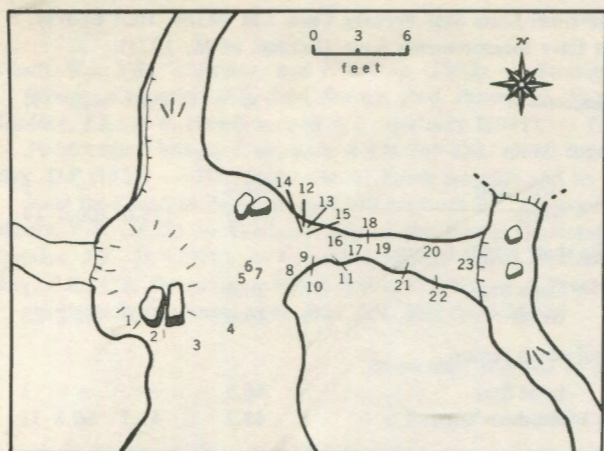


Figure 2. Distribution of peccary bones (see text for bone identifications).



Figure 3. Partial view of peccary site, looking east into crawlway that contained many of the bones.



Figure 4. Close-up of left tibia, left fibula, and right metatarsus in situ. Crushing of fibula and metatarsus due to cavers walking over area prior to excavation.

of limb bones were matrix free.

Orientation

All bones recovered were disarticulated and many elements were not there. All vertebrae, sternebrae, hyoids, carpals, tarsals, and phalanges, most ribs, and the skull were missing. Enough remained, however, to indicate that an orientation was still preserved in this badly disturbed find, indicating that the animal was at one time present at the site in an articulated condition. The bones were not randomly distributed, as would have been the case had they been washed in or worked over by predators. Fig. 2 indicates that the bones, although disarticulated (the right and left femurs were found 14 ft apart), were distributed in loose anatomical order; posterior body elements predominated in the western end of the excavation, anterior elements in the eastern portion. Excellent preservation, coupled with the complete absence of a major portion of the skeleton, suggests that prior disturbance was of such a nature that bones were either removed completely or were left undisturbed. There was no evidence either of chemical or of mechanical deterioration. Either the missing elements were flushed out by high water or were removed by some previous discoverer. Marks made by rodent incisors on the humerus, left tibia, and innominate indicate that those bones lay exposed on the cave floor following carcass decomposition and prior to final interment, suggesting that the missing skeletal parts may have been scattered and lost at a very early date.

Anatomical notes

The peccary was a young adult. All permanent lower teeth were fully erupted (Fig. 5). Toothwear was light, with only the first lower molar showing moderate wear. The age of the animal (based upon a relative toothwear scale ranging from Class 1—milk teeth erupting, to Class 8—permanent teeth worn down smooth established by study of 31 individuals from Welsh Cave, Ky.) was Class 5. All post cranial epiphyses, with the exception of the tuber ischii, were fused, indicating that growth had been completed. Traces of the line of fusion were noted at the distal ends of femur and ulna/radius. Metatarsals were fused proximally. Shafts of radius and ulna were solidly fused with no trace of the line of fusion.

Probable age

The species *P. compressus* is known only from the last, or Wisconsinan stage of the Pleistocene "Ice Age". Two carbon 14 dates have been recorded for Kentucky finds: 1. Hickman Herd—greater than 34,000 yrs. B.P. (Finch, Whitmore, and Sims,

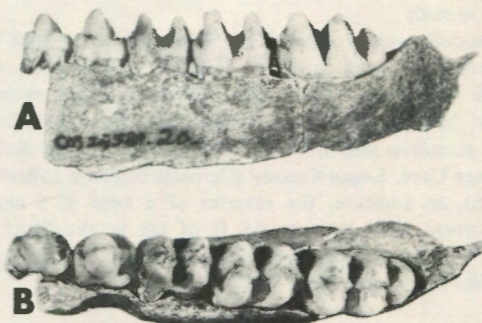


Figure 5. Partial right mandible, flat-headed peccary (*Platygonyx compressus*), Lone Star Peccary Cave, Hart County, Kentucky. P_3 - M_3 , anterior end to left. A. Lingual view. B. Occlusal view. For scale, see measurements. (Photo N. Wuerthele).

