THE NSS BULLETIN

JULY 1977

VOLUME 39 NUMBER 3

Contents

The NSS Bulletin is published quarterly, in January, April, July, and October. Material to be included in a given number must be received at least 90 days prior to the first of the month in which publication is desired. The subscription rate in effect 1 August 1975: $10.00 per year.

Discussion of papers published in the *Bulletin* is invited. Discussion should be 2,000 words or less in length, with not more than 3 illustrations. Discussions should be forwarded to the appropriate editor within three months of publication of the original paper.

Printed by
Adobe Press
P.O. Box 12334
Albuquerque, N.M. 87105

Application to mail at second-class postage rates is pending at Huntsville, Alabama and at additional mailing offices.

Relationship Between the Hydrology of Blowing Cave and Cowpasture River

Philip C. Lucas*

ABSTRACT

Blowing Cave is situated on the east bank of a water gap of the Cowpasture River, in Bath County, Virginia. An accurate vertical survey of the cave established that the lower part of the cave (which contains a small stream) is 12.9 ft below normal pool elevation for the Cowpasture River at the cave entrance. The direction of stream flow in the cave is to the northeast, opposite the flow of the river. Dye tracer tests showed that water from the cave resurges at Nimrod Hall Springs, 3.5 mi downstream from Blowing Cave. Discharge measurements of the Cowpasture River one mile below Blowing Cave indicated a loss of 36 cfs under low flow conditions. This water was also traced to Nimrod Hall Springs. Due to the position of confining sandstone and shale units, which surround the narrow band of Helderberg limestone in which the cave is developed, it appears that the Cowpasture River is underdrained by solution conduits and that the riverbed itself is leaking and does not represent base level for this area.

Introduction

In the early 1940's, members of the National Speleological Society explored and surveyed Blowing Cave, in Bath County, Virginia. Upon examination of the survey data, they found that the stream which flows within the cave was lower in elevation than the Cowpasture River, which flows by the entrance of the cave. Several of the early trip descriptions are included in *NSS Bulletin* No. 3, 1942 and No. 8, 1946. During World War II, the Army Corps of Engineers blew the cave entrance shut (Douglas, 1964). Later quarry operations opened and shut the cave once again. In January of 1971, the Shenandoah Valley Grotto organized a dig and reopened Blowing Cave. Subsequent surveys indicated that the stream located in the back of the cave was, indeed, lower than the Cowpasture River.

The original objective of this study was to exactly determine the elevation of the cave stream, the direction of flow, and the resurgence of the cave stream. As more data was collected, this study was expanded to include the underground piracy of a nearby stream (Stuart Run) and the partial piracy of the Cowpasture River, itself.

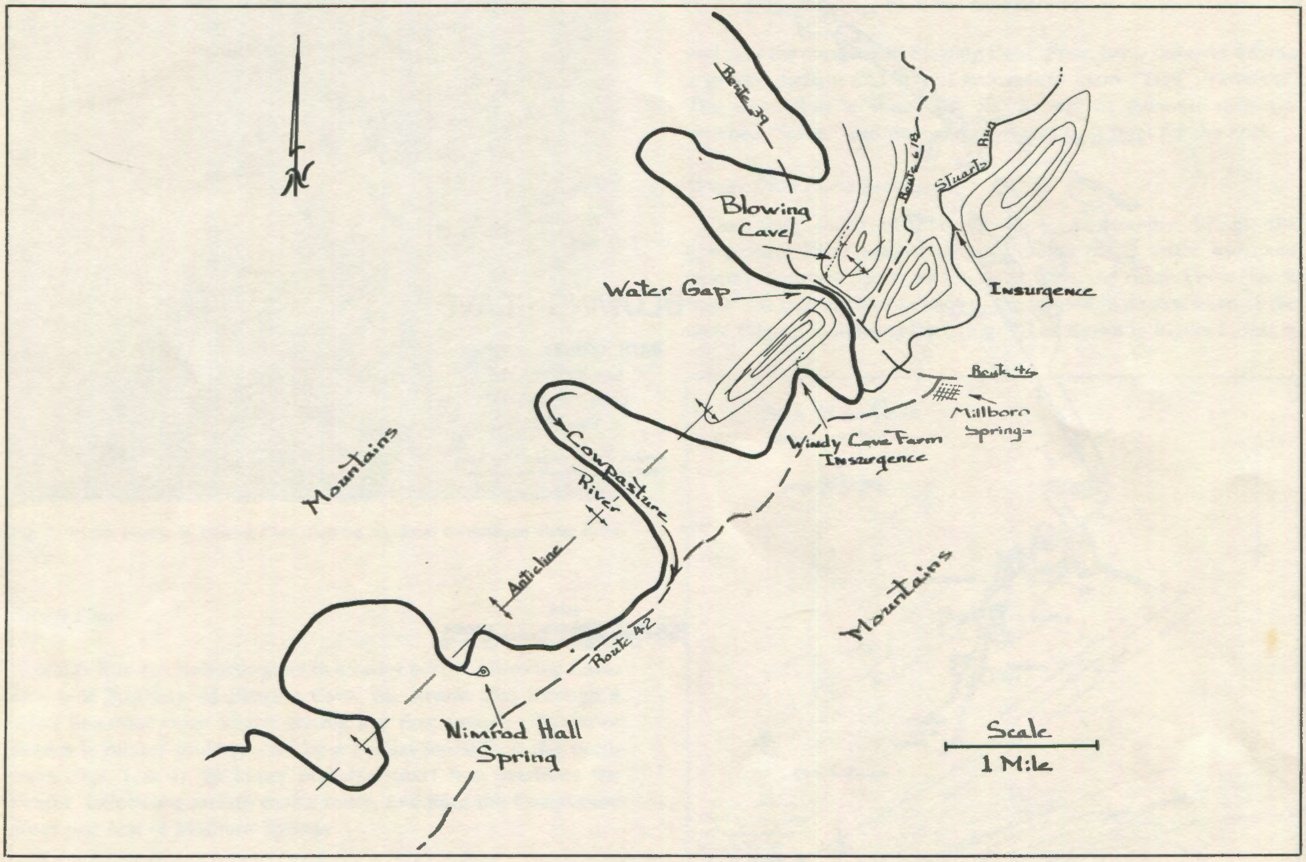


Fig. 1. Location of study area, Bath County, Virginia.

* 302 Crestfield Ct., Charlottesville, Va. 22901.

Description of Study Area

The study area is located entirely within Bath County, Virginia and is near the town of Millboro Springs (Fig. 1). The Cowpasture River flows through the area in a series of "lazy" meanders. Blowing Cave is located on the east bank of the river, at a water gap 0.5 mi west of the town of Millboro Springs. Stuart Run, a small surface stream, flows from the north and joins the Cowpasture River one-quarter mile west of Millboro Springs. A large spring at Nimrod Hall Boy's Camp is located 3.6 mi south of Millboro Springs.

Blowing Cave

The present entrance of Blowing Cave is just north of Route 39, in an abandoned quarry (Fig. 2) on the northeast side of a water gap of the Cowpasture River.

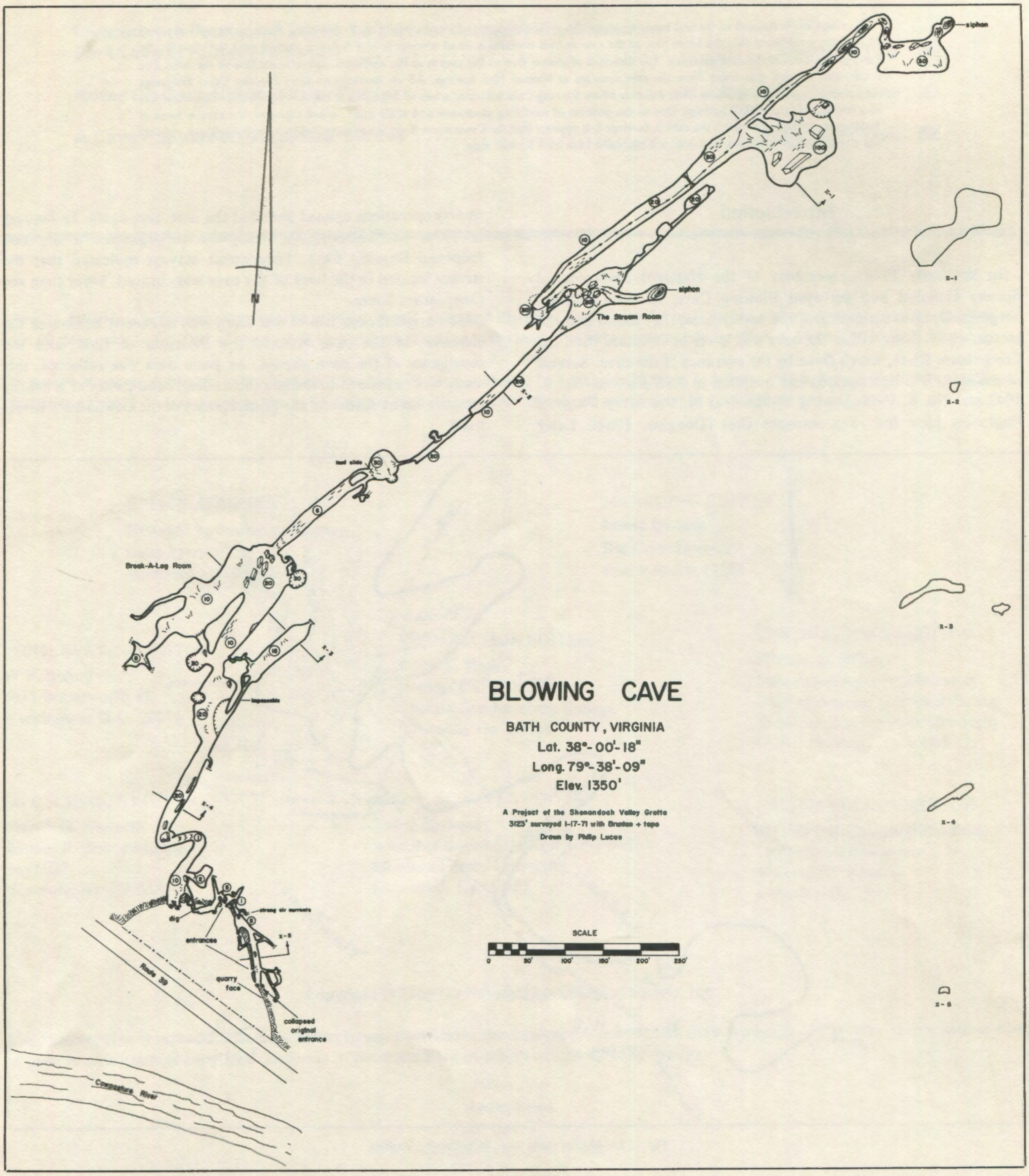


Fig. 2. Plan view of Blowing Cave.

As shown in Figure 2, the cave extends 1,562 ft to the northwest; 3,123 ft of passage have been surveyed. The main passage, which follows the strike, is generally a large walking passage, being very muddy in some sections (Fig. 3). At a point 1,140 ft from the entrance, a stream enters from the east. The stream turns to the northeast and follows the main trunk passage for 700 ft, then ends in a deep sump.

The stream flows at a nearly constant rate and remains clear despite prolonged heavy rains, which may bring Cowpasture River to flood stage. No debris or evidence of surface water has been observed within the cave. At unexplained sporadic intervals, the stream "backs up" from the sump to form an underground lake about 10 ft deep and floods the lower part of the cave. This flooding has been observed during both low and high river stages and must, therefore, be due to temporary blockage of passages beyond the sump.

Fig. 3. Stream passage in Blowing Cave, showing solutional development along strike joint.

Stuart Run

Stuart Run has its headwaters in a valley north of Blowing Cave. One mile northeast of Blowing Cave, the stream cuts through a small limestone ridge where, during low flow periods, the entire stream is pirated underground by a swallet located on the north bank (figs. 1 & 4). In wetter periods, Stuart Run overflows the swallet, follows the surface course south, and joins the Cowpasture River just east of Millboro Springs.

Cowpasture River

The Cowpasture River is the largest surface stream in the study area. It flows generally from the northeast, through the water gap,

Fig. 4. Principal Swallet on Stuart Run (low flow).

and past the entrance to Blowing Cave. From here, the river follows a gentle gradient (7.1 ft/mi) and makes many "lazy" meanders. The mean flow is about 300 cfs. As will be demonstrated, the riverbed "leaks" and does not represent base level for the area.

Windy Cove Farm Insurgence

One mile south of Blowing Cave, a meander brings the Cowpasture River against the side of the ridge, where whirlpool swallets "capture" some of the water from the river. These "suck holes" (as they are locally known) are located in an extension of the same ridge as is Blowing Cave (Fig. 1). As shown in Figure 5, this is

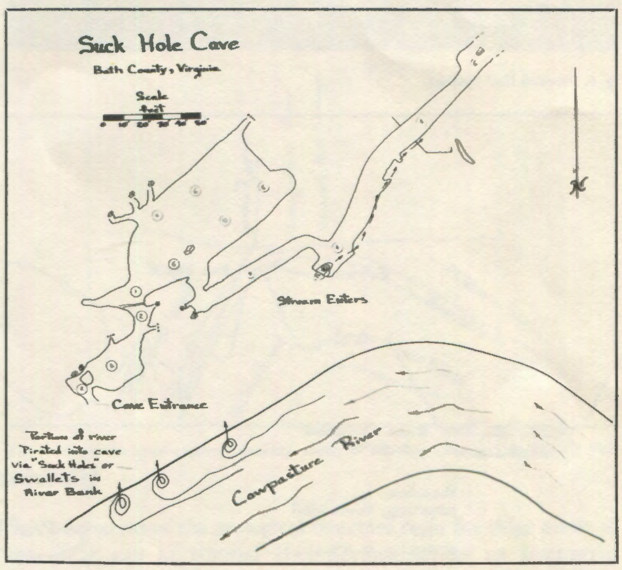


Fig. 5. Insurgences at Windy Cove Farm and plan view of Suck Hole Cave.

a fine example of stream piracy, because part of the river is diverted by several whirlpools whose efficiency is controlled by the amount of debris gathered about them. Discharge measurements made above and below these swallets during low flow conditions (August 11, 1974) showed the loss of 36 cfs.

Twenty feet above the river's edge, in a limestone outcrop, is an entrance to Suck Hole Cave. In a muddy, often flooded crawlway in the bottom of this cave, the captured river water can be seen flowing for 200 ft northeastward along the strike. In the author's opinion, all 36 cfs is pirated by this cave. The stream in Blowing Cave also flows northeast, opposite the southwest direction of flow of the Cowpasture River.

Nimrod Hall Springs

Nimrod Hall Springs (Fig. 6) is on the east side of the Cowpasture River, 3.5 mi downstream from Blowing Cave. The discharge of this large spring was measured at 48 cfs during low flow conditions. It flows into the river about 200 ft from the spring. This is the only spring in the area large enough to account for the complete resurgence of the Blowing Cave stream, Stuarts Run, and the "leakage" from the Cowpasture River. The owner of Nimrod Hall Camp reported that cleaning out the debris in the "suck holes" on the river did greatly increase the flow of the spring. This indicated that the insurgence at Windy Cove Farm is connected with Nimrod Hall Springs. Subsequent dye tracing experiments have confirmed that all three streams resurge at this spring.

Fig. 6. Nimrod Hall Springs.

Blowing Cave Vertical Surveys

After Blowing Cave was reopened by the Shenandoah Valley Grotto, a Brunton Compass and tape survey was made. This survey revealed the cave stream to be lower than the river, confirming the earlier report (Stephenson, 1946). A short time later, a more precise "vertical" survey was taken to more accurately determine this elevation difference. This survey employed the use of a hand level and a clear plastic tube which, when nearly filled with water, could be used to precisely establish level stations throughout the cave. It showed that the stream, where first encountered in the cave, is 12.9 ft lower than the normal river stage directly across from the cave entrance (Fig. 7). Cowpasture River flows well above base level one mile upstream of the first known sinks. No evidence, such as an unusual cave stream temperature, was found to suggest that any water from the river enters the cave.

At the request of land owners, a dye trace of the Cowpasture River, itself, was not performed, although it would have verified this assumption. It does seem probable that, at one time, the cave did serve to pirate river water to the northeast.

The Dye Shots

To determine the subsurface stream connections of Nimrod Hall Springs, fluorescein dye was injected into the cave stream and into Stuart Run. Using the Dunn method (Haas, 1959), dye was "captured" by activated coconut charcoal "traps" placed in Nimrod Hall Springs.

Blowing Stream Test

For the Blowing Cave stream trace, several charcoal traps were placed in Nimrod Hall Springs and in the Cowpasture River above the spring. Control traps were also placed in the river above Blowing Cave. Because of the long distance involved and the possible dilution by the river water insurgence at Windy Cove Farm, five pounds of fluorescein dye was placed in the stream in Blowing Cave. Only the traps placed in Nimrod Hall Springs tested positive and the flow-through time was three to four days.

Windy Cove Farm Insurgence

For the Windy Cove Farm insurgence stream trace, charcoal traps again were placed in the spring and in the river above the spring. Test traps were also placed in the river above Windy Cove Farm for a control. Three pounds of dye were used. This dye reappeared at Nimrod Hall Springs in approximately two days. In addition to the positive charcoal trap tests, visual observations of both traces were reported by a local resident.