TABLE 1. Comparative measurements (in mm) of *Platygonus compressus* from Lone Star Peccary Cave, CM 24589, Hart County, Kentucky and from Welsh Cave, Woodford County, Kentucky (Welsh Cave measurements from Guilday, *et al.*, 1971).

Measurement	M	min.	max.	N	Measurement	M	min.	max.	N
Length $M_1 - M_3$					Length femur				
Lone Star	50.9	-	-	1	Lone Star	187.0	-	-	1
Welsh	50.1	45.3	53.0	16	Welsh	187.3	179.0	200.0	19
Lower canine, ant.-post. diameter					Least shaft width femur				
Lone Star	10.4	-	-	1	Lone Star	20.0	-	-	1
Welsh	11.7	10.5	13.2	19	Welsh	19.6	17.9	22.2	23
Lower canine, trans. diameter					Distal width femur				
Lone Star	9.0	-	-	1	Lone Star	46.5	-	-	1
Welsh	8.7	7.8	10.1	18	Welsh	45.3	41.7	50.3	31
Length M_3					Length tibia				
Lone Star	21.8	-	-	1	Lone Star	192.0	-	-	1
Welsh	21.4	19.4	23.0	22	Welsh	194.2	184.0	207.0	15
Width M_3					Distal width tibia				
Lone Star	12.5	-	-	1	Lone Star	31.5	-	-	1
Welsh	12.5	11.5	13.7	22	Welsh	29.9	27.3	33.2	17
Humerus, distal width					Length metacarpal IV (from articular surface)				
Lone Star	41.9	-	-	1	Lone Star	87.9 (right), 88.2 (left)	-	-	2
Welsh	40.7	38.0	44.5	32	Welsh	86.3	82.0	91.3	28
Length radius					Length metatarsal				
Lone Star	160.0	-	-	1	Lone Star	93.4	-	-	1
Welsh	157.0	141.0	166.0	15	Welsh	91.1	86.6	96.6	29
Proximal width, radius					Length patella				
Lone Star	32.4	-	-	1	Lone Star	34.5	-	-	1
Welsh	30.3	27.7	33.6	28	Welsh	34.7	30.8	37.7	18
Length ulna									
Lone Star	218 (right), 215 (left)	-	-	2					
Welsh	206.9	198.0	214.0	12					

1972, p. 23); 2. Welsh Cave—12,950 $\pm$ 550 yrs. B. P. (Guilday, Hamilton, and McCrady, 1971, p. 260). The latest acceptable date for the species is 11,900 $\pm$ 750 yrs. B.P. for a skeleton from glacial deposits in Bradford County, northern Pennsylvania (Ray, Denny, and Rubin, 1970).

Other records

Flat-headed peccary remains are known from at least three other Kentucky caves: a skull collected about 1805 from Rockcastle (?) County (O.P. Hay, 1923, p. 223); skeletons of at least 31 individuals from Welsh Cave, Woodford County (Guilday, Hamilton and McCrady, 1971); and a partial skeleton from Savage Cave, Logan County (Carnegie Museum collections, CM-12986). In addition, the remains of a herd of 5 animals were recovered from beneath 65 ft of silt in the Chickasaw Bluffs of the Mississippi River near Hickman, Fulton County (Finch, Whitmore, and Sims, 1972).

CONCLUSIONS

Comparison of the Lone Star peccary skeleton with those from Welsh Cave and Savage Cave, Ky, suggests a common gene pool. The age of the Lone Star peccary is late Wisconsinan, c. 15,000 to 10,000 years old. Although peccary bones are among the commonest of Pleistocene remains from eastern caves, the Lone Star skeleton is only the fourth cave record for the

species in Kentucky and is the second case in which the circumstances surrounding the bones are known. It is hoped that this report will alert more cavers to the possibilities of discovery, so that more Pleistocene vertebrate deposits may be documented in the future. Discoveries of this nature will not only increase our knowledge of Pleistocene ecology, but will, also, aid in interpreting the evolution of caves and cave sediments.

ACKNOWLEDGEMENTS

The authors thank Mr. Butler for granting permission to carry out the excavation and to remove the bone material from the cave. Field assistance was provided by John Evans, Thom Fehrmann, and Ed Lisowski (Figs. 3, 4) of the Mid Illinois Grotto, Mark Elliott of the Bloomington Indiana Grotto, and Don Coons of the Cave Research Foundation; field work was supported by the Ralph W. Stone Award granted by the National Speleological Society to Wilson. Laboratory assistance was provided by Alice Guilday and was supported by NSF grant No. GB 42258 awarded to Guilday. We also thank Dr. Thomas C. Barr, Jr., Dr. Wayne Davis, Harold Hamilton, Dr. Robert A. Kuehne, James F. Quinlan, Pat Quinlan, and Roger Sperka for encouragement and assistance.

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ERRATUM

Uranium-Series Dating of Speleothems, *NSS Bull.*, 1975, 37(2):21-33.

p. 23, Equation (3) should read:

$$N_t^d = \left(\frac{\lambda_p}{\lambda_d - \lambda_p} \right) (N_o^p) (e^{-\lambda_p t} - e^{-\lambda_d t}) + N_o^d e^{-\lambda_d t}.$$

A Preliminary Study of Heterotrophic Microorganisms as Factors in Substrate Selection of Troglotic Invertebrates

Gary W. Dickson *

ABSTRACT

Troglotic invertebrates from three caves in Virginia were studied during the summer months of 1974 with regard to their association with the heterotrophic microorganisms found in the mud substrate and other sediments.

Mud samples were obtained aseptically from terrestrial mud banks, stream pools, and mud-bottom drip pools in the three caves. In each habitat, bacterial and fungal populations of the sediments were compared between areas of troglotic invertebrate congregations and areas in which no such animals were observed.

Troglotic invertebrates and fungal populations were positively correlated, but the distribution of bacterial populations and troglotic invertebrates were not.

INTRODUCTION

For many years biospeleologists have observed that the distribution of troglotic fauna within a cave is very patchy. Three factors often appear to be responsible for this localization of troglotes: high humidity (terrestrial areas), abundant food, and specific micro-habitat differences favorable for reproduction and development of the species (Vandel, 1965).

Because of the lack of significant autotrophic input in the cave ecosystem, due to the absence of photosynthetic activities, detrital material brought in from epigean habitats apparently constitutes the major basis of the food chain of troglotes. Chemo-autotrophic bacteria may sometimes be important, however (Caumartin, 1963; Christiansen, 1970). This detrital material serves as a substrate for populations of bacteria, fungi, and actinomycetes. The detritus and the populations of heterotrophic microorganisms associated with it probably constitute the major food source for many troglotic invertebrates (excluding predacious forms).

The present investigation attempts to evaluate the relationship between troglotic invertebrates and the mud substrates on which they congregate, and to determine if a correlation is present between areas where troglotes gather and areas of large bacterial and fungal populations.

Several comprehensive studies have been conducted on both marine and freshwater epigean invertebrates concerning their relationships to the substrate. Dannel (1933) found that the number of marine burrowing amphipods *Haustorius arenais* was directly related to the amount of organic matter present in the sand substrate. Weiser (1956) reported that the degree of attractiveness of the substrate to the crustacean *Cumella vulgaris* depended on the amount and kind of food available. Marzolf (1965, 1966) studied the freshwater burrowing amphipod *Pontoporeia affinis* and its relationship to the substrate. He found that the amphipods were strongly influenced by the presence of bacteria and organic material in the sediments.

Studies have also been conducted on terrestrial invertebrates to determine if relationships to the substrate are present. Christiansen (1961) reported that the distribution of troglotic Collembola in Hunters Cave, Iowa was greatly influenced by

soil moisture, particle size, and organic content. Poulson and Culver (1968) stated that the local species diversity in caves of the Flint Ridge-Mammoth System in Kentucky is correlated with substrate diversity, substrate organic content, and incidence of flooding. Studies conducted by Christiansen (1970) on several species of troglotic Collembola indicated that the ingestion of cave clays thought to contain chemo-autotrophic bacteria may allow long survival of these Collembola in the absence of visible food materials, and that bacteria-laden clay may be a food source in the cave environment.