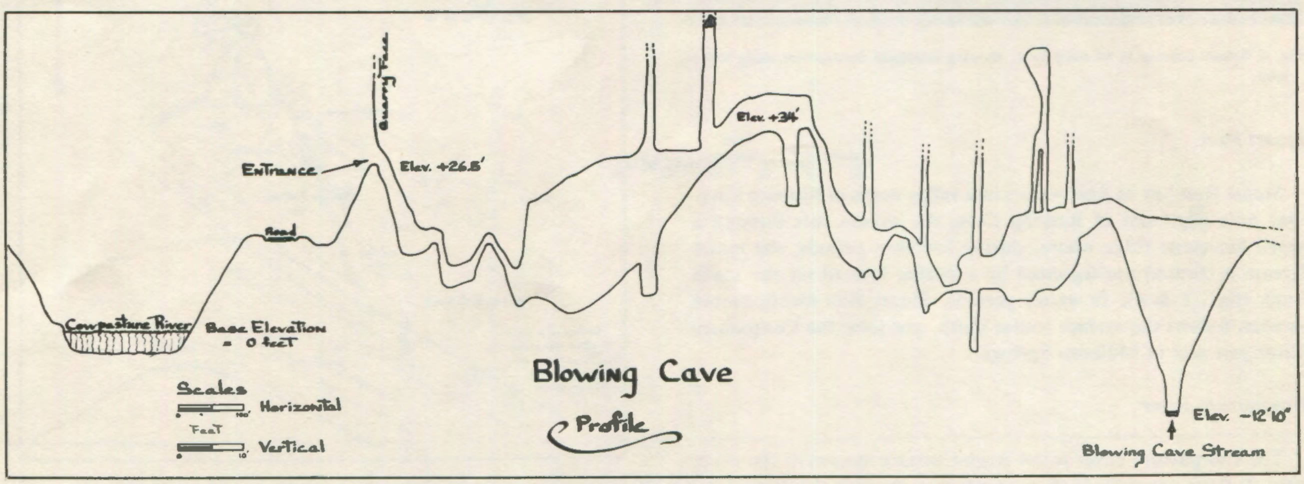


Fig. 7. Longitudinal profile of Blowing Cave, showing elevations relative to normal river stage.

TABLE 1. Stream-tracing data for Blowing Cave and area.

Swallet	Resurgence	Tracer	Date Added	Amount	Approximate Travel Time	Straight Line Distance
Blowing Cave Stream	Nimrod Hall Spring	Fluorescein	3-25-72	5 lbs.	3-4 days	3.6 Miles
Windy Cove Farm Insurgence	Nimrod Hall Spring	Fluorescein	6- 3-72	3 lbs.	< 2 days	2.9 Miles
Stuart Run Swallet	Nimrod Hall Spring	Fluorescein	11-21-74	4 lbs.	2-3 days	4.3 Miles

TABLE 2. Amount of water lost from surface streams known to resurge at Nimrod Hall Springs.

Location of Discharge Measurement	Discharge (cfs)*	Amount Lost	Percent of Total Discharge of Nimrod Hall Spring
Nimrod Hall Springs	48.0	—	—
Cowpasture River 400' above swallets	120.0	—	—
Cowpasture River 400' below swallets	83.7	36.3	75.6
Stuart Run	2.3	2.3	4.8
Total discharge lost from surface streams		38.6	80.4

Stuart Run Dye Test

When the fluorescein dye tests were made for Stuart Run, it was thought that Stuart Run could possibly be the source for the stream in Blowing Cave; therefore, traps were placed in the Blowing Cave stream as well as Nimrod Hall Spring. Four pounds of fluorescein dye were injected into the swallet of Stuart Run. Only the traps placed in Nimrod Hall Springs tested positive, thus establishing that Stuart Run does not pass through Blowing Cave enroute to Nimrod Hall Spring. The flow-through time was between two and three days. For stream flow rates and dye tracing information, see tables 1 and 2.

Geological Features

Blowing Cave is developed in the Helderberg group, on the western flank of an anticline which trends northeast-southwest. The Helderberg group is comprised of three formations; the Coeymans limestone (approximately 20 ft thick), the New Scotland limestone (approximately 20 ft thick), and the Licking Creek limestone (approximately 85 ft thick). Most of Blowing Cave is developed in the Coeymans formation, close to its contact with the Ridgeley sandstone (Bick, 1962, pp. 27-29).

The major cave passages and stream channel follow the strike of the anticline. The anticlinal axis parallels the ridge cut through by the water gap near the entrance to the cave. One mile southwest of the cave, just below the Windy Cove Farm swallet, the plunge of the anticline carries the limestones beneath the surface. The Cowpasture River, meandering back and forth across the plunging anticline, loses 40 ft in elevation from Blowing Cave to Nimrod Hall Springs. At Nimrod Hall, the anticlinal axis rises, and the spring is located at a point just before the limestone units intersect the valley floor.

Sandstone Cap and Shale Beds

The Millboro shale flanks both the east and west sides of the anticline. This shale is relatively impermeable and, probably, represents the east-west bounds of the subterranean flow paths. The Ridgeley sandstone, approximately 20 ft in thickness, conformably overlies the Helderberg group and, therefore, caps the anticline (although it has been removed at the water gaps) (Bick, 1962, pp. 27-29). The sandstone cap should prevent any upward penetration of underground streams where the limestones are below the surface. It therefore appears that subsurface flow is confined to a relatively narrow band of limestone parallel to the anticlinal axis (Fig. 8).

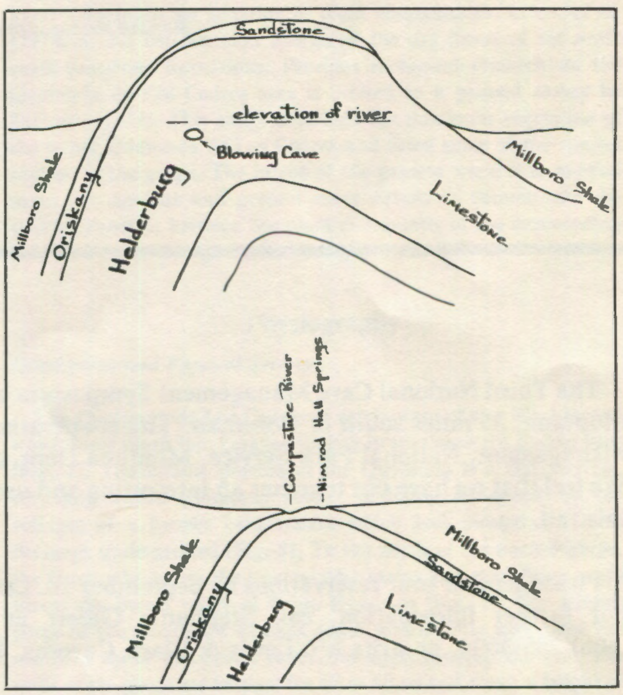


Fig. 8. Structure cross-sections, looking north, at Blowing Cave and at Nimrod Hall Springs.

Examination of the geological structure from the ridge north of the water gap to Nimrod Hall Springs invites an interesting conclusion. It appears that the cave stream, although heading in a

* Discharge measurements were all made on Aug. 11, 1974 using a standard "Price" current meter and wading rod. Measurements were made during a stable "low flow" period approaching base flow conditions.

northeasterly direction when last observed in Blowing Cave, turns back to the southwest and flows beneath the meandering Cowpasture River four times before resurging at the spring.

The captured water at Windy Cove Farm must also double back and flow to the southwest. The insurgence at Windy Cove Farm is on the opposite side of the river from the spring; therefore, it must flow at least once beneath the river to resurge. If the subsurface stream follows the anticlinal axis, it should flow below the meandering river three times. A similar flow pattern is predicted for the subsurface route of Stuart Run.

Conclusions

It has been established that the stream in Blowing Cave is 12.9 ft lower than the Cowpasture River at the cave entrance. This cave stream, like the pirated river water at the Windy Cove Farm insurgence, flows in a northeasterly direction (opposite the flow of the river) to an undertermined point, where it must "double back" to ultimately resurge at Nimrod Hall Springs. Sinking Stuart Run also resurges at Nimrod Hall Spring and, apparently, takes a similar underground route. The Cowpasture River meanders back and forth across the anticline between Blowing Cave and Nimrod Hall Springs. Structural and hydrological control is exerted over the subsurface flow direction (and cave passages) by the anticline and the position of the confining shale and sandstone units. It is, therefore, concluded that these underground streams must flow beneath the Cowpasture River several times before resurging at Nimrod Hall Springs. The Cowpasture River is a leaking karst stream for several miles and does not represent regional base level for the area around Millboro Springs.

Acknowledgements

I wish to thank the members of the Shenandoah Valley Grotto for their assistance in the surveying, digging operations, and stream tracing. Also, I especially wish to thank both Dr. John R. Holsinger, whose encouragement and guidance is most appreciated, and William K. Jones, whose field assistance and review of this material was greatly needed.

References Cited

Anon (1942) — Blowing Cave: *NSS Bulletin* **3**:10-12.

Bick, K.F. (1962) — Geology of the Williamsville Quadrangle, Virginia: *Va. Div. Min. Resources, Rept. Inv.* **2**, 40 pp.

Douglas, H.H. (1964) — Caves of Virginia: privately printed, 761 pp.

Haas, J.L. (1959) — Evaluation of Ground Water Tracing Methods used in Speleology: *NSS Bulletin* **21**:67-76.

Stephenson, W.J. (1946) — Further Work in Blowing Cave: *NSS Bulletin* **8**:93-95.

Manuscript received by the Editor 15 May 1975.

Revised manuscript accepted 25 January 1976.

The Third National Cave Management Symposium will be held October 3 through October 7, 1977 at Big Sky, Montana, 35 miles south of Bozeman. The cooperating organizations are: U.S. Forest Service, Bureau of Land Management, National Park Service, Montana Dept. of Fish and Game, and the National Speleological Society. We feel that we have put together an interesting and useful agenda that will entice you to visit the Big Sky Country this fall.

Please send in your reservations by September 10. Late registrations will be accepted, but at an increased price. For further information, call Stephanie Gibert at Lewis & Clark Caverns (406) 287-3541 or at home (406) 285-3694, or write c/o Lewis & Clark Caverns, P.O. Box 1024, Three Forks, Mont. 59752.

Isolation of a Plant Community by Karst Processes in Southwestern Puerto Rico

Barbara B. Cintrón* and Barry F. Beck†

ABSTRACT

The central mountain chain trending east-west across Puerto Rico is flanked on the north and south by off-lapping Tertiary sedimentary rocks, principally limestones. The Quebrada de Los Cedros is a deep, vertically-walled, karst gorge located in the semi-arid southeastern corner of the island. A genetically related cave-spring system underlies it. Temperatures within the gorge are 6 to 8°C cooler than in the surrounding hills and the relative humidity is 12 to 18% higher.

The surrounding hills contain plant species typical of the subtropical dry forest life zone: *Bursera simaruba, Thouinia portoricensis, Coccoloba microstachya, Bourreira dominguensis* and *Colubrina arborescens*, along with the shrubs *Croton rigidus, Lantana involucrata* and the liana *Stigmaphyllon periplocifolium. Bucida buceras*, a tall tree, is often found in the valleys. The vegetation is less than 10 m tall and is dense, with many thorns and small, thick, mostly deciduous leaves. Below the shrub layer, the forest floor is generally bare. The plant assemblage of the gorge, in contrast, is considerably taller (about 20 m) with large, thin, membranous leaves, and a dense ground cover of mosses and ferns. *Andira inermis, Guarea trichiloides*, and *Dendropanax arboreus* are common trees here but are generally typical of moist forests at higher elevations. *Tectaria martinicensis, Adiantum tenerum* and *Dennstaedtia adiantioides* are frequently observed ferns. *Ficus citrifolia, F. trigonata*, and *Clusia rosea* are common on the gorge walls and their aerial roots intertwine with the woody vine *Trichostigma actandrum*, forming dense tangles on the gorge floor. Only 45% of the known flora of the Quebrada de Los Cedros is commonly found in the surrounding areas. The deep, vertically walled gorge and the underlying El Convento Cave-Spring System, both features resulting from karst processes, have caused this shaded, cool, moist environment with its characteristic vegetation.

Introduction

Location

Puerto Rico is the easternmost and smallest of the Greater Antilles, an island chain which separates the Caribbean Sea from the Gulf of Mexico and the Atlantic Ocean. It is located approximately 1600 km ESE of Miami, Florida, and 850 km north of Caracas, Venezuela. Geologically, the island may be described as an east-west mountain range of Cretaceous igneous rocks, both intrusive and extrusive, flanked to the north and south by off-lapping layers of Tertiary sediments. Puerto Rico, at 18° north latitude, lies within the belt of the northeast tradewinds. Most precipitation occurs when the clouds being blown to the southwest by the tradewinds first reach the cool elevations of the Central Mountains. Thus, the southern slopes and coastal plain of the island are in a rain shadow and are considerably more arid than their northern counterparts.

The gorge of the *Quebrada de Los Cedros* is located within the semi-arid zone of the south coastal plain. This gorge has a unique micro-environment for this part of Puerto Rico, isolated by a landscape resulting from karst processes. The purposes of this paper are to summarize the geologic factors which produced this gorge, to delineate the climatic differences which result from the karst topography, and to describe the foral assemblage that characterizes this unique environment and differentiates it from that of the surrounding areas.

Previous Work

The gorge of the Quebrada de Los Cedros and the El Convento Cave-Spring System were the subjects of three earlier geologic papers. Moussa (1969) described the geomorphic development of the Quebrada de Los Cedros, but did not describe the cave system. Beck (1973) reported on size-frequency distributions of recent sediments from the cave stream and their significance with respect to transportation and hydrology. Beck (1974) also summarized the geology and hydrology of the cave system and furnished a map of the cave and gorge.

The stratigraphy of southwestern Puerto Rico has been the subject of recent debate (Moussa and Seiglie, 1970;1975), but the description and division cited herein are those of Monroe (1973). Monroe also contributed to an Environmental Impact Statement for this area (PRWRA, 1972); his divisions are delineated in more detail therein.

Previous work on the plant ecology of the south coast is relatively scarce. Gleason and Cook (1926), in their classic treatise on the plant ecology of Puerto Rico and the Virgin Islands, described the vegetation of the limestone hills west of Ponce and included remarks on the general appearance of the plant community and a partial list of dominant species. A more general treatment of the vegetation of the subtropical dry and subtropical moist life zones, according to the Holdridge system, is provided by Ewel and Whitmore (1973). This paper includes some remarks on effects of karst topography on zonation of plant communities. Little, *et al.* (1974, p. 20) list common species of the dry forest of the south coast limestone formations. Previous ecological research on the Quebrada de Los Cedros area is limited to a general survey by Nicholas (1974). This study described the dominant vegetation of the upper Quebrada de Los Cedros and listed some of the species present in the gorge. The intent of the present work is to expand upon this nucleus and present more details to demonstrate the striking contrast between the plant community of the surrounding hills and that of the gorge and valley proper.

Physiography

Description and Physical Setting

The Quebrada de Los Cedros is a tributary of the Río Macaná which flows south into Guayanilla Bay in southwestern Puerto Rico (Fig. 1). The middle portion of the Quebrada is a tall, narrow, vertically walled limestone gorge, probably developed by the collapse of a former cave system which had pirated the local drainage underground (Fig. 2). To the north of the narrow gorge, the Quebrada drains the Central Mountains and then flows south across the broad valley at Santo Domingo (Fig. 1). The narrow gorge of the Quebrada extends south and slightly west from the southern tip of this broad valley, for approximately 0.5 km. The walls of the gorge are vertical for 50 to 60 m and reach a height of 100 to 130 m at the nearest ridge crest. Most of the gorge is approximately 20 m wide. One hundred to one hundred fifty meters south of the upstream end of the narrow gorge, there is an abrupt vertical drop of 20 to 30 m where the upstream third of the gorge joins the more deeply incised lower portion as a hanging valley (Fig. 2). Just upstream from this cliff, the flow of the Quebrada sinks into

* Department of Botany, University of Florida, Gainesville, Florida 32611.

† Department of Earth Sciences, Georgia Southwestern College, Americus, Georgia 31709.

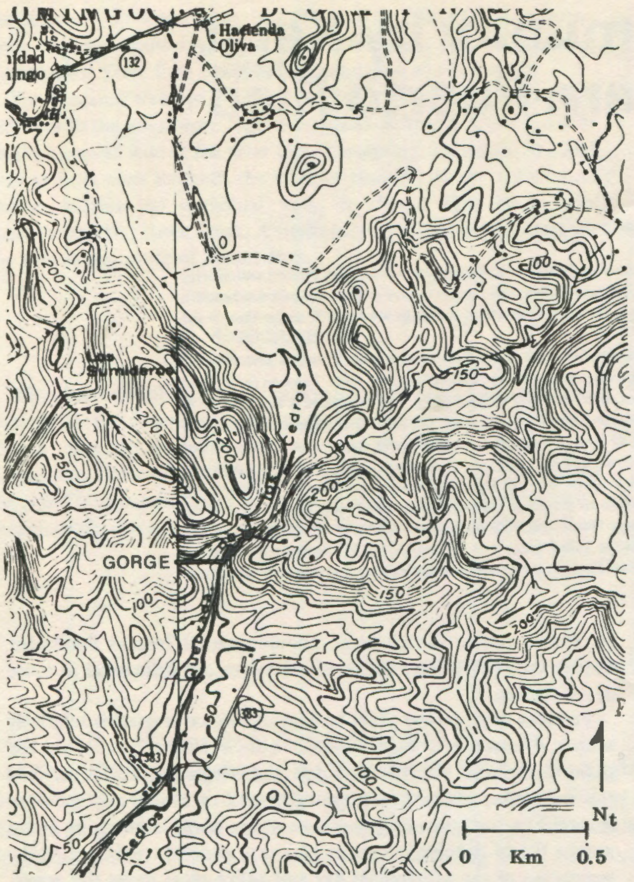


Figure 1. Topographic map of the Quebrada de los Cedros area. Guayanilla, Puerto Rico. From U.S.G.S. Peñuelas and Yauco quadrangles: N1800-W6637.5/7.5 and N1800-W6645/7.5. Contours in meters.