METHODS AND MATERIALS

Field work was conducted in June and July in two separate locations in Virginia. The terrestrial mud habitat was sampled in Madison Cave, Augusta Co. (developed in Upper Cambrian limestone). This cave contains two deep pools and several rooms with a terrestrial mud substrate. The samples from aquatic habitats were taken from two caves in Lee Co., Virginia, both developed in Middle Ordovician limestones. Spangler Cave contains a stream and small side pools along the stream periphery in which troglotic invertebrates are found. Samples of mud sediments were obtained from the small side pools. Molly Wagle Cave contains one large and several small, mud-bottom drip pools with troglotic invertebrates. No stream is present in this cave. Water enters via ceiling drips. Mud sediment samples were taken from the mud-bottom drip pools.

Stoppered bottles, which were first autoclaved, were used to sample the top layer (5 to 10 mm in thickness) of the substrate in each habitat. In the aquatic habitats, two samples were taken from areas where troglotic invertebrates were located and two samples were obtained from similar areas where no troglotes were observed. In the terrestrial habitat, the same procedure was utilized to obtain three samples in each area.

After collections were made, samples were kept cool (approx. 10°C) until analysis was conducted. Dilution-plating techniques were performed on the samples within 24 hours of collection. Nutrient agar was used as the growth media for heterotrophic microorganisms and potato dextrose agar was used as the growth media for fungi. Cultures were incubated at room temperature (approx. 22°C) and the colonies were counted at three, five, and seven day intervals after plating. Counts were recorded only from plates containing from 30 to 300 colonies, as prescribed by standard methods (Pelczar and Reid, 1972).

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RESULTS

A summary description of the areas collected and the troglobites present at the specific sampling stations is found in Table 1. The individual species will not be discussed separately, because this study deals with general relationships of troglobites with the substrate rather than with individual species-substrate relationships.

Bacterial populations (Table 2) did not reveal any statistically significant differences ($P > .05$) between areas of animal congregations and areas where no animals were observed. Bacterial populations were found to be much smaller in the stream pool habitats than in either mud-bottom drip pools or terrestrial mud sediments.

Fungal populations (Table 3) in terrestrial mud samples showed statistically significant ($P < .01$) correlations with the distribution of invertebrate congregations. Stream pool samples also indicated a definite trend toward high populations of fungi in animal congregation areas ($P < .06$).

TABLE 1. Description of sampling stations and troglobitic invertebrates present at each station.

Cave	Station number	Station description	Troglobitic species present	Number present	Area (cm ²)	Density (No./cm ²)
Spangler	1	Small side pool; water 2.5 cm deep	<i>Crangonyx antennatus</i> (Amphipoda)	5	100	0.05
			<i>Asellus recurvatus</i> (Isopoda)	2	100	0.02
	2	Small side pool; water 2.8 cm deep	<i>Crangonyx antennatus</i> (Amphipoda)	4	100	0.04
			<i>Asellus recurvatus</i> (Isopoda)	3	100	0.03
	3	Small side pool; water 2.5 cm deep	None	—	100	—
	4	Small side pool; water 2.9 cm deep	None	—	100	—
Molly Wagle	1	Large pool; water 10.0 cm deep	<i>Crangonyx antennatus</i> (Amphipoda)	20	185	0.11
	2	Large pool; water 5.0 cm deep	<i>Crangonyx antennatus</i> (Amphipoda)	15	185	0.09
	3	Large temporary pool; water 2.5 cm deep	None	—	185	—
	4	Small pool next to wood pile; water 3.5 cm deep	None	—	185	—
Madison	1	Wood pile; decaying	<i>Striaria</i> sp * (Diplopoda)	3	100	0.03
	2	Large dung pile	<i>Rhagidia weyerensis</i> (Acarina)	2	100	0.02
			<i>Striaria</i> sp * (Diplopoda)	4	100	0.04
	3	Small dung pile	<i>Pseudosinella argentea</i> # (Collembola)	8	100	0.08
	4	Mud bank; 1.0 meter from deep pool	None	—	100	—
	5	Mud bank; 10.0 cm from deep pool	None	—	100	—
	6	0.5 meter from large dung pile (Station 2)	None	—	100	—

* - Possible troglobite

- Troglophile

DISCUSSION

Early biospeleologists felt that sources of nutrition for troglobites were generally quite scarce in the cave environment (Vandel, 1965). Studies have been conducted (Barr and Kuehne, 1971; Caumartin, 1963; Gittleton and Hoover, 1969; Kirk, 1973) which reported that, to the contrary, the mud and clay sediments in caves contain populations of microorganisms, including bacteria, fungi, actinomycetes, protozoans, and small metazoans. However, the populations of microorganisms found in caves are almost always many times smaller than epigeal populations due largely to the lack of substantial organic material and, perhaps, to the physical parameters of the cave environment as well (Kirk, 1973; Vandel, 1965).

Although troglobitic invertebrates may feed directly on detrital material, bacterial and fungal populations may themselves represent important sources of food. Nelson and Scott (1962) reported that through weight ratio experiments, it was determined that part of the food of several invertebrate detrital feeders is derived from the microorganisms present on the detritus.

Studies conducted on epigeal detrital feeders indicate that fungi may constitute an important food source for troglobitic invertebrates. A number of epigeal stream detrital-feeders were found to exhibit a clear preference for leaves containing fungal colonies over autoclaved leaves (Hynes, 1970). Studies by Bärlocher and Kendrick (1973) on the amphipod *Gammarus pseudolimnaeus* indicated that the largest weight gain in young individuals occurred on a diet consisting of several types of fungi, rather than on diets consisting of autoclaved leaves or of leaves containing bacterial populations. This study also showed that 10 times as much dry leaf material as fungal material had to be ingested to show the same weight gain in young animals.

Bacteria may also represent a direct food source for troglobitic invertebrates. Holsinger (1966) conducted a study in a Virginia cave in which septic tank overflow drained into several pools containing populations of troglobitic invertebrates. Organic content and bacterial populations in these pools were sampled and were found to be greater than in other, similar, cave pools.

TABLE 2. Analysis of the bacterial population differences between areas of troglobitic invertebrate congregations (*) and areas where troglobites were not observed.

Cave	Station number	Bacteria (x10 ⁻⁴) per gram sediment	Mean bacteria (x10 ⁻⁴) per gram sediment	Standard deviation (x10 ⁻⁴)	P (#)
Spangler	1 (*)	5.5	4.25	1.7	0.1
	2 (*)	3.0			
	3	3.1	3.7	0.85	
	4	4.3			
Molly Wagle	1 (*)	144.0	794.0	700.0	0.1
	2 (*)	1444.0			
	3	370.0	385.0	15.0	
	4	400.0			
Madison	1 (*)	136.0	65.3	62.0	0.1
	2 (*)	20.0			
	3 (*)	40.0			
	4	20.8	353.6	350.0	
	5	340.0			
	6	720.0			

(#) - Probability based on t-test differences between means.

The populations of troglobitic invertebrates in these pools were much larger than those found in pools in other Appalachian caves. The increase in organic material and bacterial populations are thought to account for the unusually high invertebrate numbers observed. In France, Gounot (1960) indicated that bacteria in cave mud are important in the development and physiology of the troglobitic amphipod *Niphargus virei*.

Besides serving as a direct food source, bacteria, fungi, and actinomycetes serve an important role in the breakdown of detrital material into subunits which then can be utilized by detrital feeders. Large molecules such as cellulose, starch, and lignin are resistant to bacterial decomposition, but are readily decomposed by fungi (Andrews, 1973). Bacteria are important in the breakdown of other large molecules into usable subunits. These microorganisms may also be important in supplying essential vitamins to troglobites, because of the absence of green plants in the subterranean environment (Vandel, 1965).