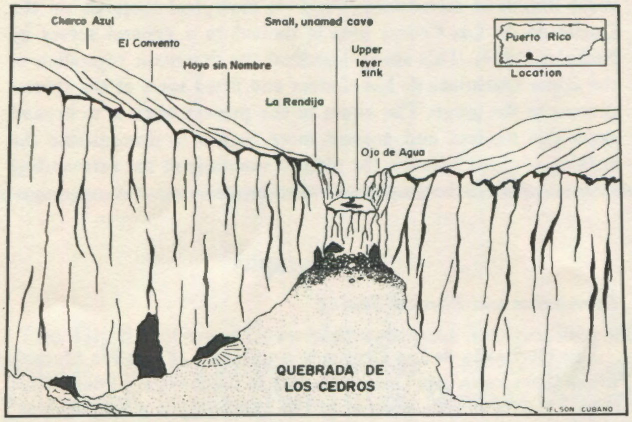


Figure 2. Artist's sketch of Quebrada de los Cedros, looking north with vegetation removed. Cueva Viento, on the east wall, is not shown.

a small swallow-hole and continues flowing south through the El Convento Cave-Spring System to resurge at the mouth of the gorge, through a spring called Charco Azul (Fig. 3). Along the base of the gorge there are six entrances to the El Convento System.

The area surrounding the gorge is also marked by karst features, such as Cueva Mapancha and several large sinkholes which are obvious on the topographic map (Fig. 1). Downstream (to the south) the Quebrada widens, and a cattle ranch was formerly located there, centered around the perennial flow of Charco Azul.

The area surrounding Guayanilla Bay, south of the Quebrada, is

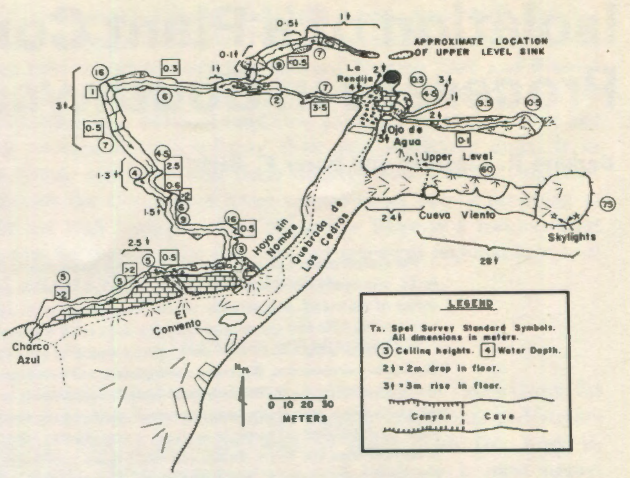


Figure 3. Map of El Convento Cave-Spring System; compass and steel tape survey by B.F. Beck and others.

highly industrialized. In the major alluvial valleys of the Río Macaná and the Río Tallaboa, agriculture is dominant, most of the land being devoted to sugar cane. The valley north of the Quebrada, between Peñuelas and Santo Domingo, is also extensively cultivated in sugar cane. In contrast, the limestone hills surrounding the Quebrada are almost totally undeveloped.

Karst Geology

The karst terrain, which includes the gorge, has developed on the middle unit of the Tertiary Juana Díaz Formation. The Juana Díaz Formation has been divided into three units: a lower, sandy or gravelly, conglomeratic mudstone up to 190 m thick; a middle zone of dense, biomicritic reef facies limestone 400 m thick; and an upper chalk or chalky limestone up to 150 m thick, which is not everywhere present (PRWRA, 1972). The only other significant karst features on the South Coast Tertiary limestones are developed on a series of dense limestone strata of the Ponce Formation (revised) which are exposed along the coast in the area near Guánica. Well developed, small-scale solution features and one significant cave are present in the Guánica area (Moussa, 1969; Beck, 1972; 1976). The common factor displayed by these two karst areas and limited to them is the dense, impermeable nature of the strata as compared to the chalky or marly character of the surrounding Juana Díaz and Ponce Formation limestones. A dense, impermeable limestone is sometimes cited as a prerequisite for karst development (Thornbury, 1954), and this appears to be corroborated in this area of Puerto Rico (Moussa, 1969; Beck, 1974).

The initial development of the gorge of the Quebrada de Los Cedros probably occurred when an enlarging limestone sinkhole expanded its catchment area sufficiently to pirate the east-flowing drainage in the Santo Domingo Valley, which formerly flowed to the Río Tallaboa, underground and to the south to the Río Macána (Fig. 1). The continuing development, enlargement, collapse, and lowering of this cave system produced the vertically-walled canyon which is the gorge of the Quebrada de Los Cedros today (Moussa, 1969). The present El Convento Cave-Spring System will eventually suffer similar collapse and continue the process of deepening and elongating the gorge.

The El Convento Cave-Spring System consists principally of a single canyon-type passage conducting an underground stream roughly parallel to the course of the gorge (Fig. 3). While it receives drainage from the upstream basin of the Quebrada, this only flows during the rainy season; however, two perennial springs are located within the cave system and the flow from the resurgence, Charco Azul, is thereby perennial, even during the driest periods of the year. The details of the present course of the cave system can be found in Beck (1974).

Climate

The gorge of the Quebrada de Los Cedros is located near the driest area in Puerto Rico, although it actually lies on the boundary between the subtropical moist forest and subtropical dry forest zones, using the Holdridge model (Ewel and Whitmore, 1973). According to Calvesbert (1970), average annual rainfall in the immediate vicinity of the gorge is approximately 1270 mm. There is no definite wet season, but rainfall is highest in August, September, October and November (Crooks, *et al.*, 1968).

The mean annual temperature is 25°C (Calvesbert, 1970). Data on the range of temperatures are not available for this immediate area, but at Santa Isabel, similarly located, the range extends from an average daily minimum of 18°C in February to an average daily maximum of 31°C in August (*ibid.*). The average annual evaporation at two stations in the subtropical *dry* forest zone is approximately 105 cm. The subtropical dry forest has a potential evapotranspiration: precipitation ratio ranging from 2.0 to 1.0, while in the subtropical moist forest zone, the range is from 1.0 to 0.5 (Ewel and Whitmore, 1973). However, the gorge is located near the drier margin of the moist zone and, when visited by the authors on numerous occasions from 1972 to 1975, conditions in the hills surrounding the Quebrada indicated that potential evapotranspiration probably exceeds precipitation here by a noticeable amount.

Ewel and Whitmore (1973) remarked that the tops of hills in the moist limestone region of Puerto Rico's north coast support a xeric type of vegetation, in contrast to the more mesic plant associations of hillsides and valleys, suggesting that differences in the plant associations were probably caused by micro-climate and soil differences. A more striking example of this micro-zonation can be seen in the Quebrada de Los Cedros, because the micro-climate of the narrow gorge differs markedly from that of the surrounding area. Immediately upon entering the confines of the gorge, a visitor is impressed by the startling temperature contrast. The temperature and relative humidity inside and outside the gorge were each measured on 2 separate days. Although simultaneous measurements could not be taken, several were taken as concurrently as possible (interior vs. exterior). These values are shown in Figure 4. Note that, in one instance, the gorge was 6 to 8°C cooler and 12 to 18% more humid than the surrounding hills. The contrast most readily felt by a visitor, however, is demonstrated in the data from Charco Azul, at the mouth of the gorge, and Hoyo Sin Nombre, approximately 120 m into the gorge: when measured on February 26, 1975, the temperature dropped 4.5° C and the relative humidity increased 12% in this 120 m distance.

There are several probable causes for this striking microclimate. The tall, vertical walls of the gorge affect the climate in two ways: they serve to shade the floor area for all but a few hours of the day near noon, and they serve to isolate the interior of the gorge from most winds, except possibly those blowing out of the south. The lack of wind would reduce the evaporation. In addition to the effects of the walls, there is also the influence of the underlying El Convento Cave-Spring System. The cave river crosses beneath the floor of the gorge near the base of the cliff, probably flowing between boulders, and a smaller distributary may flow under the entire length of the gorge. The main cave river flows parallel and immediately adjacent to the gorge for the last 120 m of its course, from Hoyo Sin Nombre to Charco Azul. In this section there are three entrances and cool, moist air can be felt in the vicinity of each of them. Near all the cave entrances, mosses grow on the rocks, indicating high humidity there. Thus, the cave river increases the atmospheric humidity and soil moisture within the gorge. Plant transpiration may also increase relative humidity.

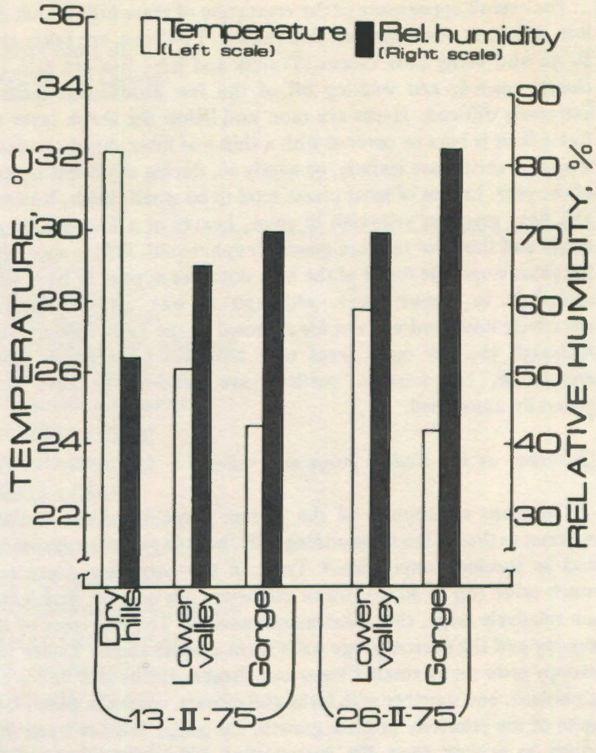


Figure 4. Paired temperature and humidity measurements taken inside and outside the gorge during two visits to the area.

The thin soil present within the gorge should not be confused with typical river bottom land, or alluvial soil, because it is a well-drained residual soil derived from the underlying, highly permeable limestones, as is the upland soil. That is to say, soil differences play a minimal role in the differentiation of plant communities between the hills and the Quebrada.

Flora

Guayanilla Hills

The hills surrounding the gorge and valley are covered by a low, semideciduous forest dominated by trees typical of the subtropical dry forest life zone (Ewel and Whitmore, 1973). The most conspicuous single tree is *Bursera simaruba* with its thick, gnarled branches and shiny, pinkish-brown bark. *Thouinia portoricensis, Coccoloba microstachya, Bourreria dominguensis*, and *Colubrina arborescens* are widespread. The smaller trees *Eugenia foetida, Pictetia aculeata, Leucena leucocephala*, and *Comocladia dodonea* are abundant. Common shrubs include *Croton rigidus* and *Lantana involucrata*. The woody liana *Stigmaphyllon periplocifolium* is extremely abundant, especially on slopes. Also on hill slopes and in ravines and valleys, an additional tree species, *Bucida buceras*, conspicuously overtops the low canopy of the other trees. Its arched branches are usually heavily festooned with the bromeliad *Tillandsia recurvata*. Other tree species found on lower slopes include *Krugiodendrum ferreum, Erythroxylon rotundifolium, Trichilia pallida* and *Schaefferia frutescens*. The small palm *Thrinax morrissii* also occurs here. During the dry season, widely scattered individuals of the lignum vitae, *Guaiacum sanctum*, stand out with their dark-green leaves against the leafless gray branches of the rest of the forest. The vine-like tree *Clusia rosea* projects from rocky ledges and its aerial roots dangle in the holes and cracks of the limestone.

The overall appearance of the vegetation of these hills is that of a low, dense, almost impenetrable thicket. Few trees are taller than 10 m, and many bear thorns. Trunks and branches are thin and closely spaced, and walking off of the few established trails is extremely difficult. Herbs are rare, and below the shrub layer the forest floor is bare or covered with a thin leaf litter. Most species of trees and shrubs are leafless, or nearly so, during the driest months of the year. Leaves of most plants tend to be small, thick, leathery, and light green or yellowish in color. Leaves of a few species are larger and thin, but they are generally ephemeral, falling soon after the rains stop. The forest of the hills does not appear to have been disturbed in recent years, although it was almost certainly selectively lumbered and cut for charcoal in the more distant past. Although the few open areas may have been grazed by goats and cattle, the forested portions are believed to have been generally untouched.

Quebrada de Los Cedros gorge and valley

The plant assemblage of the stream gorge stands in striking contrast to that of the surrounding hills, both in general appearance and in species composition.* Trees in the gorge are evergreen, much taller (up to 30 m), trunk diameters are greater, and leaves are relatively large, thin, and membraneous. The tall trees of the canopy and the narrow gorge walls form a dense shade. Under this canopy grow many smaller trees and shrubs. Herbs and lianas are abundant, and together with ferns and mosses, cover the ground. In spite of the relatively profuse growth, the gorge is more open and easier to explore than the surrounding hills, due to the wider spacing of the trees.

At the upper end of the gorge, the tallest trees are *Andira inermis* (moca) and *Guarea trichiloides* (guaraguao) (Fig. 5). These trees form a rather dense canopy at about 20 m, throwing the understory and ground levels into a dark green shade which is broken only for a short time each day by sun flecks when the sun is directly overhead. Both species are normally found at higher elevations in the subtropical moist and wet forest life zones (Woodbury, 1975, pers. commun.). Other smaller, typical wet forest trees common in the upper gorge are *Dendropanax arboreus, Celtis trinervia*, and *Nectandra coriacea*. Coffee, *Coffea arabica*, has been planted here and abandoned; it now reaches heights of 3 to 4 m. A single large ceiba (*Ceiba pentandra*) stands at the side of the trail near the lower end of the gorge. Its trunk diameter above the root buttresses is estimated at greater than 1 m, and it is about 30 m tall.

Many species of plants are found in the understory. The stinging nettle *Urera baccifera* is common. The ferns *Tectaria martinicensis* and *Adiantum tenerum* are widespread on rocks and banks near cave openings, and the large fern *Dennstaedtia adiantioides* covers part of the floor of the gorge above Hoyo Sin Nombre. The grasses *Pharus glabra* and *Olyra pauciflora* form small clumps in darker sections of the gorge. Exposed rocks near the cave openings are slippery with algae and mosses and also support the tiny prostrate herb *Pilea repens*. Many species of small trees are present, but *Palicourea dominguensis, Psychotria brownei*, and *P. nervosa* are especially common, along with the shrub *Piper amalago*.

Vines and creepers are also abundant inside the gorge. The stout woody vine *Trichostigma octandrum* forms great tangles of stems on the gorge floor, and the delicate *Serjania polyphylla* twines in the branches of the trees, along with a species of Philodendron identified by Nicholas (1974) as *P. krebsii* (Fig. 6).

On the near-vertical walls of the gorge, wild figs (*ficus citrifolia, F. trigonata*) and cupey (*Clusia rosea*) grow in cracks, sending their long roots to the valley floor. The bromeliad *Pitcairnia angustifolia*

Figure 5. View of the upper gorge, looking north. Compare tree height with human figure on the lower right.

Figure 6. Stream bed of the lower valley, looking north toward Charco Azul. *Philodendron krebsii* is the commonest liana.

* A list of the species found in the gorge and valley is included in Table I.

TABLE I: Higher Plant Species Identified From the Gorge and Valley of the Quebrada de Los Cedros.

	Also found in surrounding hills	Normally found at higher elevations or in moister sites
POLYPODIACEAE		
Adiantum tenerum		+
Dennstaedtia adiantioides		+
Tectaria martinicensis		+
POACEAE (GRAMINAE)		
Olyra pauxiflora		+
Pharus glaber		+
ARECACEAE		
Gaussia attenuata (?)		+
Thrinax morrissii	+	
ARACEAE		
Anthurium acaule	+	
Dieffenbachia seguine		+
Philodendron krebsii		+
BROMELIACEAE		
Pitcairnia angustifolia	+	
Tillandsia recurvata	+	
PIPERACEAE		
Piper amalago		+
ULMACEAE		
Celtis trinervia	+	
MORACEAE		
Cecropia peltata		+
Chlorophora tinctoria		+
Dorstenia contrajerva		+
Ficus citrifolia	+	
Ficus trigonata		+
URTICACEAE		
Pilea repens		+
Urera baccifera		+
POLYGONACEAE		
Coccoloba diversifolia	+	
NYCTAGINACEAE		
Guapira obstusata		+
PHYTOLACCACEAE		
Trichostigma octandrum		+
ANNONACEAE		
Annona reticulata	+	
*Oxandra laurifolia**	+	
LAURACEAE		
Nectandra coriacea		+
Persea americana	+	
CAPPARIDACEAE		
Capparis cynophallophora	+	
FABACEAE		
Andira inermis		+
Sabinea florida		+
MALPHIGHIACEAE		
Stigmaphyllon periplocifolium	+	
RUTACEAE		
Amyris elemifera	+	
Citrus aurantifolia	+	
Zanthoxylum martinicense		+
SIMAROUBACEAE		
Picramnia pentandra	+	
BURSERACEAE		
Bursera simaruba	+	
MELIACEAE		
Guarea trichiloides		+
Trichilia pallida	+	
EUPHORBIACEAE		
Phyllanthus epiphyllanthus	+	
ANACARDIACEAE		
Mangifera indica	+	
SAPINDACEAE		
Melicoccus bijugatus	+	
Serjania polyphylla	+	
RHAMNACEAE		
Krugiodendron ferreum	+	
BOMBACACEAE		
Ceiba pentandra	+	
GUTTIFERAE		
Clusia rosea	+	
Mammea americana		+
CACTACEAE		
Cephalocereus royenii	+	
TERMINALIACEAE		
Bucida buceras	+	
MYRTACEAE		
Eugenia foetida	+	
Eugenia rhombea	+	
ARALIACEA		
Dendropanax arboreus		+
SAPOTACEAE		
*Pouteria hotteana**		+
Sideroxylon foetidissimum		+
APOCYNACEAE		
tabernaemontana citrifolia		+
BORAGINACEA		
Cordia nitida		+
RUBIACEAE		
Coffea arabica		+
Psychotria brownei		+
Psychotria nervosa		+
CUCURBITACEAE		
Cayeponia americana (?)		+
TOTALS	27	33

(?) Tentative identification.

* Species included in the list of endangered plants of P.R. (Woodbury, Chairman, 1975).

and the aroid *Anthurium acaule* are common. A few other trees (*Eugenia foetida, E. rhombea* and the palm *Thrinax morrisii*) are occasionally found on wider ledges.

Below Charco Azul, the valley widens and more tree species appear. Tall trees along the stream include *Andira inermis* and *Guarea trichiloides* of the gorge, with the addition of *Sideroxylon foetidissimum, Picramnia pentandra, Zanthoxylum martinicense* and *Mammea americana*. Introduced fruit trees include mango (*Mangifera indica*), quenepa (*Melicoccus bijugatus*) and lime (*Citrus aurantifolia*). Small herbs and ferns are common along the stream banks but do not cover the valley floor as completely as they do in the gorge.

The gorge of the Quebrada is entirely on private property. There is evidence that some of the original vegetation of this unique ecosystem may have been removed to allow limited agriculture in the gorge and valley area. The coffee and fruit trees (both native and introduced) were probably planted there earlier in the present century. Still earlier, the valuable timber trees of the gorge may have been cut. The name of the gorge in Spanish, *Quebrada de Los Cedros*, may refer to the former presence of *Cedrela odorata* (Cedro), a timber tree in the mahogany family, which was once heavily harvested in Puerto Rico for its valuable wood (Little and Wadsworth, 1964).

Summary, Conclusions and Discussion

The narrow, vertically-walled gorge of the Quebrada de Los Cedros, and the El Convento Cave-Spring System which extends along the gorge floor, are the results of karst processes which have pirated the local drainage underground. The gorge may be a collapsed remnant of a former cave. The climate within the gorge is influenced markedly by the tall, vertical walls and the cave stream. It is more humid and cooler than that of the surrounding hills.

Sixty species of higher plants were collected or identified in the gorge and valley of the Quebrada de Los Cedros. Of these, two are listed as endangered species in Puerto Rico (Woodbury, *et al.*, 1975), and an additional 33 species are probably not found in the surrounding hills. Only 27 species (45% of the total) are common to the plant communities of the surrounding geographic area. It is probable that the aforementioned karst features and the accompanying climatic differences are responsible for this distinct and locally unique micro-environment.

The primary current dangers to this unique environment are litter and vandalism, both from occasional afternoon and weekend visitors. Rock surfaces have been defaced by spray paint, and discarded food wrappers and beverage cans are everywhere apparent. It does not seem likely that the gorge will be used for minor fruit crops again, and its development for residential or industrial use seems even more unlikely. Because of the unusual assemblage of plant species found in the gorge and lower valley, we recommend that this small area be preserved in its natural state so that the interactions of geological and biological processes can be studied further and, perhaps, presented to visitors on a self-guiding trail.

Acknowledgments

The Department of Natural Resources of the Commonwealth of Puerto Rico supplied vehicles, lodging, and laboratory facilities to both authors. Roy Woodbury assisted with plant identifications and provided observations on the range of some species. James Williams photographed the Quebrada, as noted. *Don* Rafael Lucas, mayordomo of the property on which the gorge of the Quebrada de Los Cedros is located, was a gracious host and, occasionally, a well-informed guide into the surrounding hills. To all these people the authors extend their thanks.

References

Beck, B.F. (1972) — Features of Limestone Solution, Erosion, and Precipitation along the Southwest Coast of Puerto Rico (*abs.*): *NSS Bulletin* 35:25.

———— (1973) — Size-frequency Distributions of Recent Sediments from a Cave-Spring System in Southern Puerto Rico and Their Significance with Respect to Hydrology and Transportation: Olomouc, *VI Internat. Congr. Speleol., Proc.* (in press).

———— (1974) — Geology and Hydrology of the El Convento Cave-Spring System, Southwestern Puerto Rico: *Internat. Jour. Speleol.* 6:93-107.

———— (1976) — Karst Geology and Hydrology of the Tertiary Ponce Limestone along the Southwest Coast of Puerto Rico (*abs.*): *Geol. Soc. America. Abs. Programs* 8(2):130-131.

Calvesbert, R.J. (1970) — Climate of Puerto Rico and the U.S. Virgin Islands: *Climates of the States, U.S. Dept. Commerce. ESSA. Env. Data Service, Climatography of the States,* No. 60-52, 29 pp.

Crooks, J.W.; I.G. Grossman; and D.B. Bogart (1968) — Water Resources of the Guayanilla-Yauco Area, Puerto Rico: *Commonwealth of Puerto Rico, Water Resources Bull.* 5, 55 pp.

Ewel, J.J. and J.L. Whitmore (1973) — Ecological Life Zones of Puerto Rico and the United States Virgin Islands: *U.S. Forest Service, Bull. Inv.* ITF-8, map.

Gleason, H.A. and M.T. Cook (1926) — Plant Ecology of Puerto Rico: *N.Y. Acad. Sci., Sci. Survey P.R. Virgin Islands* 7, 173 pp.

Little, E.L., Jr. and F.H. Wadsworth (1964) — Common Trees of Puerto Rico and the Virgin Islands: *U.S. Forest Service, Ag. Handbook* 249:242-246.

————; R. Woodbury; and F.H. Wadsworth (1974) — Trees of Puerto Rico and the Virgin Islands, Second Volume: *U.S. Forest Service Ag. Handbook* 449, 20 pp.

Monroe, W.H. (1973) — Stratigraphy and Petroleum Possibilities of Middle Tertiary Rocks in Puerto Rico: *Am. Ass'n. Petrol. Geologists, Bull.* 57:1086-1099.

Moussa, M.T. (1969) — Quebrada de Los Cedros, Southwestern Puerto Rico, and its Bearing on Some Aspects of Karst Development: *Jour. Geol.* 77:714-720.

——— and G.A. Seiglie (1970) — Revision of Mid-Tertiary Stratigraphy of Southwestern Puerto Rico: *Am. Ass'n Petrol. Geologists, Bull.* 54: 1887-1898.

———, ——— (1975) — Stratigraphy and Petroleum Possibilities of Middle Tertiary Rocks in Puerto Rico: Discussion: *Am. Ass'n Petrol. Geologists, Bull.* 59:163-168.

Nicholas, Bro. G. (1974) — Biology and Ecology of the El Convento Cave-Spring System (Puerto Rico): *Internat. Jour. Speleol.* 6:109-114.

Puerto Rico Water Resources Authority (PRWRA) (1972) — Environmental Impact Report for the Construction and Operation of Deep Water Wells in the Macaná Valley, Guayanilla, Puerto Rico: San Juan, PRWRA, 11 pp.

Thornbury, W.D. (1954) — Principles of Geomorphology: NYC, Wiley, 618 pp.

Woodbury, R. *et al.* (1975) — Rare and Endangered Plants of Puerto Rico, a Committee Report: San Juan, U.S. Dept. Ag., Soil Cons. Service and P.R. Dept. Nat. Resources, 85 pp.

Manuscript received by the Editor 20 July 1976.

Revised manuscript accepted 9 April 1977.

CALL FOR PAPERS

The Third National Cave Management Symposium will be held at Big Sky, Montana from October 3 until October 7, 1977. The organizing committee felt that the '77 Symposium should emphasize some of the basic tools and methodology necessary for the implementation of many of the management ideas presented at past conferences. In general, papers will be limited to a 15-20 minute presentation period, followed by a short question and answer session. Further discussion may be carried on during breaks and the evening hours.

Three copies of an abstract or the paper, not to exceed 300 words, should be sent to: Stephanie Gibert, Manager, Lewis & Clark Caverns, P.O. Box 1024, Three Forks, Mont. 59752, Phone: Caverns, 406-287-3541; Home, 285-3694.

Deadline for abstracts is August 1, 1977. The steering committee will review the abstracts and will mail out notification of acceptance or rejection of the paper by mid-August.

Two copies of the paper should be received by Stephanie by September 26, 1977, one week prior to the Symposium.

The Proceedings of the Third National Cave Management Symposium will be published as soon afther the end of the session as possible. Black and white photographs and/or drawings illustrating the paper would be greatly appreciated and should be submitted along with the paper.

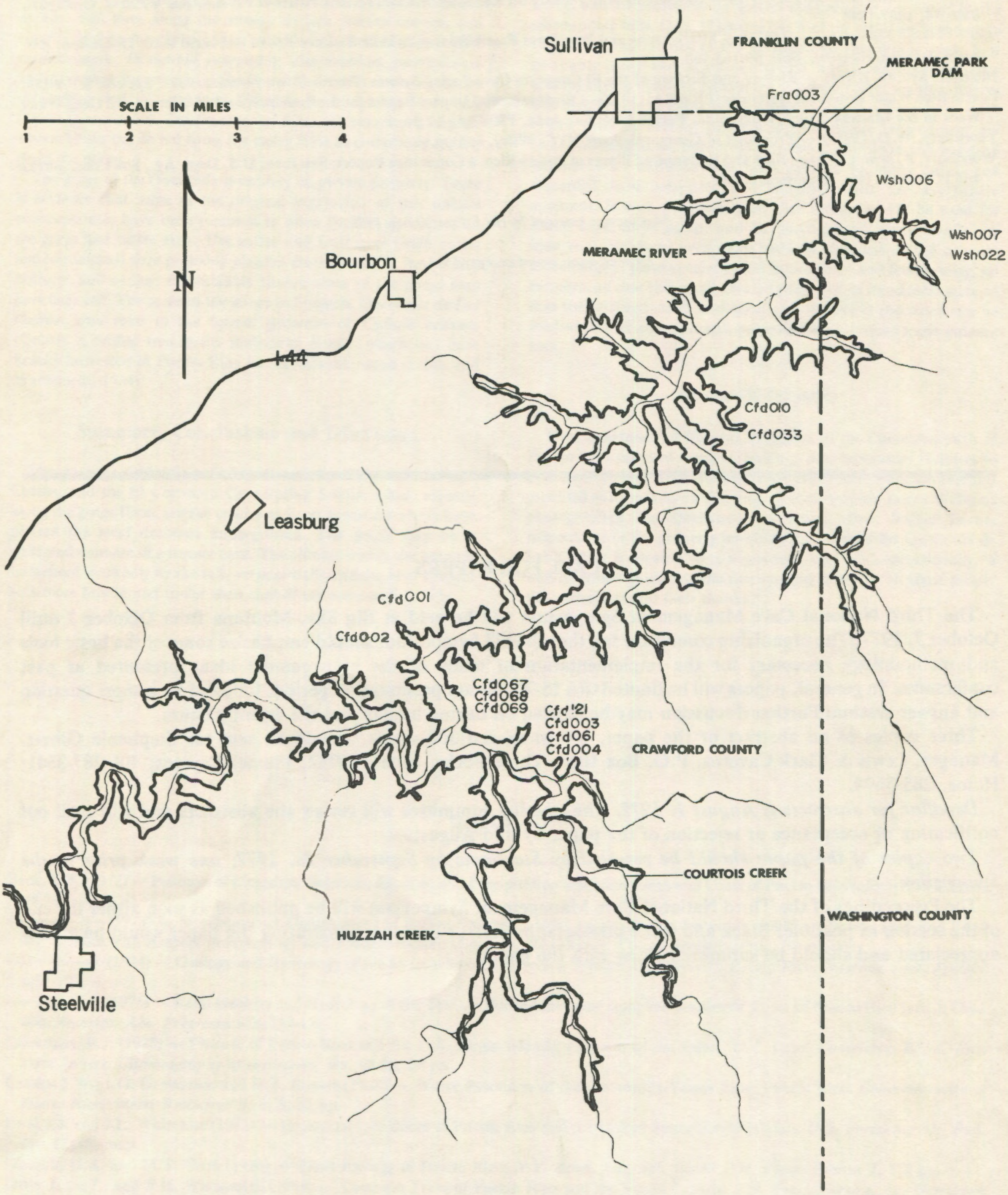


Figure 1. Meramec Park Lake, Meramec River, Missouri. Mushroom and Onyx caves will lie just above flood pool. Cfd003—Bat Cave, Cfd004—Bear Cave, Cfd002—Cathedral Cave, Wsh006—Green Cave, Wsh007—Hamilton Cave, Wsh022—Hamilton Spring Cave, Cfd067—Jagged Canyon Cave, Cfd068—Lookout Cave, Cfd069—Mud River Cave, Fra003—Mushroom Cave, Cfd010—Nameless Cave, Cfd001—Onondaga Cave, Cfd033—Onyx Cave, Cfd061—Sewer Cave, Cfd121—Stairstep Cave.

Invertebrate Faunas of Caves To Be Inundated By the Meramec Park Lake in Eastern Missouri

John L. Craig *

ABSTRACT

Ninety-eight species of invertebrates, representing 27 orders, were found in 15 caves in the area to be inundated by the Meramec Park Lake, Missouri. Nine species in 5 orders are troglobitic. At least 4 undescribed species were found: an amphipod, a pseudoscorpion, a collembolan, and a campodeid dipluran (the first record for *Haplocampa* from Missouri). Data concerning habitats, feeding habits, associations, communities, distribution, and endangered populations of some species are presented.

Over 50 percent of the known populations of 2 troglobitic species and the type locality of 2 other species may be destroyed by the reservoir. *Allocrangonyx hubrichti* is considered to be an endangered species; *Fontigens aldrichi, Stygobromus* n. sp., and *Haplocampa* n. sp. are considered to be threatened species; and *Stygobromus onondagaensis* has been recommended for "watch" status.

Introduction

Background

Construction of the proposed Meramec Dam in Crawford and Washington counties, eastern Missouri, would inundate several caves. Biospeleological data have been gathered on invertebrate cave faunas of the reservoir area. Major emphasis has been on information concerning systematics, ecology, and geographic distribution.

The Meramec and its two main tributaries, the Bourbeuse and Big rivers, drain a large portion of the northeast quarter of the Ozark Plateau. Meramec Park Lake (Fig. 1) will be centrally located in the basin (U.S. Army Engineer District, St. Louis, 1973). Flood pool elevation will be 709 ft asl; from the dam, the reservoir will extend southward 39 miles upstream along the Meramec, 11½ miles up Huzzah Creek, and 10½ miles up Courtois Creek. At normal pool (675 ft asl), the reservoir will reach upstream 33, 6, and 5 miles, respectively, along the Meramec and its tributaries.

Dams in the Meramec Basin originally were authorized by the Flood Control Act of 1938. One dam, each, was proposed for the Meramec and Big rivers. At present, the Corps of Engineers proposes five major reservoirs and 19 angler-use sites for this basin. In addition, the U.S. Department of Agriculture has proposed construction of 60 smaller impoundments in the Meramec Basin (U.S. Army Engineer District, St. Louis, 1973).

Biological data have been obtained from 15 caves in the reservoir area. Thirteen lie below flood pool level; several of them also lie below normal pool level. All of these will be grossly altered, if not totally destroyed, by the reservoir. The effects of the reservoir on two caves which lie just above flood pool level will depend largely on induced changes in groundwater levels and on their future availability to boaters and other casual visitors.

The caves are developed in cherty dolomites of the Eminence-Potosi formations (Upper Cambrian) and of the Gasconade formation (Lower Ordovician) (McCracken, 1961). Reams (1968) estimated that the present valleys have been developed beneath the general plateau surface since Pliocene time. Reams also stated that 73 percent of all caves in the Meramec Basin are located along the Meramec River, itself, and that 60 percent of these are found less than one-tenth mile from the river, at or near river level.

Cave names and code numbers used in this report are those given in the Catalog of the Caves of Missouri (Vineyard, 1973). General descriptions of some of these are given by Bretz (1956); detailed information may be obtained from the files of the Missouri Speleological Survey.†

The classification of cavernicoles used is that of Barr (1958, 1963).

Previous Investigations

Although Missouri caves have been studied for almost 100 years, knowledge of their faunas remains fragmentary. Previous reports on Missouri cave invertebrates recently were reviewed (Craig, 1975).

Earlier studies including caves in the reservoir area and their topics include: (Lepidoptera) Casper, 1975; (Oligochaeta) Gates, 1959; (Gryllacrididae) Hebard, 1934 and Hubbell, 1936; (Gastropoda) Hubricht, 1940 and 1941; (Amphipoda) Hubricht, 1943, Hubricht and Mackin, 1940, and Holsinger, unpublished; (Diplopoda) Causey, 1960 and Loomis, 1943; (Asellidae) Fleming, 1972, Mackin and Hubricht, 1940, and Steeves, 1966.

Materials and Methods

Field investigations began in March, 1973 and ended in July, 1974. I used the biological techniques and equipment for collecting in caves described by Cooper and Poulson (1968). Trapping and baiting is generally more successful than hand collecting, but usually necessitates having to revisit the cave. I favored the use of hand collecting, because it allowed me to take field notes on species in their natural habitat. I did, however, have some success using a wire mesh cricket trap baited with bologna in collecting isopods and amphipods from streams and pools. The collections were labeled, catalogued, and then identified or sent to specialists for identification and verification. Specimens were retained by the specialists or are in my care.

Faunal List

Locality records and ecological classifications of the invertebrate species known from the caves of the Meramec Park Lake area are presented on the following pages. The status of some of the less well known groups may be revised when more information is acquired. Published records are given first, followed by new records obtained during this study (designated, "New").

* Department of Biology, Central Missouri State University, Warrensburg, Mo. 64093 (present address: 34 Williams, Fort Leonard Wood, Mo. 65473).

† c/o Missouri Geological Survey, Box 250, Rolla, Missouri 65405.