The relationship between the number of bacterial and fungal colonies and the presence of troglobitic invertebrates does not indicate which factor is the dependent variable. From examination of the field data, one might just as easily decide that bacterial and fungal growth were favored by the presence of troglobitic invertebrates. It is only when the results of certain experiments dealing with selection of conditioned substrates are examined that the direction of the causal relations between these two components of the hypogean community becomes apparent. Although substrate preference experiments have not been conducted on the troglobitic invertebrate species dealt with in this study, inferences can be made from other studies conducted on detrital feeding invertebrates which have representatives in troglobitic fauna.

Marzolf (1965) observed that the amphipod *Pontoporeia affinis* selected conditioned substrates containing large populations of bacteria, while not selecting similar substrates which did not contain bacterial populations. Studies conducted on both epigeal and hypogean collembolans indicate that a number of these organisms feed directly on the hyphae of various fungi and that the distribution of fungi is a major factor in the distribution of certain collembolans (Christiansen, 1964). No statement can be made from the present study concerning the

TABLE 3. Analysis of the fungal population differences between areas of troglobitic invertebrate congregations (*) and areas where troglobites were not observed.

Cave	Station number	Fungi (x10 ⁻³) per gram sediment	Mean fungi (x10 ⁻³) per gram sediment	Standard deviation (x10 ⁻³)	P (#)
Spangler	1 (*)	14.4	11.7	2.7	0.06
	2 (*)	9.0			
	3	0.66	0.46	0.19	
	4	0.27			
Molly Wagle	1 (*)	83.0	63.0	20.0	0.1
	2 (*)	43.0			
	3	193.0	127.0	66.0	
	4	61.0			
Madison	1 (*)	186.0	108.0	78.0	0.01
	2 (*)	—			
	3 (*)	30.0			
	4	—	10.8	1.2	
	5	12.0			
	6	9.6			

(#) - Probability based on t-test differences between means.

growth of bacteria and fungi in the presence and/or absence of troglobitic invertebrates.

The possibility may also exist that the number of bacterial colonies present on the substrate could be reduced from active grazing of the invertebrates present. However, the populations of troglobitic invertebrates observed in this study were relatively small (Density [no./cm²] < 0.11) and reduction in bacterial colonies by grazing would not be expected to be significant in this case. No significant negative correlations were observed in this study between areas of invertebrate presence or absence and the number of bacterial colonies found in each area. Final conclusions on this problem will have to await further research on this specific aspect of the invertebrate-substrate relationship.

It must be pointed out that the accurate enumeration of fungal populations by plate counts must be interpreted with caution, as nutritive culture media favor the growth of molds which could possibly exist only as spores rather than as ecologically active mycelia within the cave environment (Alexander, 1961).

Populations of fungi appeared to have a positive effect on the distribution of invertebrates inhabiting the stream pools sampled in Spangler Cave. In the cave stream observed, detrital material was noted to gather in side pools and other slack-water areas. Stream pools are found to collect and to oxidize more detritus than other sections of the stream (Hynes, 1970). Troglobitic invertebrates were observed many times to congregate in side pools where detrital materials were located.

The bacterial populations of the mud-bottom drip pool sediments in Molly Wagle Cave were found to be much larger than the populations observed in the stream pool sediments. Although detritus is not washed into Molly Wagle Cave by streams or flooding, organic material probably enters the cave with the water dripping through crevices in the ceiling. The ceiling of this cave is very close to the surface (Holsinger, personal communication). The fact that water seeping into the

cave does not have to percolate through a great thickness of limestone may account for the large amount of organic material present in the sediments and for the large bacterial populations observed in these samples.

There is a significant ($P < .01$) relationship between fungal populations in the mud bank sediments in Madison Cave and congregations of terrestrial troglobites. Areas of the terrestrial mud banks where dung and decaying wood piles were located exhibited the highest plate counts of fungi and largest gatherings of troglobitic invertebrates.

Both the stream pool and the terrestrial habitats studied contained localized patches of detrital material, probably due to the means of detrital input into these cave interiors. The mud-bottom drip pools in Molly Wagle Cave appear to represent a more homogeneous habitat in respect to the localization of food sources.