PHYLUM MOLLUSCA
CLASS GASTROPODA (SNAILS)
ORDER MESOGASTROPODA

Family Hydrobiidae

Fontigens aldrichi (Call and Beecher); troglobite.

Records: Cathedral and Onondaga caves, Crawford County (Hubricht, 1940); Green and Hamilton caves, Washington County (Hubricht, 1940); **new**: Jagged Canyon Cave, Crawford County; Mushroom Cave, Franklin County, Hamilton Spring Cave, Washington County.

ORDER STYLOMMATOPHORA

Family Edodontidae

Anguispira alternata (Say); accidental.

new: Nameless Cave, Crawford County.

Family Philomycidae

Pallifera mutabilis Hubricht; troglophile.

new: Nameless Cave, Crawford County.

Pallifera sp.; troglophile.

new: Onondaga Cave, Crawford County.

Philomycus carolinianus (Bosc); trogloxene.

new: Bat Cave, Crawford County.

Family Polygyridae

Mesodon inflectus (Say); troglophile.

new: Onondaga Cave, Crawford County.

M. thyroidus (Say); trogloxene.

new: Stairstep Cave, Crawford County.

Family Zonitidae

Zonitoides arboreus (Say); troglophile.

Records: Onondaga Cave, Crawford County (Hubricht, 1941); **new**: Green Cave, Washington County.

PHYLUM ANNELIDA (WORMS)
CLASS CLITELLATA
ORDER OLIGOCHAETA

Unidentified material; probably troglophiles.

new: Bat and Nameless caves, Crawford County; Mushroom Cave, Franklin County; Hamilton Spring Cave, Washington County.

Family Lumbricidae

Unidentified species; probably troglophile.

Record: Onondaga Cave, Crawford County (Gates, 1959).

PHYLUM ARTHROPODA
CLASS ARACHNIDA
ORDER ARANEIDA (SPIDERS)

Family Agelenidae

Cicurina cavealis Bishop and Crosby; troglophile.

new; Bat and Jagged Canyon caves, Crawford County.

Cicurina sp.; troglophile.

new: Onondaga Cave, Crawford County.

Coras lamellosus (Keyserling); troglophile.

new: Nameless Cave, Crawford County.

Coras sp. (near *lamellosus* [Keyserling]); troglophile.

new: Nameless and Stairstep caves, Crawford County.

Coras sp.; troglophile.

new: Bat Cave, Crawford County.

Family Linyphiidae

Bathyphantes pallida (Banks); troglophile.

new: Bear Cave, Crawford County.

Centromerus cornupalpis (O.P. Cambridge); troglophile or trogloxene.

new: Bear Cave, Crawford County.

Centromerus latidens (Emerton); troglophile.

new: Bat and Lookout caves, Crawford County.

Linyphia marginata C.L. Koch; trogloxene.

new: Bat and Nameless caves, Crawford County.

Family Lycosidae

Pirata sp.; troglophile or trogloxene.

new: Bear Cave, Crawford County.

Family Pisauridae

Dolomedes sp. (near *tenebrosus* Hentz); trogloxene.

new: Bat and Jagged Canyon caves, Crawford County.

D. vittatus (Walckenaer); trogloxene.

new: Stairstep Cave, Crawford County.

D. sp. (near *vittatus* [Walckenaer]); trogloxene.

new: Green Cave, Crawford County.

Pisaurina mira (Walckenaer); trogloxene.

new: Lookout Cave, Crawford County.

Family Nesticidae

Nesticus pallidus (Banks); troglophile.

new: Bear and Onondaga caves, Crawford County.

Family Theridiidae

Achaeranea porteri Banks: trogloxene.

new: Green Cave, Washington County.

A. sp. (near *porteri* Banks); trogloxene.

new: Bat Cave, Crawford County.

A. tepidariorum (C.L. Koch); trogloxene.

new: Stairstep Cave, Crawford County; Green Cave, Washington County.

A. sp.; trogloxene.

new: Bear and Stairstep caves, Crawford County.

ORDER CHELONETHIDA (PSEUDOSCORPIONS)

Family Chthoniidae

Apochthonius sp. (aff. *colecampi* Muchmore); troglophile.

new: Bat Cave, Crawford County; Mushroom Cave, Franklin County.

ORDER OPILIONES (HARVESTMEN)

Family Phalangiidae

Leiobunum sp.; trogloxene.

new: Green Cave, Washington County.

Opilio sp.; trogloxene.
new: Stairstep Cave, Crawford County.

ORDER ACARINA (MITES)

Family Eupodidae
Linopodes sp. (near *motatorious* Linné); troglophile.
new: Mushroom Cave, Franklin County.

Family Laelaptidae
Pseudoparasitus austricus (Sellnick); troglophile or trogloxene.
new: Jagged Canyon and Lookout caves, Crawford County; Hamilton Spring Cave, Washington County.

Family Rhagidiidae
Rhagidia hilli Strandtmann; troglophile.
new: Bat and Bear caves, Crawford County; Green Cave, Washington County.

R. whartoni Strandtmann; troglophile.
new: Onondaga Cave, Crawford County.

CLASS CRUSTACEA (CRUSTACEANS)

ORDER OSTRACODA (OSTRACODS)

Family Cytheridae
Thermastrocythere riojai (Hoff); accidental.
new: Bear Cave, Crawford County.

ORDER ISOPODA (ISOPODS)

Family Armadillidae
Armadillidium nasatum Budde-Lund; troglophile.
new: Onondaga Cave, Crawford County.

Family Asellidae
Asellus antricolus (Creaser); troglobite.
Record: Cathedral Cave, Crawford County (Steeves, 1966).

A. sp. (near *brevicaudus* Forbes); troglophile.
new: Bat and Jagged Canyon caves, Crawford County.

A. stiladactylus Mackin and Hubricht; troglobite.
Record: Onyx Cave, Crawford County (Fleming, 1972).

A. spp.; troglobites.
new: Bat, Jagged Canyon, and Nameless caves, Crawford County; Mushroom Cave, Franklin County; Green and Hamilton Spring caves, Washington County.

Family Ligiidae
Ligidium sp.; troglophile or trogloxene.
new: Bear Cave, Crawford County.

ORDER AMPHIPODA (AMPHIPODS)

Family Gammaridae
Allocrangonyx hubrichti Holsinger; troglobite.
new: Hamilton Spring Cave, Washington County.

Bactrurus brachycaudus Hubricht and Mackin; troglobite.
new: Jagged Canyon and Nameless caves, Crawford County.

Crangonyx forbesi (Hubricht and Mackin); troglophile.
Records: Green and Hamilton caves, Washington County (Hubricht, 1943); **new**: Bear and Mud River caves, Crawford County; Mushroom Cave, Franklin County.

Gammarus minus Say; troglophile or trogloxene.
Record: spring near Hamilton Cave, Washington County (Hubricht, 1943).

Stygobromus onondagaensis (Hubricht and Mackin); troglobite.
Records: Onondaga (type locality) and Onyx caves, Crawford County; Mushroom Cave and a seep 0.5 mi northwest of Mushroom Cave, Franklin County (Hubricht, 1943; Hubricht and Mackin, 1940).

S. new species; troglobite.
Records: Cathedral Cave, Crawford County; Hamilton Cave, Washington County (Holsinger, pers. comm.); **new**: Green and Hamilton Spring caves, Washington County.

ORDER DECAPODA (CRAYFISH)

Family Cambaridae
Cambarus (*Lacunicambarus*) *diogenes diogenes* (Girard); accidental.
new: Bear Cave, Crawford County.

CLASS CHILOPODA (CENTIPEDES)

ORDER SCUTIGEROMORPHA

Family Scutigeridae
Scutigera coleoptrata (Linné); troglophile or trogloxene.
new: Onondaga Cave, Crawford County.

ORDER LITHOBIOMORPHA

Family Lithobiidae
Lithobius atkinsoni Bollman; troglophile.
new: Onondaga Cave, Crawford County.

ORDER GEOPHILOMORPHA

Family Geophilidae
Geophilus mordax Meinert; troglophile or trogloxene.
new: Bear Cave, Crawford County.

CLASS DIPLOPODA (MILLIPEDES)

ORDER POLYDESMIDA

Family Euryuridae
Euryurus sp. (near *leachii* [Gray]); trogloxene.
new: Bear and Stairstep caves, Crawford County.

Euryurus or *Auturus* sp.; trogloxene or accidental.
new: Green Cave, Washington County.

Family Polydesmidae
Pseudopolydesmus sp.; troglophile or trogloxene.
new: Nameless and Onondaga caves, Crawford County.

ORDER CHORDEUMIDA

Family Cleidogoniidae
Cleidogona or *Tiganogona sp.*; troglophile.
new: Onondaga caves, Crawford County.

Family Conotylidae
Austrotyla specus Loomis; troglophile.
Record: Mushroom Cave, Franklin County (Causey, 1960).

Family Tingupidae

Tingupa pallida Loomis; troglobite.

Records: Onondaga and Onyx caves, Crawford County (Loomis, 1943); Mushroom Cave, Franklin County (Causey, 1960); **new**: Bat, Bear, and Jagged Canyon caves, Crawford County; Hamilton Spring Cave, Washington County.

ORDER JULIDA

Family Parajulidae

Ptyoiulus sp.; accidental.

new: Lookout Cave, Crawford County

ORDER SPIROBOLIDA

Family Spirobolidae

Narceus sp.; trogloxene or accidental.

new: Bear Cave, Crawford County.

ORDER CAMBALIDA

Family Cambalidae

Cambala sp. (*arkansana* ?); trogloxene or accidental.

new: Bear Cave, Crawford County.

CLASS INSECTA

ORDER COLLEMBOLA (SPRINGTAILS)

Family Entomobryidae

Pseudosinella (*argentea* group); troglophile.

new: Bear and Jagged Canyon caves, Crawford County.

Sinella caeca Schott; troglophile.

new: Onondaga Cave, Crawford County.

S. cavernarum (Packard); troglophile.

new: Hamilton Spring Cave, Washington County.

Family Hypogastruridae

Hypogastrura (*Ceratophysella*) (*denticalata* complex); troglophile.

new: Jagged Canyon Cave, Crawford County.

Family Isotomidae

Folsomia candida Willem; troglophile.

new: Mushroom Cave, Franklin County.

Family Onychiuridae

Onychiurus sp.; troglophile.

new: Bear Cave, Crawford County.

Family Sminthuridae

Arrhopalites pygmaeus (Wankel); troglophile.

new: Bear, Jagged Canyon, and Onondaga caves, Crawford County; Mushroom Cave, Franklin County; Green and Hamilton Spring caves, Washington County.

A. sp.; troglophile.

new: Hamilton Spring Cave, Washington County.

Family Tomoceridae

Tomocerus (*Pogognathellus*) *flavescens* (Tullberg); troglophile.

new: Bat and Onondaga caves, Crawford County.

T. (*P.*) *elongatus* Maynard; troglophile.

new: Onondaga Cave, Crawford County.

ORDER DIPLURA (BRISTLETAILS)

Family Campodeidae

Haplocampa new species; troglobite.

new: Bear and Jagged Canyon caves, Crawford County; Green and Hamilton Spring caves, Washington county.

ORDER ORTHOPTERA (CRICKETS, GRASSHOPPERS, ETC.)

Family Tetrigidae

Unidentified material; trogloxenes or accidentals.

new: Bear Cave, Crawford County.

Family Gryllacrididae

Ceuthophilus sp. (near *ozarkensis* Hubbell); trogloxene.

new: Jagged Canyon and Nameless caves, Crawford County.

C. silvestris Bruner; trogloxene.

new: Onondaga Cave, Crawford County; Mushroom Cave, Franklin County.

C. uhleri Scudder; trogloxene

Record: outside entrance to Onondaga Cave, Crawford County (Hubbell, 1936).

C. williamsoni Hubbell; trogloxene.

Record: Onondaga Cave (type locality), Crawford County (Hebard, 1934); **new**: Bat, Lookout, Mud River, and Stairstep caves, Crawford County.

ORDER HOMOPTERA (APHIDS)

Family Aphidae

Unidentified material; probably accidental.

new: Nameless Cave, Crawford County.

ORDER MEGALOPTERA (HELLGRAMMITES)

Family Corydalidae

Chauliodes sp.; trogloxene or accidental.

new: Mud River Cave, Crawford County.

ORDER COLEOPTERA (BEETLES)

Family Carabidae

Chlaenius brevilabris LeConte; troglophile.

new: Onondaga Cave, Crawford County.

Dicaelius ambiguus Laf.; troglophile.

new: Onondaga Cave, Crawford County.

Harpalus fulgens Csiki; troglophile.

new: Onondaga Cave, Crawford County.

Platynus tenuicollis Le Conte; troglophile.

new: Bat Cave, Crawford County; Green Cave, Washington County.

Tachyura ferruginea Dej.; troglophile.

new: Onondaga Cave, Crawford County.

Family Scarabaeidae

Ataenius sp. (near *spretulus* [Haldeman]); troglophile.

new: Bear Cave, Crawford County.

Copris minutus (Drury); trogloxene.

new: Mud River Cave, Crawford County.

Onthophagus hecate hecate (Panzer); trogloxene or accidental.
new: Bear Cave, Crawford County.

Family Staphylinidae
Philonthus sp.; troglophile.
new: Bear and Onondaga caves, Crawford County; Mushroom Cave, Franklin County; Green Cave, Washington County.

Psephidonus brunneus (Say); troglophile or trogloxene.
new: Bear Cave, Crawford County.

Rimulincola divalis Sanderson; troglophile.
new: Onondaga Cave, Crawford County.

Staphylinus cinnamopterus Grav. (?); troglophile.
new: Onondaga Cave, Crawford County.

Tachinus scrutator G.&H.; troglophile or trogloxene.
new: Nameless Cave, Crawford County.

Unidentified material (subfamily Aleocharinae); troglophiles.
new: Mushroom Cave, Franklin County.

Unidentified material (larvae); probably troglophiles.
new: Bear, Lookout, Sewer, and Nameless caves, Crawford County.

ORDER LEPIDOPTERA (MOTHS, BUTTERFLIES)

Family Noctuiidae
Scoliopteryx libatrix Linné; trogloxene.
Record: Bat Cave, Crawford County (Casper, 1975); **new**: Lookout and Mud River caves, Crawford County.

Unidentified material; trogloxenes.
new: Lookout and Mud River caves, Crawford County.

Unidentified material; trogloxenes.
new: Lookout and Mud River caves, Crawford County.

ORDER DIPTERA (FLIES)

Family Chironomidae
Unidentified material; troglophiles.
new: Green Cave, Washington County.

Family Culicidae
Anopheles Punctipennis (Say); trogloxene.
new: Bat Cave, Crawford County.

Unidentified material; trogloxenes.
new: Lookout and Mud River caves, Crawford County.

Family Dolichopodidae
Unidentified material, trogloxenes.
new: Green Cave, Washington County.

Family Drosophilidae
Unidentified material; trogloxenes.
new: Nameless Cave, Crawford County.

Family Empididae
Unidentified material; trogloxenes.
new: Bat Cave, Crawford County.

Family Heleomyzidae
Aecothea specus (Aldrich); troglophile or trogloxene.
new: Bear and Sewer caves, Crawford County; Hamilton Spring Cave, Washington County.

Amoebelaria defessa (Osten Sacken); troglophile or trogloxene.
new: Bat, Bear, Jagged Canyon, Nameless, Sewer, and Stairstep caves, Crawford County; Green and Hamilton Spring caves, Washington County.

Heleomyza brachypterna (Loew); troglophile or trogloxene.
new: Bat, Lookout, and Mud River caves, Crawford County; Green Cave, Washington County.

Family Mycetophilidae
Unidentified material; trogloxenes and troglophiles.
new: Mud River and Nameless caves, Crawford County.

Family Sciaridae
Unidentified material; troglophiles or trogloxenes.
new: Onondaga Cave, Crawford County; Mushroom Cave, Franklin County; Green Cave, Washington County.

Family Sphaeroceridae
Unidentified material; trogloxenes.
new: Bear and Nameless caves, Crawford County; Hamilton Spring Cave, Washington County.

Family Tipulidae
Unidentified material; trogloxenes.
new: Stairstep Cave, Crawford County; Mushroom Cave, Franklin County.

Discussion

Several aspects of the biology of species recorded during this study are discussed below. More biological data for some species are presented elsewhere (Craig, 1975).

Habitat Selection and Species Associations

The aquatic cavernicoles occupy two major habitats: drip and rimstone pools, and streams. Further, the stream community can be divided on the basis of pools and riffles.

Drip and rimstone pools typically include two species: the amphipod *Stygobromus onondagaensis* and the isopod *Asellus* sp. *S. onondagaensis* appears to occupy mainly shallow drip pools, but has occasionally been encountered in shallow films of water under boards near such pools. *S. onondagaensis* was not found with any other macroörganisms in drip pools.

The stream riffle community contains the amphipod *Stygobromus* n. sp., the isopods *Asellus* sp. (near *brevicaudus*) and other *Asellus* spp., and the snail *Fontigens aldrichi*. One of the asellids listed as *Asellus* spp. closely resembles *Asellus dimorphus*, while smaller specimens (1 mm long) are either a separate species or immatures. The two forms never occupy the same cave. Although asellids resembling *A. dimorphus* most frequently occupied lentic habitats, particularly rimstone pools, they were occasionally found feeding on decaying wood or carrion, *e.g.* dead gray bats, in the quieter parts of streams. The smaller specimens of *Asellus* and *Stygobromus* n. sp. occupy the microhabitat among stream gravel, usually in riffles. *Asellus* sp (near *brevicaudus*) occurs in riffles, in accordance with its adaptation to existence in springs and spring-fed streams. The most widely occurring (and probably the most abundant) species occupying riffles is the troglobitic snail, *Fontigens aldrichi*; it is found principally on the undersides of rocks in shallow, gravel-bottomed streams. Hubricht (1941) noted that *Amnicola aldrichi antroecetes* (= *F. aldrichi*) was always found in streams with isopods of the genus *Caecidotea*) (= *Asellus*). I observed a similar association.

The stream pool community includes the troglobitic amphipods *Allocrangonyx hubrichti* and *Bactrurus brachycaudus*, occasionally troglobitic isopods of the genus *Asellus*, and the troglophilic amphipod *Crangonyx forbesi*. These are similar to the rimstone pool species, but differ from the riffle community species in being much larger. *C. forbesi* was usually found in stream pools near the entrance, but was occasionally encountered well into the dark zone and was there associated with troglobitic *Asellus*. Specimens were sometimes almost totally white in the interiors of caves, but the eyes appeared no different from those of specimens found outside. Maguire (1961) found that caretenoid pigments in algae, when metabolized, produce color in epigean crayfishes; the same may be true for this amphipod. Holsinger (1972), however, found no appreciable lack of pigment in epigean amphipods found inside caves. *Gammarus minus* is reported from the mouths of caves, but not from the interiors (Hubricht, 1943).

Allocrangonyx hubrichti, 14 to 18 mm long, were found only among stream gravel at the bottoms of pools in a very small stream. *Stygobromus* n. sp., 4 to 6 mm long, were also collected from this stream, but were found among gravel in riffles. Culver (1970, 1973) found that amphipod species not differing significantly in size do not co-exist, and that smaller species tended to be found deeper, in finer gravels below the coarser gravels near the surface. This differs from the stratification occurring in *A. hubrichti* and *Stygobromus* n. sp. by being vertical rather than horizontal. However, the limiting factor in these two species may be the size of the gravel, rather than the stream pools and riffles, since larger gravels were noticeably lacking in stream riffles and were more abundant in stream pools. This probably results from sorting by flowing water. Culver (1970) further found that no aggression toward individuals of the same or different species occurred, but that only one individual occupied a given rock. This was accomplished by avoidance behavior. *Stygobromus* n. sp. was not associated with any other amphipods in Green Cave and occupied the spaces among gravel in stream pools and riffles, often attaching itself to rocks. This is probably an adaptation to withstand the high velocity of the Green Cave stream.

Collembola were usually found on or near rotting wood or fungi, but *Arrhopalites pygmaeus* and *Sinella caeca* were occasionally encountered on the surfaces of pools. Christiansen (1966) has rarely found *A. pygmaeus* in epigean habitats and feels that this species is probably a troglobite which retains some tolerance for outside conditions. Although *Sinella cavernarum* has been called a troglobite (Christiansen, 1960), it is now considered to be a troglophile (Christiansen, pers. comm.) which may retain a similar tolerance.

Taxonomy and Distribution

Other troglobitic species of the snail genus *Fontigens* occur in Illinois (Hubricht, 1940), Indiana (Hubricht, 1963), Maryland (Wayne Grimm, National Museum of Canada, pers. comm.), Virginia (Holsinger, 1963a), and West Virginia (Culver, 1970; Hubricht, 1963). Grimm reported that Hubricht identified a troglobitic species of *Fontigens* from caves and springs in Maryland and Virginia as *F. aldrichi*. It seems unlikely that species occurring in the Ozarks also occur in the Appalachians, especially since different species occur in intervening states. Hubricht (1940) described an eyed, pigmented form from springs, including Onondaga Spring, which he considered to be *F. aldrichi*, but it remains controversial whether this is the same species as the troglobite. The family Hydrobiidae, particularly the genus *Fontigens*, appears to be in a state of confusion and, apparently, needs revision.

Two females of the pseudoscorpion genus *Apochthonius* were collected from two caves. Although the specimens have a morphological affinity with *A. colecampi*, of which only the female holotype is known, Muchmore (pers. comm.) does not consider them to be conspecific with the holotype.

Prior to Ferguson's (1975) report of four new cavernicolous species of the dipluran genus *Haplocampa* from California, Idaho and Washington, this genus was represented only by epigean species in California, Montana, Oregon, Washington and Alberta (Ferguson, pers. comm.). My collections of an undescribed species represent the first record of this genus in Missouri. This new species is known from only one other cave, Mammoth Cave, Monroe County, Illinois. Specimens from Illinois are noticeably smaller than those from the reservoir area, but this may be due only to habitat differences (Ferguson, pers. comm.).

Stygobromus n. sp. and *S. onondagaensis* have never been found in the same cave, although their ranges are practically the same. In addition, they were considered a single species, *S. onondagaensis*, until recently (Holsinger, pers. comm.). It would seem, then, that sympatric speciation has occurred rather recently in geologic time.

Dobzhansky (1970) indicates several possible isolating mechanisms (*e.g.*, habitat isolation, sexual isolation) that maintain the identity of two closely related species of *Drosophila*. The same principle may apply to these closely related amphipods, because I found *S. onondagaensis* primarily in drip pools, as did Holsinger (1972), while *Stygobromus* n. sp. was found primarily in streams. I found either streams or rimstone and drip pools, but rarely both, in the same cave. Therefore, these species appear to be distinctly habitat (allotopically) isolated. It has been postulated that other troglobitic amphipod genera had epigean ancestors that were pre-adapted to a subterranean existence and invaded the groundwater environment at the maximum extent of the Mississippi Embayment, during the Eocene (Holsinger, 1967, 1969, 1971). This may explain the current distribution of these two species of Stygobromus.

The range of *Allocrangonyx hubrichti*, previously limited to two caves in the Gasconade River basin (Holsinger, 1971), is extended some 50 miles to the east by the new Meramec record.

Specimens listed as members of the *Pseudosinella argentea* group are probably a new species (Christiansen, pers. comm.), but additional material must be collected before this can be ascertained.

Trophic Relationships

Rotten wood, probably introduced into the caves by periodic flooding of the Meramec and its tributaries, is a principal food source. Caves not close to the river generally have downward-sloping entrances, which facilitate the in-washing of wood. Most of the wood in commercial caves, *e.g.*, Onondaga Cave, has been artificially introduced as ladders, bridges, walkways, and other structures. Feces of raccoons (*Procyon lotor*), pack rats (*Neotoma floridana*), and bats, and carrion (primarily dead crickets and rats) were encountered rarely and are probably less important trophic resources.

Probable terrestrial saprophiles include the collembolans, particularly *Arrhopalites* but also *Folsomia, Hypogastrura, Onychiurus, Pseudosinella, Sinella*, and *Tomocerus*; the dipluran, *Haplocampa*; the millipedes *Tingupa* and *Austrotyla*; and sometimes oligochaetes and the snail *Zonitoides*. Predators include the mites *Linopodes, Pseudoparasitus*, and *Rhagidia*, the spider *Cicurina*, and the pseudoscorpion *Apochthonius*.

The feeding habits of the aquatic cave invertebrates are poorly known and discussion of their trophic relationships would be pure conjecture; however, some observations were made.

A lack of organic detritus was observed in the streams of all caves where *F. aldrichi* was found, except Mushroom. Hubricht (1941) also observed an apparent lack of food in cave streams in which this snail is found. He reported (1940) their size as extremely variable and, apparently, determined by food supply. I observed no correlation between snail size and the presence of organic materials.

Several investigators (Barr and Kuehne, 1971; Caumartin, 1963; Poulson and White, 1969; Vandel, 1965) have discussed the occurrence of bacteria and fungi in cave environments and their possible use by heterotrophs. Further, Gounot (1960, cited in Vandel, 1965) showed experimentally that something produced by cave clay has a salutary effect on the growth and survival of cave amphipods. Christiansen (1970) showed that the survival capacity of Collembola raised on cave clay, alone, is correlated with cave adaptation. Thus, a nutrient connection between *F. aldrichi* and its clay substrate may exist. Troglobitic amphipods, *Stygobromus*, and isopods, *Asellus*, were also found in habitats apparently devoid of organic material. They are known to migrate over moist terrestrial surfaces, presumably in search of food (Craig, 1975; Holsinger, 1963b) and may also utilize chemosynthetic bacteria for food.

Population Fluctuations

From December to April, the population of the cave snail, *F. aldrichi*, in Jagged Canyon Cave decreased. This could be a result of their being washed out during spring flooding, as occurs with isopods and amphipods (Culver, 1971).

No diplurans were found during the winter (December—February), but, in the spring and summer (April—July), mature males and females were found quite frequently on wet flowstone and near the edges of streams.

If the smaller of the Asellids ("*Asellus* spp." in the faunal list) represent immature specimens, then some explanation is required. This smaller *Asellus* appears in collections made in May, June, and July. Adult asellids were rarely found in cave streams during these months, although they had been fairly abundant during December and February. One explanation might be the release of young before spring flooding, an alternative adaptation to evolving the ability to withstand strong currents (Culver, 1971). A female with 16 young in the brood pouch was collected in late May from a very small pool in the Bat Cave stream; however, these asellids may not be affected by spring flooding, because that stream showed no evidence of increased flow.

Probable Effects of the Lake on the Invertebrate Fauna

Populations of 98 different invertebrate species, including 9 troglobites, may be eliminated by the Meramec Park Lake. Table 1 shows the incidence of troglobitic species in the study area and in Missouri. Of the 5 troglobitic genera of Gammaridae in North America, the study area possesses three. Over 50% of the known populations of some cave invertebrates in North America, *e.g.*, *Fontigens aldrichi* and *Haplocampa* n. sp., may be eliminated by construction of the dam (Table 2). In addition, populations of two other probably undescribed species (a pseudoscorpion, *Apochthonius*, and a collembolan, *Pseudosinella*) may be eliminated.

Habitat in Onondaga Cave, the type locality of *Ceuthophilus williamsoni* and *Stygobromus onondagaensis*, will be greatly altered, if not destroyed.

A. Hubrichti has been recommended to the Office of Endangered Species and International Activities, U.S. Department of the Interior, as a candidate for endangered species status, and *S. onondagaensis* has been recommended for "watch" status (Holsinger, pers. comm.). I am recommending the snail, *F. aldrichi*, the amphipod, *Stygobromus* n. sp., and the dipluran, *Haplocampa* n. sp. for threatened species status.

TABLE 1. Incidence of Troglobitic Invertebrate Species in Missouri and in the Proposed Meramec Park Lake Area.

	Missouri		Meramec Park Lake	
	Number of species	Percent of total	Number of species	Percent of total
TURBELLARIA				
TRICLADIDA	2	4.5		
GASTROPODA				
MESOGASTROPODA	5	11.1	1	11.1
CRUSTACEA				
OSTRACODA	2	4.5		
ISOPODA	10	22.2	2	22.2
AMPHIPODA	12	26.6	4	44.5
DECAPODA	2	4.5		
DIPLOPODA				
CHORDEUMIDA	3	6.6	1	11.1
ARACHNIDA				
ARANEIDA	1	2.2		
CHELONETHIDA	1	2.2		
INSECTA				
COLLEMBOLA	2	4.5		
DIPLURA	3	6.6	1	11.1
COLEOPTERA	2	4.5		
TOTAL	45	100.0	9	100.0

TABLE 2. Comparison of Known Populations of Troglobitic Invertebrate Species with Populations in the Area to be Flooded by Meramec Park Lake.

Species	Number of known populations	Number of populations in the Meramec Park Lake area	Percent of known populations endangered
MESOGASTROPODA			
Fontigens aldrichi	12	7	58
ISOPODA			
Asellus antricolus	16	1	6
Asellus stiladactylus	5	1	20
AMPHIPODA			
Allocrangonyx hubrichti	3	1	33
Bactrurus brachycaudus	38	2	5
Stygobromus onondagaensis	21	4	19
Stygobromus new species	13	4	30
CHORDEUMIDA			
Tingupa pallida	23	7	30
DIPLURA			
Haplocampa new species	5	4	80

Note: Most of the asellid collections made during this study have not been identified.

Acknowledgements

This paper is based on an MS thesis presented to Central Missouri State University in April, 1975. I am grateful to Drs. William B. Peck, Oscar Hawksley, and John B. Hess for use of their personal libraries, equipment, and other courtesies while serving on my committee. Special thanks go to Drs. Hawksley and Peck for their critical review of the manuscript.

I am indebted to the following systematists for providing literature, helpful comments, and identification and verification of specimens in the taxa noted: Thomas C. Barr, Jr. (Carabidae), Kenneth Christiansen (Collembola), Kathleen S. Craig (Chilopoda), Wilbur R. Enns (Acarina), Lynn Ferguson (Campodeidae), Benjamin A. Foote (Diptera), Clarence Goodnight (Opiliones), Alan R. Hardy (Scarabaeidae), Lee Herman (Staphylinidae), John R. Holsinger (Amphipoda), Horton H. Hobbs, Jr. (Decapoda and Ostracoda), Theordore H. Hubbell (Gryllacrididae), Leslie Hubricht (Gastropoda), Preston Hunter (Acarina), William B. Muchmore (Chelonethida and Oniscoidea), William B. Peck (Araneida), William A. Shear (Diplopoda), and Russell W. Strandtmann (Acarina).

I am grateful to Mr. and Mrs. Cloyd Shea for impromptu lodging during several collecting trips; to William Breen, manager of Onondaga Cave, for permission to collect; and to several residents of the Meramec Basin for providing directions to caves and other courtesies.

Charles Calloway, Kathleen Craig, Mike Hopping, and Jim McKelvey helped in field work. Jerry Vineyard gave me access to the cave files of the Missouri Speleological Survey and provided copies of several cave reports. Other individuals aided in various aspects of this study and I am in their debt.

A special note of thanks goes to my wife, Kathleen, for her tolerance and help.

This research was supported, in part, by two grants from the Research Advisory Committee of the National Speleological Society.

Editor's Note (FGH): This paper exemplifies scientific reconnaisance support for decision-making on land use. The certain disruption and possible destruction of habitats for a number of unique cave species in the Meramec Reservoir area is clearly detailed. This is one of the environmental costs which (by law) must be documented and taken into consideration by the decision-making process. Aside from satisfying our scientific curiosity and adding to our store of basic knowledge, contributions such as this play a vital role in real-world problem-solving.

Literature Cited

Barr, T.C., Jr. (1958) — Studies on the Invertebrates of the Interior Lowlands and Cumberland Plateau: Vanderbilt Univ. Thesis, 306 pp.

———— (1963) — Ecological Classification of Cavernicoles: *Cave Notes* 5:9-13.

———— and R.A. Kuehne (1971) — Ecological Studies in the Mammoth Cave System of Kentucky. II: The Ecosystem: *Ann. Spéléol.* 26:49-96.

Bretz, J H. (1956) — Caves of Missouri: Mo. Geol. Survey, **2nd Ser. 39**, 490 pp.

Casper, Cheri (1975) — Chaminade Grotto: *NSS News* 33:12.

Caumartin, Victor (1963) — Review of the Microbiology of Underground Environments: *NSS Bulletin* 25:1-14.

Causey, N.B. (1960) — Troglobitic Millipedes in Missouri: *Mo. Speleol.* 2:60-65.

Christiansen, K.C. (1960) — The Genus *Sinella* Brook (Collembola : Entomobryidae) in Nearctic Caves: *Entomol. Soc. America, Ann.* 53:481-491.

———— (1966) — The Genus *Arrhopalites* in the United States and Canada: *Internat. Jour. Speleol.* 2:43-73.

———— (1970) — Survival of Collembola on Clay Substrates with and without Food Added: *Ann. Spéléol.* 25:849-853.

———— — Biology Department, Grinnell College, Grinnell, Iowa.

Cooper, J.E. and T.L. Poulson (1968) — A Guide for Biological Collecting in Caves: *NSS News* 26:127-138.

Craig, J.L. (1975) — A Survey of the Invertebrate Faunas of Caves to be Inundated by the Meramec Park Lake in Eastern Missouri: Central Missouri State Univ. Thesis, 100 pp.

Culver, D.G. (1970) — Analysis of Simple Cave Communities: Niche Separation and Species Packing: *Ecology* 51:949-958.

———— (1971) — Analysis of Simple Cave Communities. III. Control of Abundance: *Am. Midland Nat.* 85:173-187.

———— (1973) — Competition in Spatially Heterogenous Systems: An Analysis of Simple Cave Communities: *Ecology* 54:102-110.

Dobzhansky, Theodosius (1970) — Genetics of the Evolutionary Process: NYC, Columbia Univ. Press, 505 pp.

Ferguson, L.M. (1975) — Subterranean Campodeids (Insecta : Diplura : Campodeidae) from the Northwestern United States (*abs*): *Ass'n Southeastern Biologists, Bull.* 22:53.

———— Biology Department, Va. Polytechnic Institute and State University, Blacksburg.

Fleming, L.E. (1972) — The Evolution of the Eastern North American Isopods of the Genus *Asellus* (Crustacea : Asellidae): Va. Polytechnic Inst. and State Univ. Thesis, 244 pp.

Gates, G.E. (1959) — Earthworms of North American Caves: *NSS Bulletin* 21:77-84.

Gounot, A.M. (1960) — Recherches sur le Limon Argileux Souterrain et sur son Rôle Nutritif pour les Niphargus (Amphipodes : Gammarides): *Ann. Spéléol.* 15:501-526.

Grimm, Wayne — Design and Display Division, National Museum of Canada, Ottawa.

Hebard, Morgan (1934) — The Dermaptera and Orthoptera of Illinois: *Ill. Dept. Registration and Ed., Div. Nat. Hist., Bull.* 20:125-279.

Holsinger, J.R. (1963a) — Annotated Checklist of the Macroscopic Troglobites of Virginia with Notes on Their Geographic Distribution: *NSS Bulletin* 25:23-36.

———— (1963b) — Studies on the Ecology and Geographic Distribution of Macroscopic Cavernicolous Invertebrates of the Central Appalachians: Madison College Thesis, 112 pp.

———— (1967) — Systematics, Speciation, and Distribution of the Subterranean Amphipod Genus *Stygonectes* (Gammaridae): *U.S. Nat. Mus. Bull.* 259:1-175.