Bacterial and fungal populations may, indeed, serve as basic food sources in the cave ecosystem and influence the distribution of troglobitic invertebrates. This preliminary study has indicated that the distribution of fungal populations may be more important than bacterial population distributions in influencing substrate relationships of invertebrates in two of the three troglobitic habitats studied. Further research, involving larger numbers of samples, must be accomplished in order to permit statistical analysis of these troglobite-substrate relationships. Also, studies dealing with substrate selection and food preferences of troglobitic invertebrates are necessary for further resolution of these problems.

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INFORMATION FOR CONTRIBUTORS TO *THE NSS BULLETIN*

Papers discussing any aspect of speleology are considered for publication in *The NSS Bulletin*. We particularly welcome articles describing important caves and cave areas, on the history of caves and of speleology, on problems and techniques of cave conservation, and critical reviews of current literature, in addition to papers on the more traditional subjects of cave geology, geography, anthropology, fauna, and ecology. The material presented must be original and of lasting interest. Authors should demonstrate the significance of their work to speleological theory and should elucidate the historical antecedents of their interpretations by reference to appropriate literature. Presentations consisting of raw data, only, will not be accepted.

A narrative style of writing is preferred. Fine prose is terse yet free from lacunae, sparkles without dazzling, and achieves splendor without ostentation. Data and interpretations blend effortlessly along a logical continuum so that the reader, having read, neither knows nor cares how many pages he may have turned while following the author's exposition.

As written language must communicate through time as well as across space, neologisms should be introduced only if needed to express new concepts or to record new percepts. This is especially important in an archival journal such as *The NSS Bulletin*. Standard usage, therefore, is required of all authors. For general style, refer to papers in this *Bulletin* and to the following handbooks: "Suggestions to Authors" (U. S. Geological Survey), "Style Manual for Biological Journals" (American Institute of Biological Sciences, Washington, D. C.), and "A Manual of Style" (The University of Chicago Press).

Articles on earth sciences (including pseudokarst), life sciences, conservation, history, anthropology, and exploration should be sent directly to the appropriate specialist on the Board of Editors (see masthead); articles not clearly falling into any of those categories may be sent to the Managing Editor. Potential contributors, especially those not professional scientists or writers, are invited to consult with the editors for guidance or aid in the presentation of their material.

Two double-spaced, typewritten copies of each manuscript, including all illustrations, are required. Manuscripts should not exceed about 10,000 words in length (approximately 40 pages of typescript), although this limit may be waived when a paper has unusual merit. Photographs must be sharp, high in contrast, and printed on glossy paper. All line drawings should be neatly rendered in "india" ink or its equivalent; the smallest lettering must be at least 2 mm high after reduction. Typed lettering is not satisfactory. Captions will be set in type and added in proof. The dimensions of original drawings and of cropped photographs should be made some multiple of the length and width of a column or of a page, when possible, in order to avoid problems with the layout. In case of doubt regarding length or illustrations consult with the editors.

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Contributed papers will be refereed by one or more authorities in the appropriate specialty and will be edited for style before publication. After being refereed and again after being edited, papers will be returned to the authors for inspection and for any revisions which may be necessary.

By act of the Board of Governors of the NSS (#81-277, dated 8-12-74), a charge of not less than \$25 per printed page will be levied against the author's institution or other funding agency after a paper has been refereed, edited, and accepted for publication. Payment will not be expected of scholars whose research was not sponsored or whose budgets do not include money earmarked to subsidize publication. In no event, will the ability to pay page charges be discussed until after final acceptance of a manuscript.

Reprints may be ordered when galleys are returned by the authors to the Managing Editor; these will be supplied at cost.

Selected Abstracts from Recent Meetings

NSS Convention, Angels Camp, California, 27 June 1975

Cavern Development in the Helderberg Plateau, East Central New York

Ernst H. Kastning *

The major factors affecting cavern development in the Helderberg Plateau are bedrock lithology and jointing. Locally, fault zones are dominant controlling influences. Most caves have developed in a down-dip direction, parallel to the hydraulic gradient. Portions of many caves have been wholly or partially modified by flooding during periods of high runoff.