———— (1969) — The Systematics of the North American Subterranean Amphipod Genus *Apocrangonyx*, with Remarks on Ecology and Zoögeography: *Am. Midland Naturalist* 81:1-28.

———— (1971) — A New Species of the Subterranean Amphipod Genus *Allocrangonyx* (Gammaridae), with a Redescription of the Genus and Remarks on its Zoögeography: *Internat. Jour. Spéléol.* 3:317-331.

——————— (1972) — The Freshwater Amphipod Crustaceans (Gammaridae) of North America: U.S. Environmental Protection Agency, Biota of Freshwater Ecosystems, Identification Manual No. 5, 89 pp.

——————— — Biology Department, Old Dominion University, Norfolk, Virginia.

Hubbell, T.H. (1936) — A Monographic Revision of the Genus *Ceuthophilus* (Orthoptera : Gryllacrididae : Raphidophorinae): Florida Univ. Publ. Biol, Ser. 2, 551 pp.

Hubricht, Leslie (1940) — The Ozark Amnicolas: *Nautilus* **53**:118-123.

——————— (1941) — The Cave Mollusca of the Ozark Region: *Nautilus* **54**:111-113.

——————— (1943) — Studies on the Nearctic Amphipoda, III. Notes on the Freshwater Amphipods of the Eastern United States with Descriptions of Ten New Species: *Am. Midland Naturalist* **29**:683-719.

——————— (1963) — New Species of Hydrobiidae: *Nautilus* **76**:138-140.

——————— and J.G. Mackin (1940) — Descriptions of Nine New Species of Freshwater Amphipod Crustaceans with Notes on New Localities for other Species: *Am. Midland Naturalist* **23**:187-218.

Loomis, H.F. (1943) — New Cave and Epigean Millipeds of the United States, with Notes on some Established Species: *Mus. Comparative Zoöl., Bull.* **92**:373-410.

Mackin, J.G. and Leslie Hubricht (1940) — Descriptions of Seven New Species of Caecidotea (Isopoda : Asellidae) from Central United States: *Am. Microscopical Soc., Trans.* **59**:383-397.

Maguire, Bassett, Jr. (1961) — Regressive Evolution in Cave Animals and its Mechanism: *Tex. Jour. Sci.* **13**:363-370.

McCracken, M.H. (1961) — Geologic Map of Missouri: Rolla, Mo. Geol. Survey.

Muchmore, William — Biology Department, University of Rochester, Rochester, New York.

Poulson, T.L. and W.B. White (1969) — The Cave Environment: *Science*, **ns 165**:971-981.

Reams, M.W. (1968) — Cave Sediments and the Geomorphic History of the Ozarks: Washington Univ. Thesis, 167 pp.

Steeves, H.R., III (1966) — Evolutionary Aspects of the Troglobitic Asellids of the United States. The Hobbsi, Stygius, and Cannulus Group: *Am. Midland Naturalist* **75**:392-403.

U.S. Army Engineer District, St. Louis, Mo. (1973) — Final Environmental Statement, Meramec Park Lake, Meramec River, Missouri: St. Louis, (Vol. 1) 380 pp.

Vandel, Albert (1965) — Biospeleology, the Biology of Cavernicolous Animals (Trans. B.E. Freeman): NYC, Pergamon, 525 pp.

Vineyard, J.D. (1973) — Catalog of the Caves of Missouri: Rolla, Mo. Speleol. Survey, 177 pp.

Manuscript received by the Editor 26 January 1976.

Revised manuscript accepted 14 August 1976.

See pp. 91 and 95 for descriptions of current expeditions.

Notes on Cave Utilization by Beaver

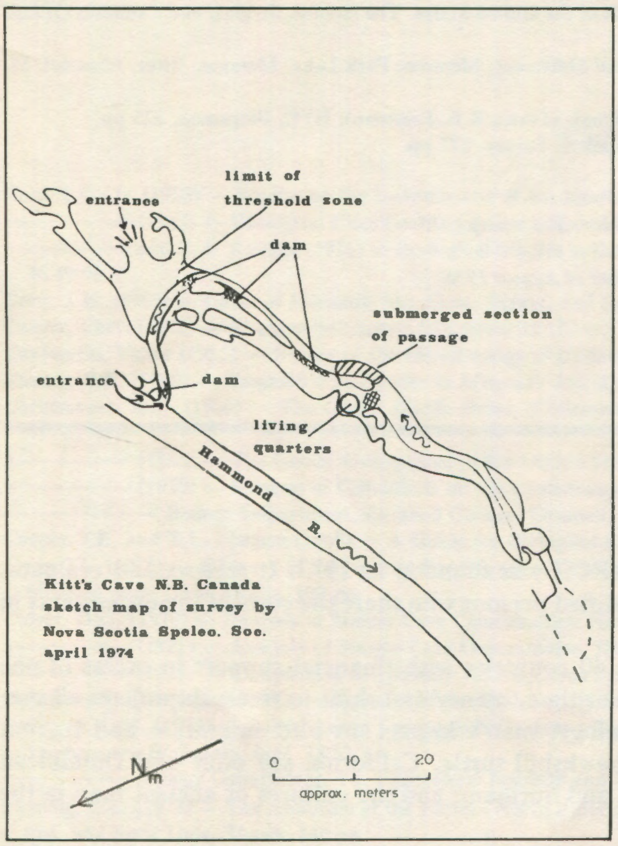
Donald F. McAlpine *

ABSTRACT

A record of a trogloxenic *Castor canadensis* in New Brunswick, Canada is described in detail. Two further records from the Huntsville, Alabama area and one from Missouri are also presented.

While exploring Kitts Cave near Hammondvale, Kings County, New Brunswick, on the 29th February 1976, the living quarters of a beaver, *Castor canadensis*, and considerable stores of willow, *Salix* sp. and Alder, *Alnus rugosa* were discovered in the cave.

The main entrance to Kitts Cave is a limestone sinkhole located approximately 15 m back from the Hammond River. A sizeable stream runs through the cave (see map), parallel, but in the opposite direction, to the river. Immediately within the entrance, there is little more than 5 cm of water, but the water gets progressively deeper within the cave. Over most of the stream length, a depth of 45 to 60 cm of water is normal. However, the water depth at the sump is about 180 cm. The stream width varies from 105 to 350 cm. The stream has its origin at a pool on the hillside overlooking the river, then progresses through a 9m sump to the cave proper. It wends its way through 64m of cave passage, then, turning abruptly, exits the cave into Hammond River at river level after a further 27m. Hammond River is narrow over much of its length, at this point being approximately 5m wide, and is relatively fast flowing, more so than waters generally inhabited by beaver in this area.



The condition of decay of the lower branches in the caches and dams indicate the cave has been used for some years by beaver. Branches obviously cut by beaver were deposited at various points throughout the cave, from the stream exit to the sump.

A small dam has been constructed across the stream passage in the dark zone. The backed up water has created a short, artificial sump in an area of low ceiling that leads directly to the living quarters used by the beaver. This situation is much like the underwater entrances to standard beaver lodges.

The living quarters are in a circular cavern approximately 2.5m wide by 80 cm high and about 56m from the stream exit. The cavern is adjacent to the cave stream, opening directly into it. A cache of sticks starting at water level works towards the back of the cavern, where an open depression of wood chips is located. The outer dimensions of the wood chip "nest" are 70 cm by 60 cm, while the depression itself is 40 cm by 30 cm.

The beaver was not sighted, and recent high water in the cave prior to the initial observation seemed to have removed any trace of tracks. It appeared, however, that some of the willows had been fed on recently and a relatively fresh beaver scat was discovered among a small group of wood chips on a ledge just above water level at the sump pool, so at that time the cave appeared still to be in use by at least one beaver. A number of subsequent trips failed to produce an actual sighting. On 23d July 1976 when the cave was visited, no changes in food caches were noted and the wood chip "nest" had molded considerably, indicating the beaver had probably discontinued use of the cave. Kitts Cave has been more frequently visited by cavers in the last year than formerly, and quite possibly the beaver has vacated due to this disturbance.

Although lodges are most commonly recognized as the typical beaver habitation, bank burrows are often excavated. The Kitts Cave den bears many characters similar to lodges. However, Kitts is probably more closely analogous to a bank burrow. Records of trogloxenic beaver appear to be lacking in the literature.

In one of the few records, at the time, of beavers resident in Colorado River, Grater (1936) felt the rocky nature of the shoreline indicated a shelter amongst the rocks, rather than the bank burrows normally excavated in areas where beaver inhabit the more swiftly flowing water courses. An observation of a beaver living in an abandoned mine tunnel (Alcorn, 1934) was as close an example of cave habitation as could be discovered in a search of the literature.

An appeal for information regarding beaver in caves through *The North American Biospeleology Newsletter* and *The Nova Scotia Speleological Society Newsletter* brought two replies:

Mr. Bill Torode (National Speleological Society) related two incidents in the Huntsville, Alabama area. During 1970 and 1971 or 1972, he observed beaver in two caves. In the first, a spring was being checked for cave potential. About 15m of passage was navigable to the cavers. A beaver was observed in the passage and the odour would indicate that this cave was regularly used by some

* New Brunswick Museum, 277 Douglas Ave., Saint John, N.B., Canada E2K 1E5.

animal. A number of dams and numerous beaver-felled trees were seen in the area. In the second, a beaver was seen to enter the spring entrance to Lamons Cave. No other evidence of beaver were seen in this area.

Dr. Oz Hawksley forwarded an observation made in Great Scot Cave, Missouri some years ago. The stream flowing outward from the cave had been dammed, so that entrance was gained by wading through a pond that extended back some distance into the cave. One beaver was encountered in the dark zone. No examination for actual habitation within the cave was made, but Dr. Hawksley did not feel conditions were such that beaver would be actually living in the cave, although he could not discount the possibility entirely. He felt many caves in Missouri appeared suitable for beaver use, as they were adjacent to rivers and creeks.

From the above examples, it would appear that those caves with direct connections to suitable-sized bodies of water are favoured. A regular trek overland could be particularly perilous for a beaver, as it is a relatively clumsy animal on land. While neither the Alabama nor the Missouri cases show evidence of use as extensive as does Kitts Cave, they do indicate that Kitts is not an isolated example.

Colonization of Kitts has made possible the use by beaver of what appears to be an otherwise unsuitable habitat. In other cases, the protection caves offer from predation may be the most important stimulus for their use by beaver.

Pleistocene beaver remains have been discovered in a number of caves (Hawksley, *et al.*, 1973). While some authors feel these animals were carried in by predators, others feel they may have wandered in during times of high water. The observations presented here indicate that beaver may in some cases actively colonize cave systems.

I am indebted to Dr. Oz Hawksley for his observations on beaver in caves, both living and fossil and to Mr. Bill Torode for his observations from the Huntsville, Alabama area. I would like to thank the Nova Scotia Speleological Society for use of their Kitts Cave mpa. I wish to thank Dr. Stanley W. Gorham for confirming identification of the beaver scat. I also want to thank Mr. David Christie and Dr. Gorham for criticizing the manuscript.

Literature Cited

Alcorn, G.D. (1934 — Unusual Home of Beaver: *Murrelet* **25**:82.

Grater, R.K. (1936) — An Unusual Beaver Habitat: *Jour. Mammalogy* **17**:66.

Hawksley, Oscar; J.F. Reynolds; and R.L. Foley (1973) — Pleistocene Vertebrate Fauna of Bat Cave, Pulaski County, Missouri: *NSS Bulletin* **35**:61-87.

Manuscript received by the Editor 1 October 1976.

Revised manuscript accepted 6 February 1977.

A Cave Population Statistical Survey

John A. French *

ABSTRACT

In order to determine the total cave population of the Farley (Ala.) quadrangle, randomly selected quarter-sections were searched thoroughly by walking parallel paths 100 ft apart. From the findings in these areas, it was calculated that the quadrangle contains about five times as many caves as were known to exist previously. Existing "cave surveys" are thought to include relatively small fractions of the total cave populations in their areas.

Introduction

Accurate estimates of cave populations would be useful in hydrology, geology, etc., as well as in providing guidelines for sport caving, because studies of karst areas tend to state conclusions based on the number and locations of known caves. The highly detailed descriptions of known caves provided in "cave surveys" create the misleading impression that the data are essentially complete.

Some karst analyses have been based on detailed examinations of limited areas, where data could be made essentially complete. According to Jennings (1971), dolines were first used for quantitative analysis by Lozinski (1907), because they "often occur in large numbers close together." In 1941, Cramer worked with measures of mean doline size, doline density (quantity per km^2), and total doline area per km^2. Williams (1969) proposed this last measure as an index of karstification. The above authors assumed that each study area had been carefully and thoroughly searched.

The questions are now raised, "What about areas too large to be searched completely?", and, "What about rough terrain, where dolines may be difficult to identify?" Random sampling of portions of such areas may be a solution to both questions. Further understanding of the karst can then be gained through applying Curl's methodology for estimating unobservable caves (1966).

The Alabama Cave Survey included 617 caves on 1 June 1965 (Tarkington, *et al.*, 1965); it included 1281 caves by January of 1972 (anon, 1972); there are over 1400 caves known in Alabama at this writing (Varnedoe, 1973). Between 1965 and 1974, the known cave population of the Farley quadrangle increased from 10 to 29, exclusive of the caves discovered during the methodical search described later in this paper. The increase in known caves in the Farley quadrangle was 1.9, somewhat greater than for the state as a whole. New caves are so frequently reported from northern Alabama that the degree of completeness of the present Alabama Cave Survey is open to serious question.

Eighteen additional caves have been found in the Farley quadrangle by this writer (more than the total number of caves known there in 1965). But, 47 caves are still less than the probable total cave population of the quadrangle. The project reported in this paper sought to predict the total cave population of the Farley quadrangle and its characteristics from a smaller sample of randomly selected areas within the Quadrangle. The selection of the Farley quadrangle as a study site was arbitrary.

Farley Quadrangle

The Farley 7½-minute quadrangle is located to the south and east of Huntsville. It includes portions of the City and of the Redstone Arsenal. The bounding meridians are 86°30' and 86°37'30" west. The bounding parallels are 34°30' and 34°37'30" north.

The total area of the Quadrangle is about 60 square miles. One-third of this is hilly land or consists of low mountains ranging up to 1400 ft in elevation. The remaining two-thirds is relatively level, mostly agricultural land lying between 600 and 700 ft above sea level. About 2% is swampy ground. The Tennessee River crosses the area of the Quadrangle.

Methodology

To locate all of the caves in 60 sq mi would be a formidable undertaking. The problem was reduced to manageable proportions by searching only randomly selected small portions of the area and extrapolating the data to the whole.

Each Public Land Survey section of land included in the Quadrangle was divided into quarter-sections. Each quarter-section was given a number and numbered slips representing the quarter-sections were placed in a container. After the slips were mixed thoroughly, several were drawn from the container. The numbers on the drawn slips determined which quarter-sections were searched for caves.

The boundaries of the quarter-sections were approximately determined in the field by surface observations and by compass bearings. Streams and other barriers often dictated that the sample areas searched were not precise quarter-sections. The actual areas searched (Fig. 1) were plotted on the Quadrangle and measured with a

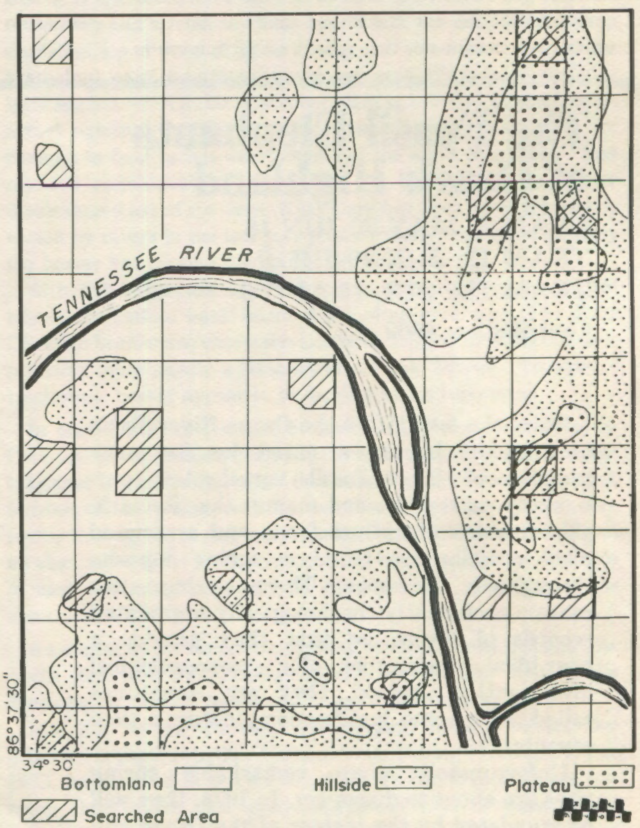


Fig. 1. The Farley 7½" series quadrangle, Alabama, showing section lines, landforms, and sample areas.

* 10101 Westleigh, Huntsville, Ala.

precision polar planimeter. The sample size (acres searched) was found by summing planimeter readings.

The Alabama Cave Survey has established an arbitrary standard of 50 ft in combined length and depth for a natural opening before it will be recorded as "a cave." Rock shelters and small cavities are thus excluded from the data.

A minimum cave entrance is defined by man's ability to pass through it without changing its dimensions (Curl, 1966). Medville (1970) described five proven methods for discovering entrances. Cole (1968) reported using aerial photographs in stereographic pairs. Williams (1968) discussed a combination of 1:25,000 maps and stereographic photographs.

Aerial photographs are useless in finding other than very large entrances. Motor vehicles can be used on only a small portion of the Farley quadrangle. A foot search was the only practical method available. Generally, paths were walked about 100 ft apart, and efficiency was estimated to be from 85% to 95%. A nominally straight-line path often became a zig-zag route across a strip of land 100 ft to 200 ft wide. The width of a strip times the length of a strip times the search efficiency* is hereinafter termed the "area searched." Experienced cave hunters have noted that a small cave entrance can be missed from a distance of 15 ft, in this kind of terrain. On each search occasion, note-taking included cave locations, sketches, and observations on the areas searched.