In general, major cavern development occurred in the shallow-phreatic zone. The Thatcher, Ravena, and Onondaga limestones are most susceptible to dissolutional enlargement of fracture openings. As the region was uplifted and baselevel dropped, caves were drained and captured surface streams continued to modify the existing passages in the vadose zone. Glaciation during the Quaternary Period markedly altered some karst-water flow patterns. This is reflected in many of the caves by deposits of coarse clastic debris and dissolution features produced by flood-water.

Cavern genesis may have begun during the Mesozoic Era and the early Tertiary Period, but dissolution was greatly accelerated by regional uplift of the carbonate units above baselevel prior to the late Tertiary Period. Most cavern development has occurred during the Cenozoic Era.

An understanding of karst aquifers is necessary for regional environmental and water-resource considerations. Those especially important in the Helderberg Plateau region are transmittal of pollutants by karst waters, sinkhole collapse, and private and public water supply.[†]

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[†] This paper is available, from the author, as *Bulletin 1* of the *New York Cave Survey*.

NSS Convention, Decorah, Iowa, 12 August 1974

Karst Areas in Puerto Rico, Exclusive of the North Coast

Barry F. Beck *

The classic karst topography developed on the off-lapping Tertiary limestones of Puerto Rico's north coast is well documented. However, there are numerous other, smaller limestone areas which have also developed karst features. Variations in lithology, structure, climate, and history have combined to produce different sets of karst characteristics.

The Cotui Limestone Member of the Upper Cretaceous San German Formation caps hills in southwestern Puerto Rico. In some areas, knife-like residual pinnacles are separated by pits up to 9 m deep. Caves are commonly found at the contact of the limestone with the underlying volcanics, probably due to lateral movement of groundwater over this impermeable boundary. An isolated block of limestone with similar karst features is found to the north, near Rosario; it is, apparently, a slide-block of Cotui Limestone separated by thrust faulting.

On the south coast, between Guanica and Guayanilla, the Tertiary Ponce Limestone forms a broad, almost flat-lying limestone pavement. Relatively thin beds (about 0.3 m) are marked by raindrop pits, clints approximately 1 by 2 m square separated by grikes 0.2 to 0.5 m deep, an absence of soil cover, and an apparent headward retreat of the individual beds exposing less intensely dissected strata below. One known cave underlies this pavement. Located approximately 1 km inland, it contains a brackish lake in which cave-adapted shrimp live.

Large-scale karst features are developed on the middle reef limestone unit of the Tertiary Juana Diaz Formation in southern Puerto Rico, just north of Guayanilla Bay. Drainage from the Central Mountains sinks underground upon reaching the limestone, passes through the El Convento Cave-Spring System and resurges, augmented by groundwater, as a perennial spring. A deep gorge, possibly a relict of previous collapse, is associated with the cave and several sinks are developed on the upland above the gorge.

The Aguas Buenas karst area is probably the best known example of karst topography in Puerto Rico, excluding the north coast. The Aguas Buenas Caves have been visited for years and an N.S.S. team studied the area in 1968. Two separate blocks of Aguas Buenas Limestone (the basal member of the Early Cretaceous Torrecilla Breccia) are both densely dissected by karst processes. Drainage sinks into one limestone block, rises upon reaching the intervening volcanics,

and then sinks again on the second block. The Aguas Buenas Caves are the main resurgence for all drainage in the basin. Recent discoveries by the author and associates will significantly enlarge the known cave system.

There are, also, well-developed karst features on Mona Island, situated approximately 80 km west of Puerto Rico. The island is principally composed of Tertiary Lirio Limestone and the underlying Isla de Mona Dolomite, which form steep cliffs, up to 90 m high, on 3 sides. The island's surface is covered with dense, thorny scrub and the limestone displays a jagged, intensely pitted surface. Caves are developed principally in a narrow zone (probably less than 0.5 km) along the periphery of the island, just above the limestone-dolomite contact. Many can be entered through collapsed sinks in the upland surface and several were formerly mined extensively for guano. There are several areas in the central part of the island marked by numerous sinkholes, but none of these are yet known to lead to caves.

Minor karst development occurs on the Melones Limestone, the Cuevas Limestone, and the Sabana Hoyos Limestone (Maravillas Formation), but the above account contains all karst areas of significant areal extent.

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