The main search technique on hillsides became one of walking contours between two identifiable extreme positions, moving up (or down) hill about 100 ft, and walking a new contour. Boundary markers were natural features such as ridges and draws, or were determined by compass bearings taken on roads or houses. Flat land was searched by walking parallel paths spaced according to visibility conditions.

Essentially all data were taken in the winter, when there was no foliage to impede visibility (these are primarily deciduous forests; search efficiency would be much lower in summer). On several occasions, I worked alone. At these times, I could not immediately explore pits, but I did check out many small caves in order to determine whether or not they met the 50-ft minimum.

The newly found pits have been re-visited and all new finds have been completely explored.

Results

Table I summarizes the data on caves within the sample areas. Table II compares sample area caves with caves elsewhere in the Farley quadrangle and with Alabama caves, generally. Note that, in all three areas, caves tend to group at elevations between 600 ft and 700 ft and again near 1000 ft elevation (where relatively more pits exist).

TABLE I. Caves Located in the Sample Areas.

Ala. Cave Survey No.	Length	Depth	Elevation	Host rock
1324	134	131	1010	Bangor ls
1377	111	91	1020	"
1548	40	30	1100	"
748	300	45	950	"
1294	100	50	1100	"
1321	303	40	1100	"
862	85	27	650	Gasper ls
1546	35	35	1160	Pennington ls
1626	500	8	1180	"

* "Efficiency factor" is defined as the estimated ratio of terrain actually observed to the total area within the boundaries of the searched area. The efficiency factor varies with rockiness, vegetation density, steepness of the ground, etc.

TABLE II. Sample area, Farley quadrangle, and Alabama caves ranked by elevation.

Elevation	Sample area caves	Farley quad caves	Alabama caves
0— 556	0	0	≈342
557— 599	0	4	56
600— 699	1	15	266
700— 799	0	2	208
800— 899	0	1	158
900— 999	1	7	91
1000—1099	2	8	99
1100—1199	5	6	53
1200—1299	0	4	64
1300—1399	0	0	37
1400—1499	0	0	26
TOTALS	9	47	≈1400

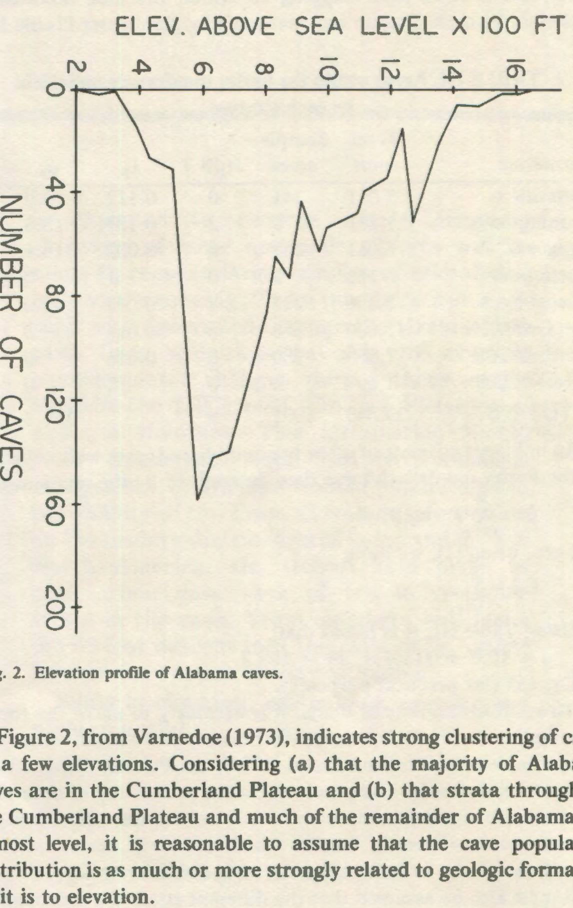


Fig. 2. Elevation profile of Alabama caves.

Figure 2, from Varnedoe (1973), indicates strong clustering of caves at a few elevations. Considering (a) that the majority of Alabama caves are in the Cumberland Plateau and (b) that strata throughout the Cumberland Plateau and much of the remainder of Alabama are almost level, it is reasonable to assume that the cave population distribution is as much or more strongly related to geologic formation as it is to elevation.

Analysis

Sampling theory predicts that the ratio of the number of caves found in a sampled area to the number of caves in the total area will approach the ratio of the size of the sampled area to the size of the total area, as the size of the sampled area is increased. Since the sampled area is small, compared to the total area, it may be expected that there is a significant degree of uncertainty associated with the calculation.

The average number of caves which is expected to be found is designated "E ( )". Statistically, $E\{N_i(B)\} = \mu_i\lambda_i$ 1.
where

$N_i(B)$ = the number of items (caves) found in subregion B of strata A_i ($i = 1, 2, \ldots n$),

μ_i = the true (but unknown) number of items in subregion B of Strata A_i , and

$\lambda_i = m(B)/m(A_i)$, the ratio of acreage searched in strata A_i to the total acreage of strata A_i.

While the term "strata" has a statistical meaning, in the context used here, the statistical and geological meanings are generally interchangeable. This analysis will subdivide the area of the Farley quadrangle into identifiable strata, will calculate μ_i for each stratum, and will sum the μ_i to obtain an estimate of the total number of caves in the Quadrangle.

Within this part of the Cumberland Plateau, the strata are nearly horizontal and fairly uniform, lithologically. The land slopes to the south, and there is a difference in elevation of about 180 ft between equivalent topographic features at opposite ends of the area of the Quadrangle. The margins of the principal geological formations were drawn on the Quadrangle by reference to geologic maps and by field observations. After thus mapping all strata, the area immediately underlain by each stratum was measured by planimeter (Table III).

TABLE III. Areas within the Farley quadrangle underlain by each stratum.

Formation	Total acres	Sample acres	$N_i(B)$	λ_i	μ_i
Pottsville ss	3,051	341	0	0.112	0.0
Pennington ls	1,387	176	2	0.127	15.8
Bangor ls	5,061	263	6	0.052	115.4
Hartselle ss	156	0	0	0	0
Gasper ls	5,128	213	1	0.042	24.0
Ste. Geneviève ls	15,030	658	0	0.044	0
Tuscumbia ls	7,860	280	0	0.036	0
(river)	1,667	0	0	0	0
TOTALS	39,340	1931	9		155.2

An unbiased estimate of μ (the total number of caves within the area of the Farley quadrangle) was then determined by the relationship:

$$\hat{\mu} = \sum_{i=1}^{n} \lambda^{-1} N_i(B) = \qquad 2.$$

Then, using (1), we have:

$$E\hat{\mu} = \sum_{i=1}^{n} \mu_i = \mu \qquad 3.$$

Using Table III, it is found that:

$\mu = 15.8 + 115.4 + 24 = 155.2$,

Or, 155 (for practical purposes).

To establish confidence limits, it is necessary to make the further assumption that $N_i(B)$ is Poisson-distributed, with a mean value $\mu_i\lambda_i$. According to Johnston and Leone (1964), the Poisson distribution is often "occasioned by a situation where the probability of occurrence of a simple event is extremely small, while the opportunity of occurrence is extremely large," which certainly agrees with the experience of the writer while performing the field work!

It must also be assumed that the different strata are independent. Figure 3 provides evidence in favor of the independence of the strata. Especially notable is the great vertical development of both sample caves and other caves in the Bangor limestone, relative to the vertical range of individual caves in the other strata. Average horizontal lengths of caves differ little among the strata, but the density of caves within a stratum varies greatly among the strata.

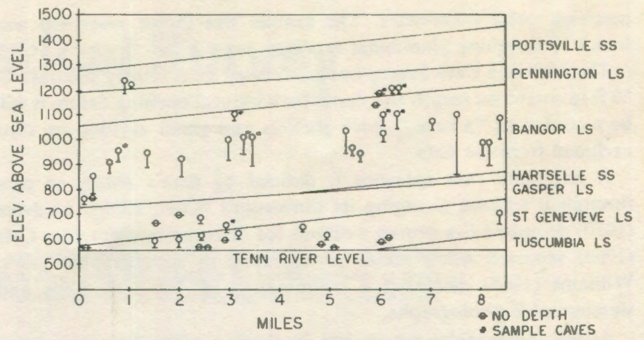


Fig. 3. Generalized profile looking west across the Farley quadrangle, showing all known caves.

On the basis of the preceding assumptions, the estimated variance of μ is concluded to be:

$$\mathrm{Var}\hat{\mu} = \Sigma\ \mathrm{Var}\,[\lambda^{-1}\,N_i\,(B)] \qquad 4.$$

$$= \Sigma\ \lambda_i^{-2}(\mu_i\lambda_i) \qquad 5.$$

$$= \sum_{i=1}^{n}(\mu_i\lambda_i^{-1}) \equiv \sigma^2 \qquad 6.$$

From Table III it is found that

$\sigma^2 = 124.4 + 2219 + 571$

$= 2914$

$\sigma = 53.9$

An approximation to 95% confidence limits is obtained by using a normal approximation to $\hat{\mu}$

$\hat{\mu} + 2\sigma = 263$ (upper 95% limit)

$\hat{\mu} - 2\sigma = 47$ (lower 95% limit)

Sources of error stemming from the problems of sampling and searching difficult terrain require special emphasis:

a. The search area efficiency factor can be validated only by noting that the two caves (Ala. nos. 748 and 862) previously known to exist in the areas searched were re-discovered without deviating from the search pattern and that only one other has been reported in the searched areas subsequently. The assignment of search efficiencies remains a subjective judgement of the searcher.

b. Difficult field conditions often resulted in irregular sample shapes, regardless of how the samples were selected, and in uncertainty as to the exact size of the area.

c. In regard to the assumed independence of strata, there may be reason to suspect a genetic relationship between proximate caves in different strata. Faults and joints may cross stratigraphic boundaries.

Conclusions

Statistical sampling techniques are an effective method for expanding knowledge and understanding of karst and cave areas. They can be applied to provide better estimates of average cave length, depth, etc., in addition to the number of undiscovered (but accessible) caves.

The expected number of accessible caves in the area of the Farley quadrangle (155) is over three times the number of currently known caves and over five times as many caves (29) as were known before special interest was taken in the Farley quadrangle. The evidence that Farley has more caves is, of course, less significant than the implication that cave populations in other areas may be similarly underestimated.

Acknowledgements

Dr. Gerald Anderson performed the statistical treatment of the data. John van Swearingen III and other members of the Huntsville Grotto, NSS assisted with the field reconnaissance. The aid of these friends is deeply appreciated.

Literature Cited

Anon (1972) — Interim Alabama Cave Survey: Huntsville Grotto (Nat. Speleol. Soc.), unpaged.
Cole, J. W. (1968)—Aerial Photographs for Cave Hunting: *Huntsville Grotto Newsletter* (Nat. Speleol. Soc.) 9(4):1-60.
Curl, R.L. (1966) — Caves as a Measure of Karst: *Jour. Geol.* 74:798-830.
Cramer, Helmut (1941) — Die Systematic der Karstdolinen: *Neues Jahrb. Mineral. Geol. Palaontol.* 85:293-382.
Jennings, J.N. (1971) — Karst: Cambridge, MIT Press, 252 pp.
Johnson, N.L. and F.C. Leone (1964) — Statistics and Experimental Design: NYC, Wiley, 513 pp.
von Lozinski, W. (1907) — Die Karsterscheinungen in Galayisch-Podolien: *Iber Geol. Bundesanst. Wien*, pp. 683-726.
Medville, Douglas (1970) — New Caves in West Virginia: A Statistical Summary: *Philadelphia Grotto Digest* (Nat. Speleol. Soc.) 9(1):2-10.
Tarkington, Terry; W.W. Varnedoe, Jr.; and John Veitch (1965) — Alabama Caves: Huntsville Grotto, (Nat. Speleol. Soc.), unpaged.
Williams, P.W. (1968) — Morphometric Analysis of Temperate Karst Landforms: *British Geomorphological Research Group, Occasional Publ.* 4:12-30.
———— (1969) — The Geomorphic Effects of Ground Water, IN: R.J. Chorley (Ed.), Water, Earth, and Man: London, Methuen, pp. 269-284.

Manuscript received by the Editor 19 October 1974.

Revised manuscript accepted 16 January 1976.

Natural Trap in the Big Horn Mountains

TEAM I: JUN 12-JUL 2
TEAM II: JUL 10-30
TEAM III: AUG 7-27

Contribution: $725

For more than 12,000 years a natural cave in the Big Horn Mountains near the Montana border has trapped unsuspecting animals at the bottom of its 65-foot vertical shaft. The trap is unique in the richness of its skeletal remains from the late Pleistocene, including Dire wolf, western bison, mammoth, and both the large and small forms of Equus, the ancestor of the modern horse. Most striking, perhaps, have been the discoveries of an extinct cheetah-like cat and the American lion, both extremely rare in the United States.

Dr. B. Miles Gilbert of the University of Missouri will direct the fourth season of excavations at Natural Trap. This year's work is expected to recover nearly complete skeletons of large mammals. Efforts will be made to recover large samples of microfauna by water screening. Team members will work their way downward through the strata of the cave floor and thus be able to examine environmental changes during three major periods: the full glacial, the late Pleistocene, and the Holocene. This information should yield important data on environmental changes which affected human populations in the vicinity of the Trap, as well as information on the modern distribution of fauna and flora in North America. Dr. Gilbert also plans to radiocarbon date each of ten indentifiable strata in the cave. Team members will make the 65-foot descent into the cave daily, either by free fall rappel or via scaffolding.

Skills in climbing, spelunking, geology and zoology useful.

Staging Area: Cody, Wyoming

? WHITHER ?

The January, 1977 issue of *The NSS Bulletin* marked the end of a four-year transition period encompassing more changes than have taken place in *The NSS Bulletin* during any similar period in its existence. Two of these are particularly obvious: First, we nearly always publish during the nominal month of issue; and second, we have a larger format, permitting maps and other illustrations to be printed with less reduction in size. Less obvious changes, which allow us to print twice as much material with only a one-third increase in budget, are: The use of a self-cover in place of catalog envelopes or wrappers, the elimination of stiff paper for the cover, the substitution of photo-offset printing for linotype/letterpress methods, and mailing at second-class instead of bulk rates. It is worth noting, also, that the Bulletin budget now provides for hiring an addressing and mailing service, which frees NSS Office staff time and money for other things.

The scientific and literary quality of *The NSS Bulletin* is as good as, if not better than (we think), it has been at any time in the past. The variety of topics discussed in its pages is broader than at any time since the earliest years of publication—and, of course, modern papers are incomparably more professional than were the majority of those printed in the first issues. Heavy emphasis on aggressive soliciting of manuscripts and exhaustive refereeing has taken a toll of associate editors, unfortunately. Their average tenure has been less than two years; only one has carried on more than four years.

We have failed to achieve some of our other goals. A series of independently financed and sold "supplementary volumes," containing reprints, long monographs, and other material unsuited for publication in the regular series of quarterly issues, would be a valuable service to the scientific community; the NSS Executive Committee forbade it out of a concern that anything associated with *The NSS Bulletin* would have to be distributed free to all members, at intolerable cost. Titles, abstracts, and/or reviews of recent literature, collected and printed regularly, are essential to research and scholarship; no one could be found willing to edit this feature. News of national and international speleological meetings here and abroad are also important; again, no one could be found willing. Some of these items are printed by the NSS sections, but the latters' publications are ephemera of very limited distribution and do not satisfy the need.

We still need a larger number of contributions: The number of papers received is barely adequate to fill four issues yearly. Publishing deadlines could be more easily met were more mss received, and it would be possible to balance the topical content of each issue. Ideally, no accepted paper should be delayed more than six months in press, after the refereed and revised manuscript is submitted for copy editing. Most short papers now are printed within six months, but many longer papers meet with delays of a year or more due to the need to maintain a backlog of manuscripts to cover possible shortfalls for some issues. The problem, at root, is that, while enough speleological manuscripts are being written, too few authors see *The NSS Bulletin* as a timely, prestigious, and widely available outlet for their work. We can mail every copy in time for delivery during the first week of the nominal month of issue, but we need readers' help in securing contributions and subscriptions, especially library and other institutional subscriptions. In early 1974, we had only 95 paid subscriptions and 12 exchanges in the United States; 43 paid subscriptions and 61 exchanges overseas (mostly in Western Europe and Canada). Domestic subscriptions declined to 87 by the middle of 1977, while foreign subscriptions rose slightly to 46. There's much room for improvement. May we send a complimentary copy and a covering letter inviting its subscription to your library?

Having introduced the subject at some length, let us now enquire, "Whither *The NSS Bulletin*?" What other economies of production, what greater services to our audience, may we effect?

The purposes of the "*Bulletin*" are to provide an archive for information about caves, to provide a means of communicating new discoveries and new ideas among specialists, and to create a greater awareness of and appreciation for the science of speleology within the caving public. Basic management policies are determined by the NSS Board of Governors, with the advice of the Congress of Grottoes. The selection of manuscripts, editorial judgements, and other operating decisions are made more or less informally by the Board of Editors, the printer, and any NSS member or *Bulletin* subscriber who has an idea and who cares enough to share it with the editors. If you think you can help us do a more satisfactory job, our suggestion box is as near to you as the closest U.S. Mail box. **(JH, BFB, FCH)**

National Speleological Society
Cave Avenue
Huntsville, Alabama 35810

Address Correction Requested
Forwarding & Return
Postage Guaranteed

12386 R 0778 NSS 7
HORTON H. HOBBS, III
601 WHITE OAK DR.
SPRINGFIELD, OH 45504

S